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TIMING ERRORS - THEIR DETECTION AND CORRECTION IN THE IMP INFORMATION PROCESSING SYSTEM

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SUMMARY

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One of the major problems encountered by many experimenters in the analysis of data retrieved by experiments flown on board satellites has been that of obtaining correct Universal Time in conjunction with this data.

This paper presents the scheme that was used by the IMP Information Processing System in the processing of the data from IMP-I which provided a means of eliminating most of the timing errors before they reached the experimenter. In addition this scheme proved valuable in the initial debugging of the IMP analog to digital line and most significant in evaluating the stability of and providing a check on the IMP-I spacecraft telemetry system.

AUTHOR

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INTRODUCTION

The generation of Universal Time at the ground station, the merging of this time with recorded spacecraft data, and the subsequent processing of this time through analog to digital conversion equipment has, historically, had a multiplicity of problems associated with it. It would appear that a certain amount of these problems are unavoidable when one considers the complexity of the over-all situation.

The "aggregate" timing of data from most spacecrafts is a product of a relatively large number of Prime Minitrack Time Standards located throughout a world wide network of Space Tracking and Data Acquisition Stations. Each of these time standards is designed to provide a time base for the spacecraft data that is in agreement with Universal Time, i.e., WWV, to within one millisecond when the time standard has been synchronized correctly with WWV and the propagation delay times between WWV and the station have been compensated (see reference 12, page 2-95). The prime function of these time standards is to provide a time code that can be written on analog tape simultaneously with the recording of the spacecraft data at the various telemetry receiving stations. This analog tape is then shipped to a central information processing facility where it provides the input for analog to digital conversion equipment, one function of which, is to decode the time and convert it to a digital format in conjunction with the data, and finally production of a digital magnetic tape which can subsequently be processed with computers.

As the practice of flying scientific experiments which required high resolution of the ground station time became prevalent it became obvious to the experimenters that they were not always realizing the design capabilities of the timing standards, i.e., one millisecond agreement with WWV when propagation effects have been accounted for, due to the degradation of the timing as it traversed the above mentioned series of operations. The occurrences of these "timing errors" was so frequent in some cases as to require a considerable expenditure of effort on the part of the individual experimenters to verify the integrity of the timing associated with their data.

One solution to this problem was to incorporate as part of the information processing facilities a systematic method, necessarily computer orientated because of the large volumns of data, of detecting and correcting timing errors before they reached the experimenter.

Up to the advent of the IMP-I spacecraft and its crystal controlled telemetry system a scheme for the detection and correction of timing errors of the nature described in this paper was, in most cases, impractical because the telemetry systems, even those that telemetered "pseudo clocks", (see reference 11, page 9) were not stable enough with time to allow the telemetry patterns or pseudo clocks to be used as an independent "clock" against which ground station time could be accurately compared. However, with the successful launch of IMP-I on November 27, 1963, a satellite became available which had a telemetry format consisting of a repeating pattern of telemetry sequences with a relatively stable period that could be used to perform an independent check on ground station time. This aspect of the IMP-I telemetry system was taken advantage of in the design of the IMP Information Processing System (IMP-IPS). (See reference 13.)

This paper gives a brief summary of the IMP-IPS, discusses in detail those phases of the IMP-IPS which are concerned with the detection and correction of timing errors and how this aspect of IMP-IPS was employed to trouble-shoot the IMP analog to digital line and monitor the IMP-I spacecraft telemetry system throughout the useful life of the spacecraft.

APPLICABILITY OF THE IMP-I TELEMETRY FORMAT TO TIME ERROR DETECTION AND CORRECTION

The IMP-I telemetry system is a modification of the basic type of PFM telemetry system flown on some of the past satellites, e.g., Explorer XII and UK-1. For a discussion of this telemetry system see references 1, 15 and 17.

There are <u>two</u> significant features of the IMP-I telemetry format that permit the effective implementation of a time error detection and correction scheme of the type described in this paper:

A. The telemetry format is a synthesis of a repeating pattern of four telemetry sequences each approximately 81.914 seconds in length (see Figure 1). Each of these sequences with the exception of the fourth, consists of an array of sixteen channels by

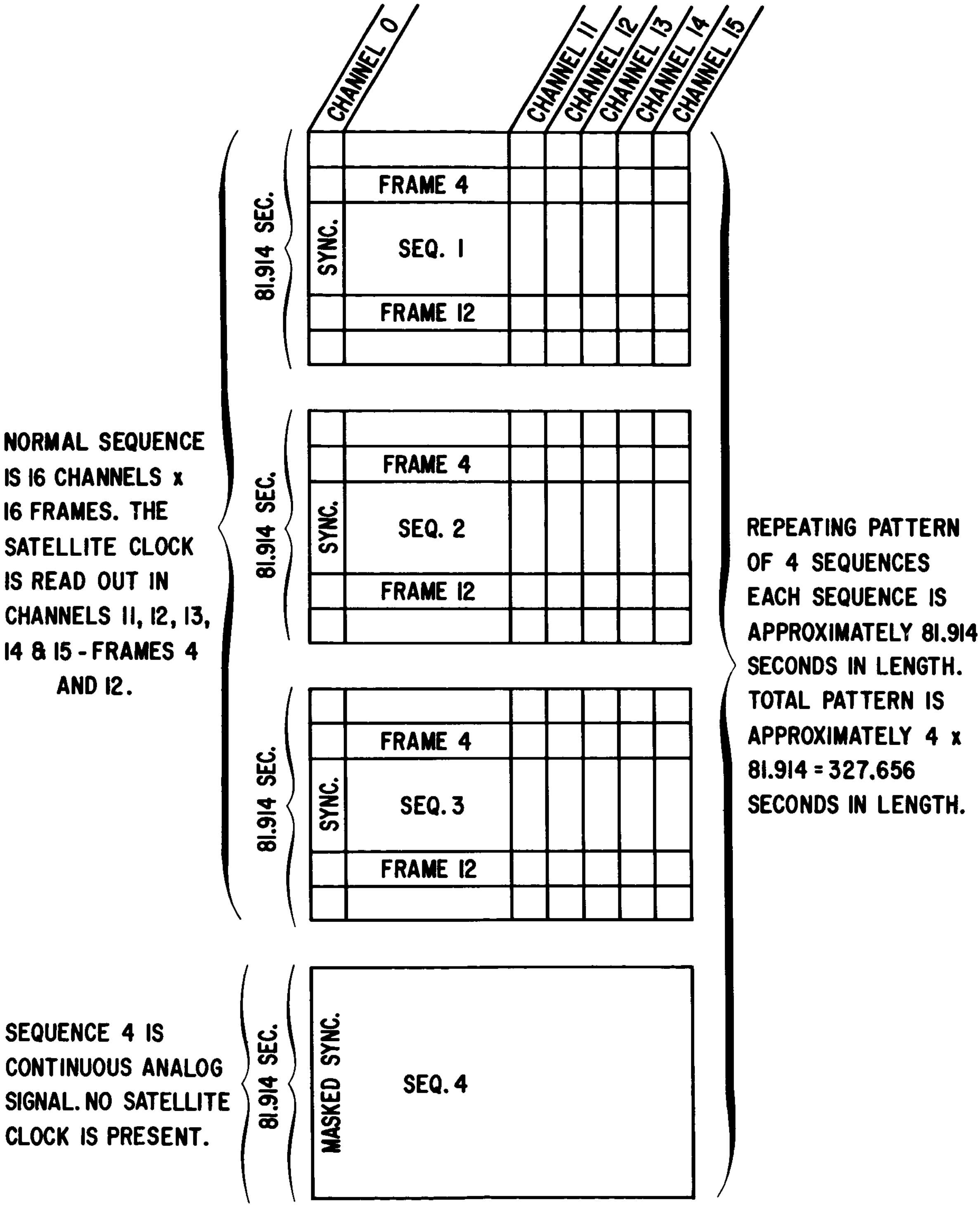

Figure 1 – The IMP-I Telemetry Format

sixteen frames. The first three sequences contain an octal satellite clock reading in channels 11 through 15, frames 4 and 12, which increases by one decimal unit each sequence including the fourth. The low order octal digit of the satellite clock reading is decoded by the analog to digital line into a 1, 2 or 3 depending on whether it is the first, second, or third telemetry sequence respectively. This information is included as part of the digitized data and is utilized by the time error detection software. The fourth sequence (Rubidium vapor magnetometer sequence) contains continuous analog data and consequently is missing the satellite clock reading. (The satellite clock still up-dates itself by one decimal unit in this sequence even though it is not read out.)

B. The periodicity with time of the channel rate is insured through the use of a 20kc crystal as a basic component of the spacecraft telemetry system. This basic crystal frequency is divided down to obtain the desired sampling rate and is backed up with a free running multi-vibrator synchronized to one of the subdivided frequencies from the crystal. When not synchronized with the crystal the multi-vibrator runs some 25 percent lower in frequency than when in synchronization with the crystal. The significance of this feature becomes apparent in later discussions in this paper.

IMP INFORMATION PROCESSING SYSTEM (IMP-IPS)

The IMP-Information Processing System is an integrated set of analog to digital conversion equipment and computer programs which receive as input information in an analog format and output information in a standard Binary Coded Decimal format. Documentation of this system is extensive and details can be found in References 6, 7, 9, 13, 14, 16, and 18.

Because information is processed serially through the system a brief explanation of each of the steps is appropriate to allow the presentation of the Time Error Detection and Rectification Software in its proper place with respect to the over-all series of operations (see Figure 2).

The flow of information through the IMP-IPS commences with the reception of the analog tapes from the network of stations covering the spacecraft. These analog tapes are processed through the IMP analog

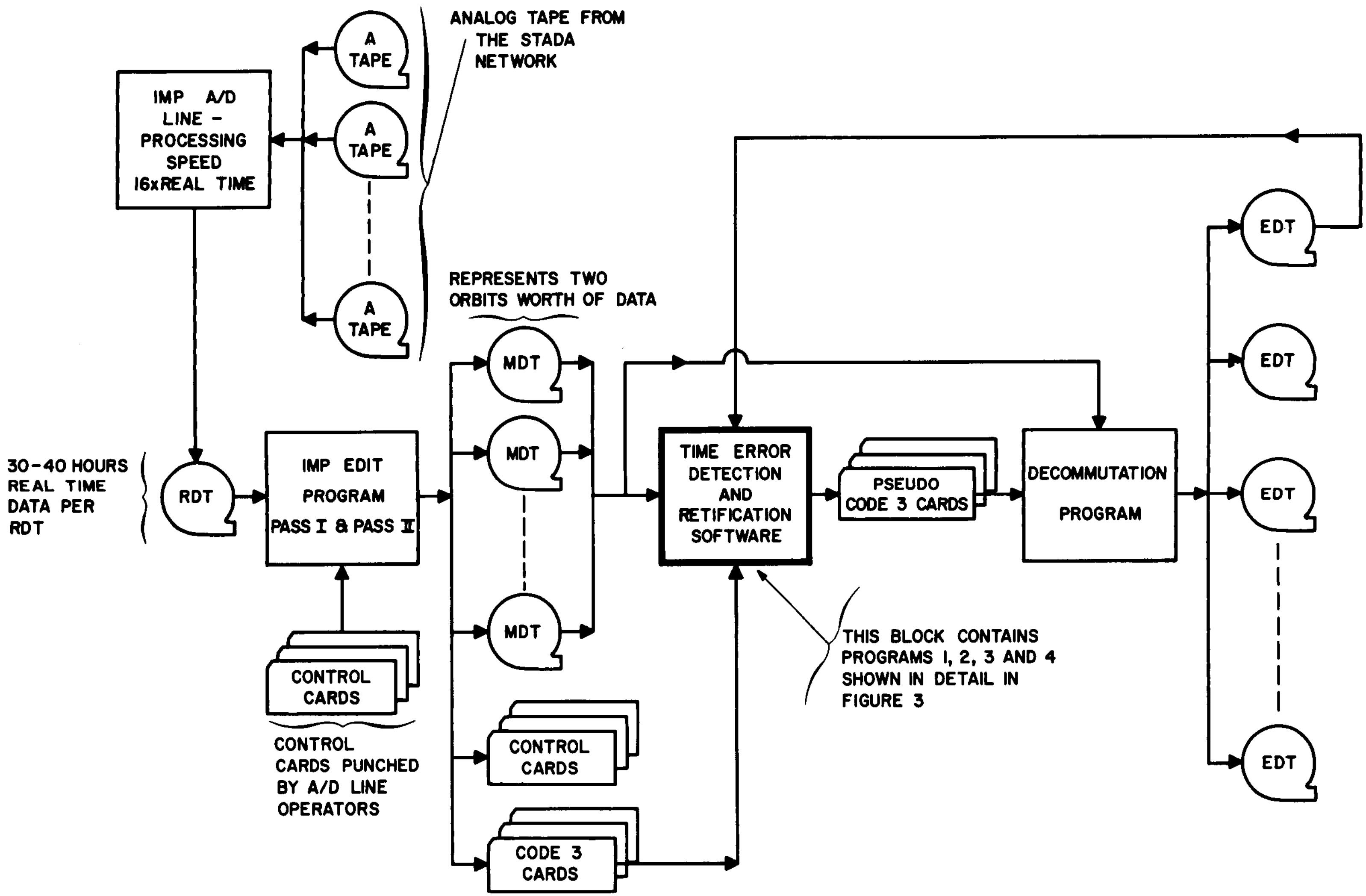

Figure 2 – The IMP Information Processing System (IMP-IPS)

to digital (A/D) line, (see references 7, 9, and 18) which digitizes the analog data and time and creates various flags and symbols that are a function of the time-data array at 16 times "real time". The digitized output of the A/D line is written on tape in a BCD format, this tape is called a Raw Data Tape (RDT) and contains from 30 to 40 hours of digitized "real time" data. This 30 to 40 hours of data constitutes many satellite passes* from a number of different stations. The RDT, along with control cards punched by the A/D line operators, serve as input to the IMP Edit Program (see reference 16). This edit program, which is operationally broken into two passes on the computer, performs in the most general sense the following functions:

A. The Program checks for and corrects operational and equipment A/D line errors, i.e., "cleans up" the RDT.

B. Uses the IMP-I satellite clock† to tag each telemetry sequence with a monotonically increasing number for each 90 days of satellite operation.

C. Uses the error detecting and correcting properties of the IMP-I satellite clock to create a flag for each telemetry sequence which gives a measure of the quality of the data in the sequence.

The final output of the IMP Edit Program is a Master Data Tape (MDT) which contains 120 to 160 hours of real time data, and control cards that are punched by the program. Of special interest is the Code 3 Control Card which, after being operated on by the Time Error Detection and Rectification Software, serves as the timing interface between the MDT, which contains "raw time", and the Experimenter Data Tapes (EDTs) which contain "corrected and smoothed" time.

At this point in the series of computer operations the MDTs are allowed to backlog until two consecutive orbits' worth of data have accumulated. As each complete orbit takes about 93 hours this constitutes about eight days of real time data on each MDT.

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*A pass is defined as one uninterrupted data recording made at a single station (average pass on IMP-I is about 4 hours).

†The spacecraft "clock", a 15-bit accumulator, can accumulate a maximum of 32,767 counts, i.e., 2^{15} counts, before it returns to zero. To fill this accumulator takes approximately 30 days. This clock, through the use of programming techniques on the ground, has been extended to a 90-day clock in the data that the experimenter receives (see Appendix G).

The two orbits' worth of data are then processed through the Time Error Detection and Rectification Software system. In this series of computer operations, which will be covered in detail in the following sections, errors in time are detected and provision is made for the subsequent correction of these errors and "smoothing" of the time through the creation of the Pseudo Code 3 Cards. These Pseudo Code 3 Cards and the MDTs then provide the input to the decommutation program (see reference 6) which "smooths" and corrects, if necessary, the time for each pass contained in the two orbits' worth of data being processed, and creates the experimenter tapes containing each individual experimenter's data. Finally, one of the experimenter tapes is fed back into the Time Error Detection and Rectification Software where the alteration made to the timing through the use of the Pseudo Code 3 Cards is reviewed.

THE TIME ERROR DETECTION AND RECTIFICATION SOFTWARE

The Time Error Detection and Rectification Software consists of four separate IBM 1410 computer programs which have been represented by a single block in Figure 2. The contents of this block are shown in detail in Figure 3, where the four programs are serially numbered from 1 to 4.

This series of programs is designed to accomplish the following objectives:

A. The MDT Time Verification Program (program 1 in Figure 3) produces a plot tape, which, when sorted chronologically with respect to time and plotted, provides a means of visually detecting timing errors as well as providing information on the performance of the spacecraft telemetry system and the A/D line, and when input to the Pseudo Code 3 Card Program (program 3 in Figure 3) allows the timing to be analyzed, corrected and smoothed.

B. The Time Verification Sort Program (program 2 in Figure 3) insures that the data sent to the experimenter is in chronological order and provides a sorted input tape for the Pseudo Code 3 Card Program.

C. The Pseudo Code 3 Card Program performs an analysis on the timing and corrects timing errors that may exist by altering the Code 3 Cards to Pseudo Code 3 Cards which are used to control

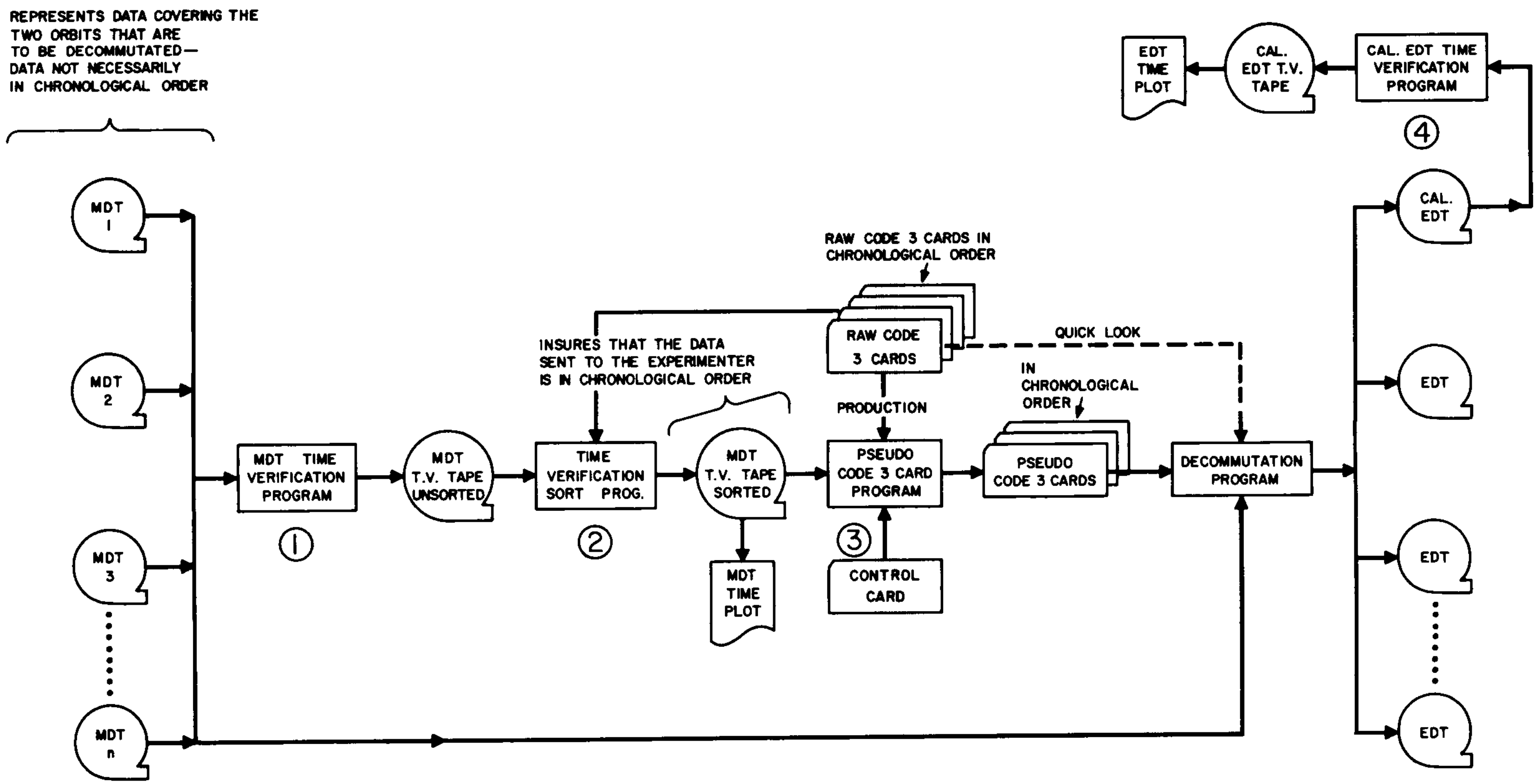

Figure 3 – The Time Error Detection and Rectification Software

the timing that is generated by the decommutation program for the experimenters' tapes.

D. The California EDT Time Verification Program (program 4 in Figure 3) again produces a plot tape which when plotted illustrates the alterations that have been made to the timing by the use of the Pseudo Code 3 Cards.

The MDT Time Verification Program - A Tool for Detecting Time Errors and Monitoring the A/D Line and Spacecraft Telemetry System Performance

Referring to Figure 1, the MDT Time Verification Program (program 1 in Figure 3) takes advantage of the fact that channel 0 of frame 0 of each telemetry sequence 1 occurs approximately every 327.6 seconds. This enables the program to assign a unique number defined as N to each sequence 1, i.e., the program counts the number of sequence 1s that have occurred since some chosen reference sequence 1 (at the reference sequence 1, N equals zero). N is determined by the program as follows:

$$N = \left[\frac{t_n - t_o}{\Delta t}\right] \quad (1)$$

(Note that the brackets indicate that N has been rounded to an integer.)

Where:

t_o is defined as the time for channel 0 of frame 0 of the reference sequence 1,*

t_n is the time for the current channel 0 of frame 0 of the sequence 1 being counted, and

Δt is a chosen supercommutated sequence rate† and is equal to 327.656 seconds. (It should be noted that the above supercommutated sequence rate was chosen at the same time that t_o was chosen and does not represent the average supercommutated sequence rate from t_o to t_n.)

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*It has been necessary to change this reference point once during the useful life of the spacecraft. (See Appendix A orbit 25.)

†The sequence rate is assumed to be 81.914 seconds (see Figure 1).

The above quantities are used by the program to compute the parameter Delta for each sequence 1 that is counted. Delta is defined by the following formula:

$$\text{Delta} = \left(t_n - t_o\right) - N(\Delta t) \tag{2}$$

Where:

$\left(t_n - t_o\right)$ represents the actual elapsed time for N sequence 1s, $N(\Delta t)$ represents the elapsed time that would be predicted for N sequence 1s if the actual supercommutated sequence rate was a constant, and Delta represents the algebraic difference of the two foregoing quantities.

A sample computation of Delta is presented in Appendix F. Note that the computation of N is accurate as long as t_n is in error by less than 50 percent of 327.6 sec. minus the accumulated error due to the slightly improper choice of the supercommutated sequence rate.

As previously mentioned the parameter Delta is computed for each sequence 1 that is counted by the program. This parameter Delta along with its corresponding N is written on magnetic tape by the program in a format that allows, after being sorted chronologically with respect to time (program 2 in Figure 3), Delta versus N to be directly plotted with an EAI* data plotter. Appendix A contains the complete library of these plots for the useful lifetime of the spacecraft.

These plots are an extremely useful tool in verifying the integrity of the timing associated with each pass of data that has been recorded and processed through the A/D line during any particular orbit. In addition, a great deal of information about the performance of the spacecraft telemetry system, i.e., stability of the bit rate, can be derived from a review and analysis of these plots.

The following paragraphs treat the applicability of these plots to the detection of timing errors originating at the station and during analog to digital conversion. In addition the plots proved valuable in the initial debugging of the A/D line. A discussion encompassing the usefulness of the plots in the evaluation of the performance of the spacecraft telemetry system is also included.

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*Electronic Associates, Inc. Model 3440.

Detection of Timing Errors Originating at the Ground Station

A. The Ground Station clock set incorrectly with WWV during the recording of a pass.

This relatively common error (see Appendix E) is reflected in the plot of Delta versus N as a positive or negative displacement in the ordinate values, i.e., Delta, from the nominal curve during the pass. Appendix A, orbit number 1, contains a number of passes recorded at Rosman, North Carolina which contain this particular error. Two of these passes have had the BCD time code and the WWV signal simultaneously strip charted to illustrate the discrepancy in the two time codes. These strip charts are displayed on the same page with the plot of orbit Number 1 in Appendix A.

B. Errors introduced by the initial disagreement of the station clocks.

During the life of IMP-I the tracking stations were not compensating for the propagation time from WWV to the station site. This results in all the station clocks initially being in disagreement with each other and with WWV. Appendix D contains a tabulation of these delay times.

This initial disagreement of the station clocks combined with the fact that the distance from the spacecraft to the tracking stations changes abruptly as coverage passes from station to station is readily apparent in all the plots appearing in Appendix A as small positive and negative steps in the curve of Delta versus N.

C. Analog to Digital line could not synchronize properly with the data because of a weak or noisy telemetry signal. This adversely effected the timing.

This anomaly is reflected in the plot of Delta versus N as a predominant scattering of the points during the pass. Appendix A, orbit 5 around sequence 1 counts of 4189 and 4789 are good examples.

D. Both BCD and Serial Decimal time were found to be unacceptable and the pass was processed with relative time*.

This type of error is generally reflected in the plots as a gap in the data where the pass would, under normal circumstances, be located. This is due to the fact that the values of Delta and N will generally be completely erroneous during the pass and consequently are off scale when the plots are made.

E. Incorrect ID

Because in the computation of t_n the program utilizes the ID of the file (see sample calculation in Appendix F) an incorrect ID will also result in completely erroneous values of Delta and N. Again when the data is plotted a gap will be present where the pass would, under normal circumstances, be located.

This ID check is an important feature of this scheme, as incorrect IDs are very common (particularly when the recording of a pass at the station commences very close to midnight) and when not detected and corrected can cause the experimenter considerable difficulty in rectifying the proper date.

Trouble-Shooting the IMP Analog to Digital Line

As the A/D line had completed the final stages of construction just prior to the launch of the spacecraft there were a certain amount of undiscovered problems that remained to be resolved and improvements made during the processing of the first orbits of data.

A. At the time that data from the sixth orbit was being processed a refinement was made to the line in the form of a circuit that served as a window to look for phase errors at the end of each channel between the system flywheel frequency, which determines when time is sampled, and the 50 cycle channel rate derived from the recorded data on the analog tape. During installation this window was mistakenly inverted. The plot of Delta versus N reflected this malfunction as small "ramps" in the plots of each pass. (See Appendix A orbits 6 through 13; orbit 10 around

*Relative time is defined as time that is generated by the A/D line accumulator after the accumulatorhas been set to zero. (See reference 18.)

sequence 1 counts of 9709 and 9909 is a particularly good example.)

The chances of seeing an error of this magnitude would have been remote if a scheme, such as described in this paper, for detecting time errors was not being employed. The reason for the ramps in the plots was investigated and subsequently discovered and corrected (see reference 6) as can be seen in Appendix A in the plots after the 13th orbit.

B. Another interesting and yet incompletely explained structure in the plots of Delta versus N are the "tails" observed on many of the passes. (See Appendix A orbits 2 and 3.) It is conjectured by the designers of the A/D Line that these tails are due to a disagreement between the frequency of the flywheel, which determines the rate at which time is sampled, and the 50 cycle channel rate derived from the recorded data on the analog tape at the start of processing of the pass. As can be seen in the plots as time progresses the flywheel slowly "syncs" in on the 50 cycle channel rate. This malfunction seems to have remedied itself during the processing of data in the later orbits but again appears in plots after orbit 38.

Monitoring the Spacecraft Telemetry System

Because the program is looking at the difference between the actual time for each sequence 1 and the predicted time for each sequence 1 (assumed supercommutated sequence rate of 327.656 sec.) a considerable amount of information is made available about the periodicity with time of the sequence rate. One of the distinct advantages of this analysis is the fact that a change in the sequence period will be reflected in the curve.

A. In Appendix A, orbit 1 a sudden change in the period of a single supercommutated sequence introduced an approximate 71 second discontinuity in the curve (see Appendix A, orbit 1, sequence 1 count of 800). As explained in the section titled Applicability of the IMP-I Telemetry System to Time Error Detection and Correction the stability of the sampling rate of the spacecraft is assured through the use of a 20kc crystal which is backed up with a free running multi-vibrator synchronized to one of the subdivided frequencies from the crystal. Apparently this discontinuity was caused by an overload on the satellite power system which prevented the multi-vibrator from synchronizing to the crystal. Consequently it "free ran" about 25 percent low for about 5 minutes. (See reference 16, Appendix F, page 8.)

B. Orbit number 42 in Appendix A covers that period when the spacecraft was eclipsed by the Earth for 7^h 57^m, as is evident from the plot the spacecraft transmitted for 1^h 17^m after entering the Earth's shadow. It was completely shut off for a period of 15^h 17^m and became operational again on May 7 at 07^h 38^m U.T. (see reference 2 and 4). It is estimated that during the period of time that the spacecraft was not operational the temperature of the satellite electronics dropped to temperatures between -60° and -80°C (see reference 8, page 3). This "cold soak" evidently changed the operating frequency of the crystal and consequently the sequence rate.

The telemetered temperature of the spacecraft battery, which is physically located close to the encoder and thus the crystal, is shown plotted against time following spacecraft turn on after the shadow in Figure 4. The "raw time" plot of Delta versus N for this same period of time has also been included to illustrate the changing sequence rate. As can be seen from Figure 4 it took about 19.5 hours before the crystal frequency stabilized close to its original value. The graphs of Average Sequence Rate per Pass versus Satellite Clock Number in Appendix C also reveal this rather "radical" change in the sequence rate.

C. Appendix C provides a summary of the stability characteristics of the IMP-I telemetry system during the useful life of the spacecraft*. Graph 1 was generated by plotting the apogee value of Delta against the appropriate orbit number. Referring to equation (2), i.e.,

$$\text{Delta} = \left(t_n - t_o\right) - N(\Delta t)$$

it would be expected that if Δt was chosen incorrectly it would introduce a constant slope in the plot of the Apogee Values of Delta versus the Orbit Number.

*With two exceptions the spacecraft operated continuously from launch on November 27, 1963 until May 30, 1964 at 09^h 18^m U.T. (see reference 3). After May 30 the satellite became extremely intermittent.

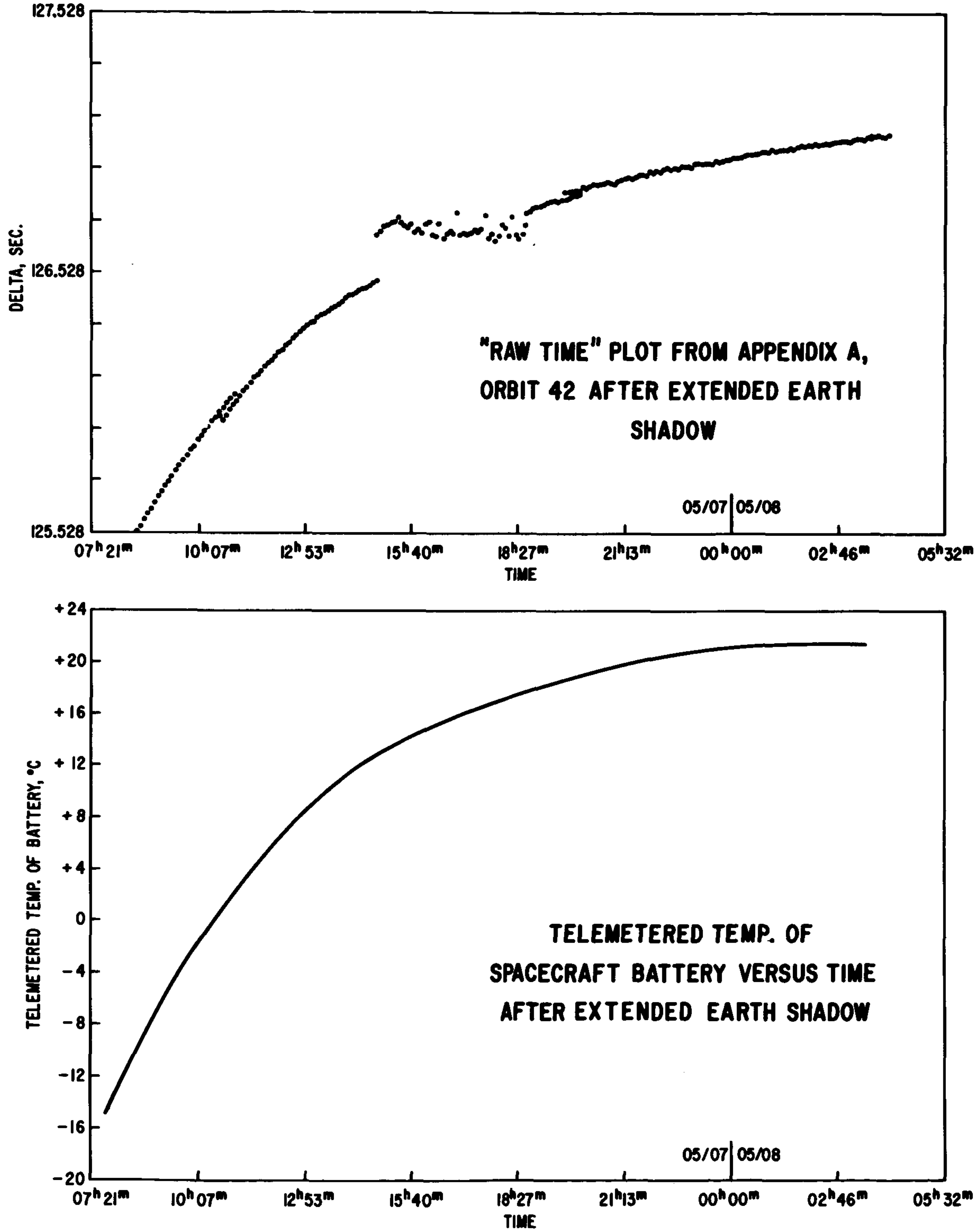

Figure 4 – Telemetered Temperature of Battery after Spacecraft Turn On Following the Extended Earth Shadow Compared with the "Raw Time" Plot During this Time.

As it turned out Δt equal to 327.656 was not precisely the average supercommutated sequence rate. This fact is reflected in the plot of the Apogee Values of Delta versus the Orbit Number in Appendix C.

The interesting aspect of this plot is not the slope itself but the rate of change of the slope which gives a measure of the long range stability of the telemetry system. Construction of a tangent to a least squares quadratic fit of data from the 5th to the 24th orbit at the 5th orbit indicates the sequence rate had drifted on the order of 4 seconds in 6.4 million seconds through the 24th orbit. From the 25th orbit until the satellite was eclipsed for an extended length of time in the 42nd orbit the stability undergoes some deterioration.

D. In addition to the Apogee Values of Delta plotted against the Orbit Numbers, Appendix C contains a plot of the Average Sequence Rate Per Pass plotted against the Satellite Clock Reading at the beginning of the pass. The instabilities that were mentioned in the previous paragraph are particularly evident in this plot.

The Pseudo Code 3 Card Program - A Means of Correcting and Smoothing Time

The Pseudo Code 3 Card Program (program 3 in Figure 3) uses the sorted MDT Time Verification Tape, generated by the MDT Time Verification Program (program 1 in Figure 3) and sorted by the Time Verification Sort Program (program 2 in Figure 3), as input. This tape contains the tabulation of Delta versus N (the sequence 1 count) for the two consecutive orbits, henceforth referred to as the Delta-N data array, of data being processed.

At the outset the program operates on the Delta-N data array algebraically subtracting the delay time of WWV propagation to the station site (see Appendix D) from each of the Deltas computed for each sequence 1 that comprise a pass. This compensation for the delay time of WWV synchronization to the station site is carried out on each of the passes that comprise the orbit being processed.

As an example in Appendix F there is a sample calculation for the Delta corresponding to the first sequence 1 in a pass that was recorded at Woomera, Australia on January 8, 1964. In this calculation Delta is computed to be +86.697 sec. Now referring to Appendix D the delay time from WWV to the station site at Woomera is 59.1 milliseconds. Thus the adjusted Delta would be:

$$+86.697 - .059 = 86.638$$

Next the program operates on the adjusted Delta-N data array for each individual orbit fitting it, using least squares, to a quadratic equation. It is readily apparent from the plots in Appendix A that a second degree equation of the form:

$$\text{DELTA} = A_1 + A_2 N + A_3 N^2 \tag{3}$$

will approximately fit the data if we proceed from perigee to perigee.* Appendix B shows a comparison of the raw time and the adjusted and least squares smoothed and corrected time for orbits 36 and 37. Note that the adjusted and smoothed time curve is below the raw time curve during most of the orbit due to the propagation delay time adjustments that have been made. After making the least squares fit the program operates on the Code 3 Cards which were generated by the IMP Edit program (see Figures 2 and 3). There is one of these cards per pass, containing the following information:

1. The start time of each pass
2. The corresponding satellite clock reading for the start time
3. The stop time of each pass
4. The corresponding satellite clock reading for the stop time
5. "Logging" information, e.g., ID of the file, MDT tape number, etc.

(A complete write up on the Code 3 Cards can be found in reference 16, Appendix B.)

In this operation the program obtains from the sorted MDT Time Verification Tape the ground station time for the first sequence 1 in each pass and the corresponding N and Delta and uses this N in the second degree equation that it has just generated for the orbit, i.e., equation 3, to compute a theoretical Delta. It then subtracts the actual Delta taken from the sorted MDT Time Verification tape from the

*Other mathematical expressions have been suggested by Cyrus J. Creveling of the Data Systems Division, GSFC. In particular, he feels that fitting the time curve to an analytically-generated curve of a cycloid shows promise of increasing the accuracy of the operation with an accompanying saving in computer time (see reference 5).

theoretical Delta and algebraically adds this difference to the ground station time of the first sequence 1 in the pass.

In a similar manner the time for the last sequence 1 of the pass is adjusted to agree with the second degree equation. The adjusted start and stop times and corresponding satellite clock readings* are then punched into the Pseudo Code 3 Cards along with the logging information.

Use Of The Pseudo Code 3 Cards In The Decommutation Program

The Pseudo Code 3 Cards, along with the MDTs, now provide the inputs to the Decommutation Program (see Figure 3) where information from the Pseudo Code 3 Cards is used to compute the average sequence rate per pass which in turn is used to increment the time that goes on the experimenter tape.

The average sequence rate per pass is computed by dividing the difference between the start time on the Pseudo Code 3 Card and the stop time on the Pseudo Code 3 Card by the difference between the two 30-day clock readings associated with these start and stop times. This computation results in an average sequence rate for each pass. This average sequence rate is then used by the program to update the time for each sequence throughout the pass using the start time as the reference time. Thus the time that is written on the experimenter tape for each pass is a linear approximation to that particular segment of the least squares fit where the pass occurs.

Actually then, the smoothed time plots which appear in Appendix B are made up of straight line segments each of which represents one pass. This feature is not readily apparent in the plots in Appendix B because the curvature is very small.

The California EDT Time Verification Program

This program is identical to the MDT Time Verification Program except that it is written to accept the California Experimenter Data Tape instead of the Master Data Tape. Its purpose is to provide a means of checking the alterations that have been made to the time

*The satellite clock (30-day clock) and N (the sequence 1 count) are related such that one can easily be computed from the other (see Appendix G).

through the use of the Pseudo Code 3 Cards in the Decommutation Program (the same time goes on all experimenter tapes, thus it is necessary to check only one of them). The smoothed time plots that appear in Appendix B are a result of plotting the plot tape that is created by this program.

This final check on the timing is an important feature of the entire scheme as the time that actually is present on the experimenters' tapes is being reviewed in this operation.

CONCLUSIONS

As is evident from Appendix A the scheme just described for detecting and correcting time errors was successfully applied throughout the useful life of IMP-I*, i.e., for almost 48 orbits, with the following results:

A. A large percentage of the timing discrepancies were filtered out before the data was received by the experimenters. This has saved the experimenters considerable time and effort in the analysis of their data and permitted rapid evaluation of the scientific significance of the data.

B. At least two malfunctions of the A/D line were detected that otherwise would have probably gone unnoticed.

C. The scheme provided a means of continuously keeping track of the spacecraft telemetry system.

D. Finally, it provided a relatively easy way in which statistics could be compiled on the timing failures when they did occur. Appendix E contains a tabulation of these timing failures through the 23rd orbit.

This scheme is currently being employed to analyze the timing associated with the data from IMP-II which was launched on October 4 of 1964.

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*The Pseudo Code 3 Card Program was written after the launch of IMP-I when the initial "raw time" plots from the first few orbits of data indicated that the procedure for correcting and smoothing the time discussed in this paper would be a feasible approach to the problem of time errors, consequently, the first eleven orbits were not fit. In addition, orbits 42 and 43 were not fit due to lack of transmission from the spacecraft during portions of these orbits.

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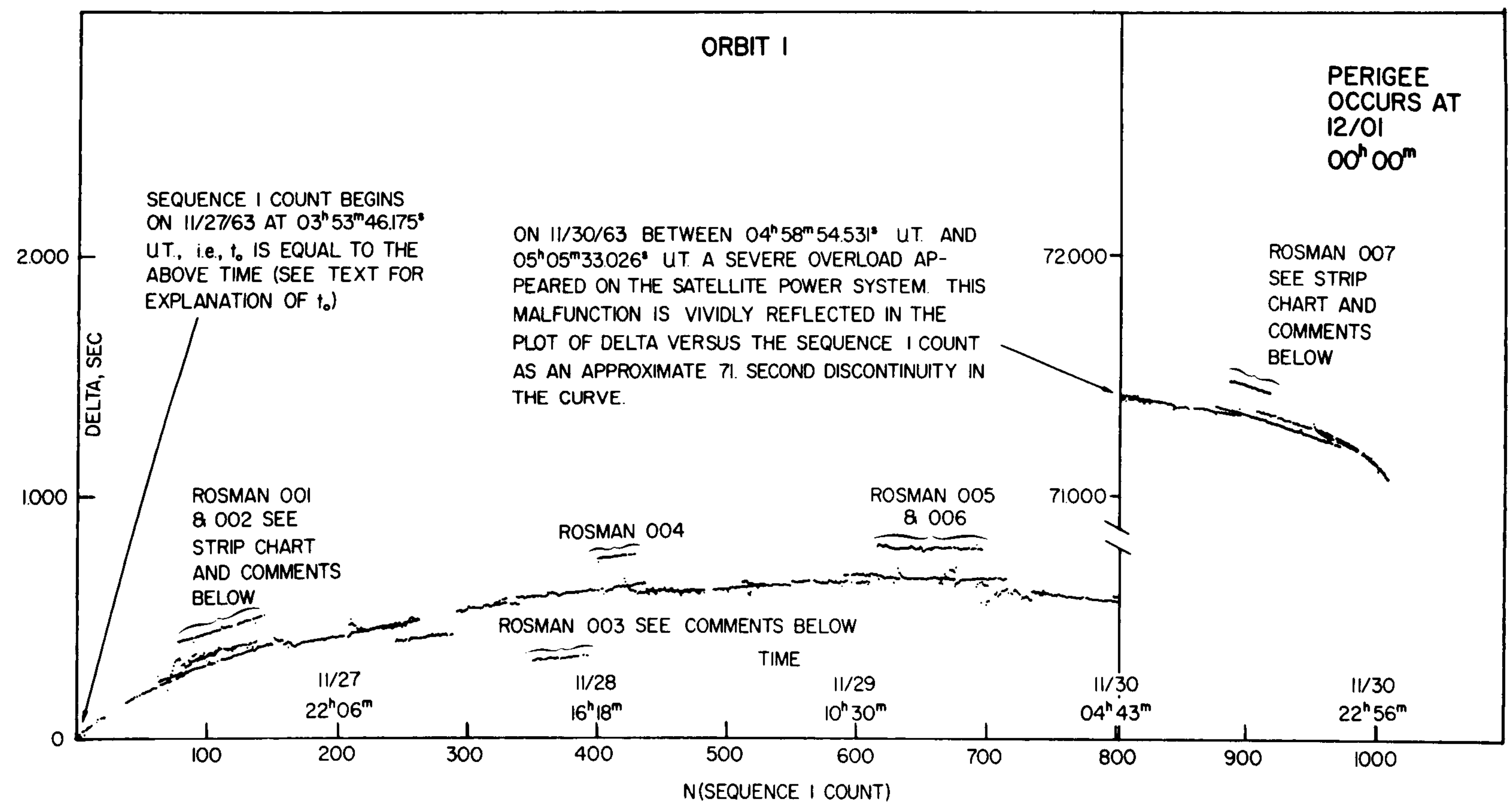
18. Wolfgang, John L., Jr., "Design Philosophy of the IMP Information Processing System", Transactions of the 1964 International Space Electronics Symposium.

APPENDIX A

"Raw" time plots of DELTA versus
N (The Sequence 1 Count)
for the useful life of IMP-I

A-3-a

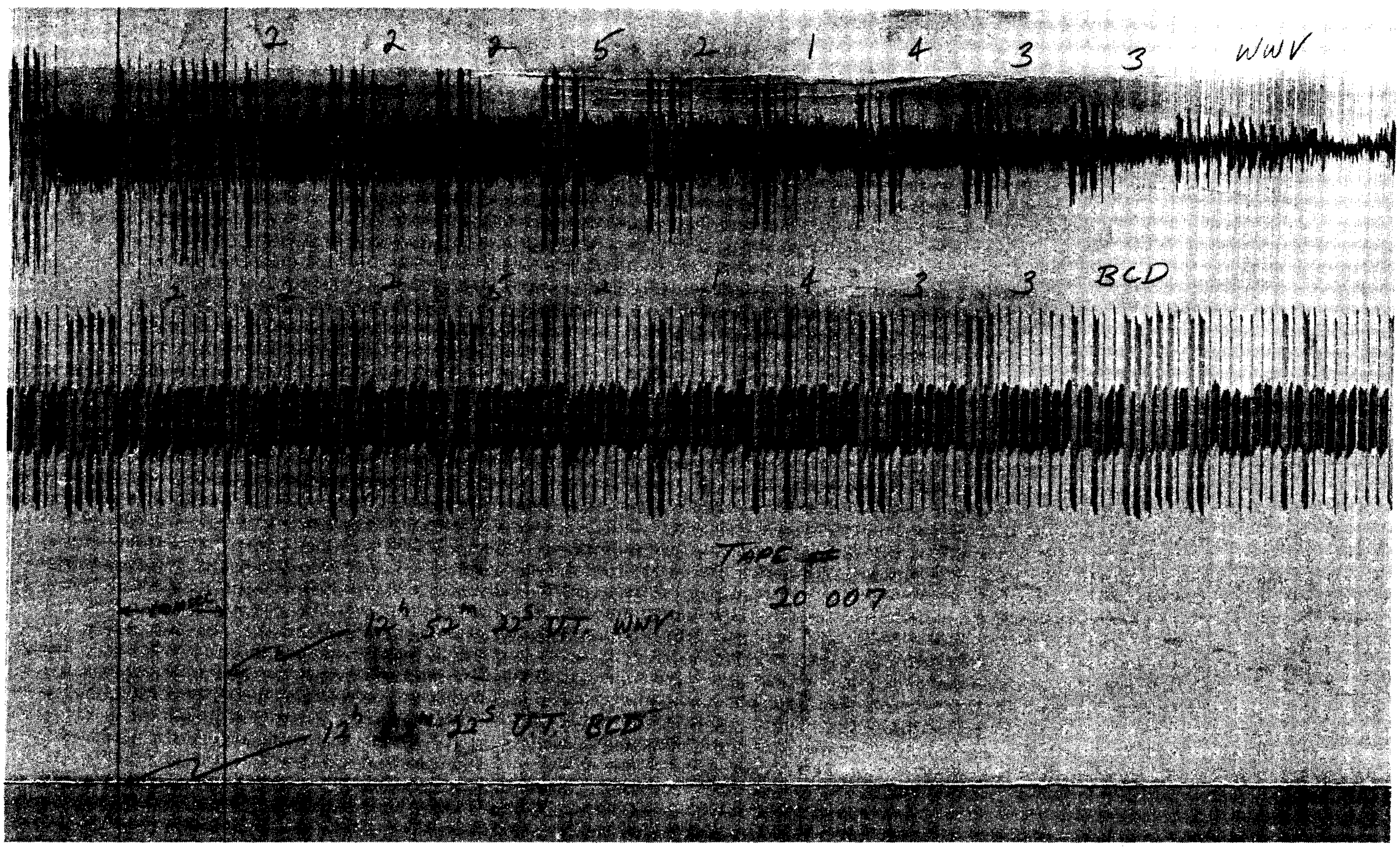


These strip charts were run on two of the seven Rosman tapes recorded during the first orbit. Note the BCD time code leads the WWV signal (top trace on each chart) by 95 to 100 milliseconds. All seven tapes recorded at Rosman during the first orbit exhibit this error.

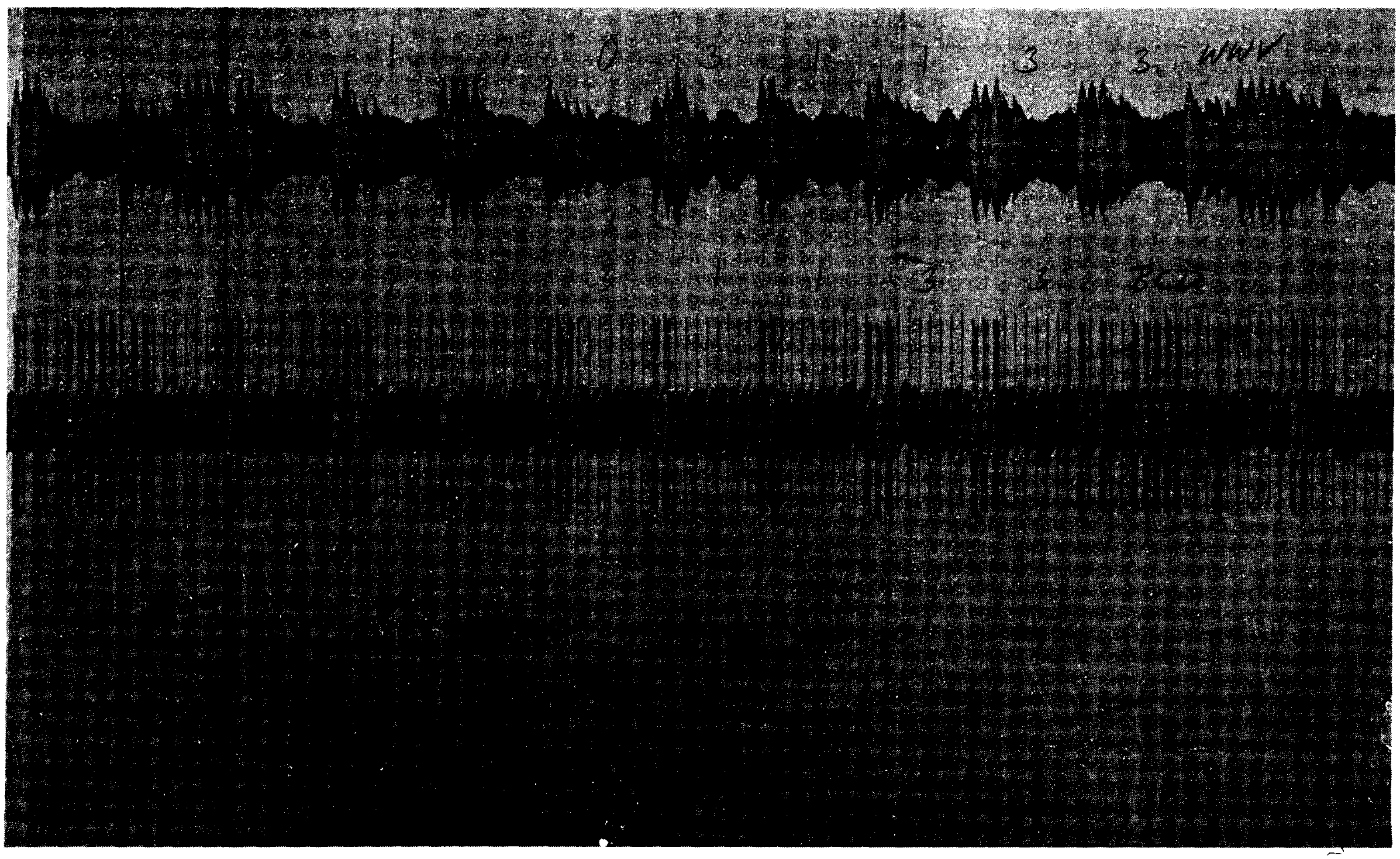
This displacement is reflected in the plot of Delta versus N (the Sequence ⊥ Count) above as a positive displacement of approximately 100 milliseconds in the ordinate values from the nominal curve for these particular tapes.

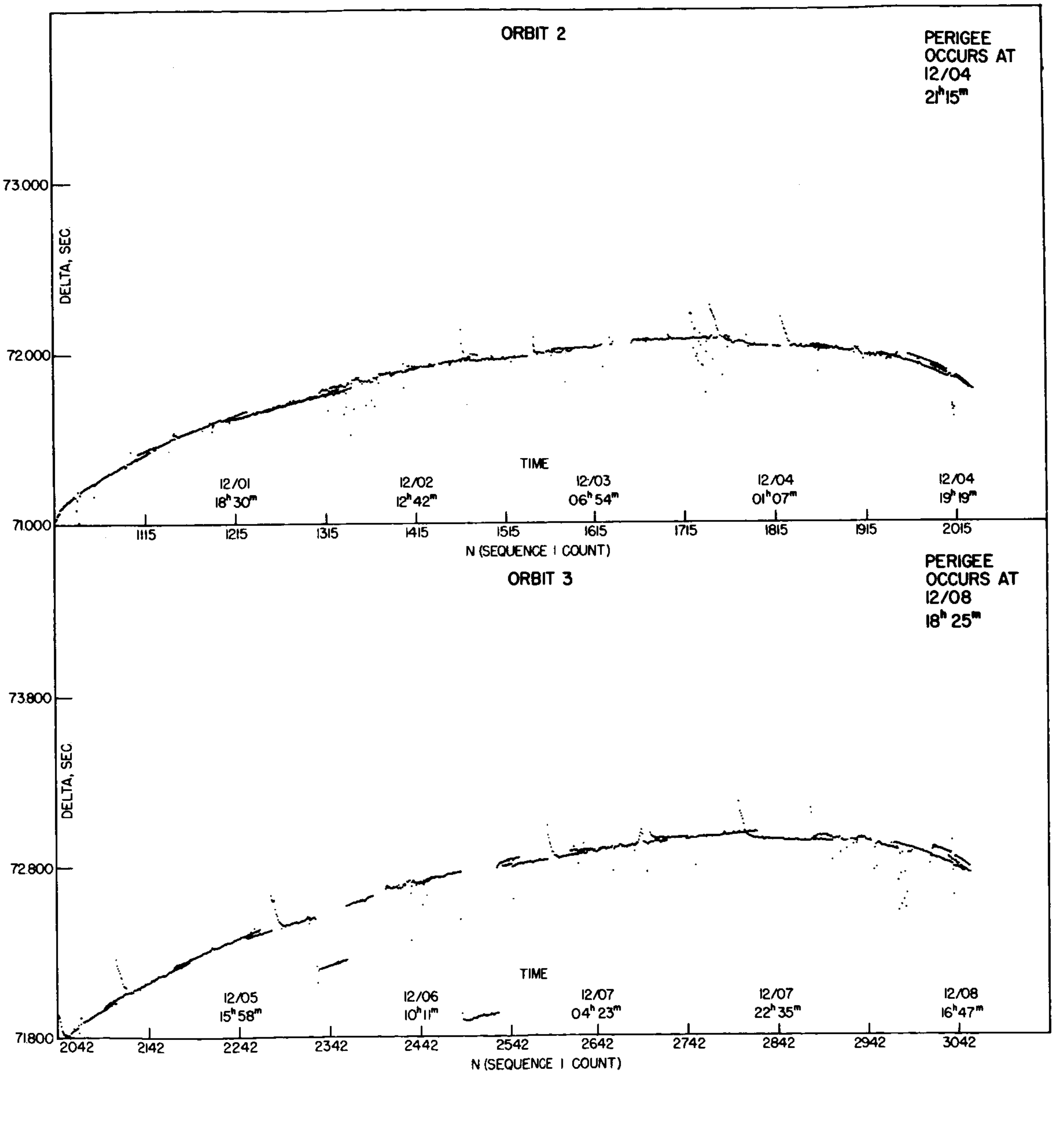
Rosman 003, which also contained the above mentioned error, exhibits a negative displacement on the above plot. This error was introduced by the A/D line when time was decoded.

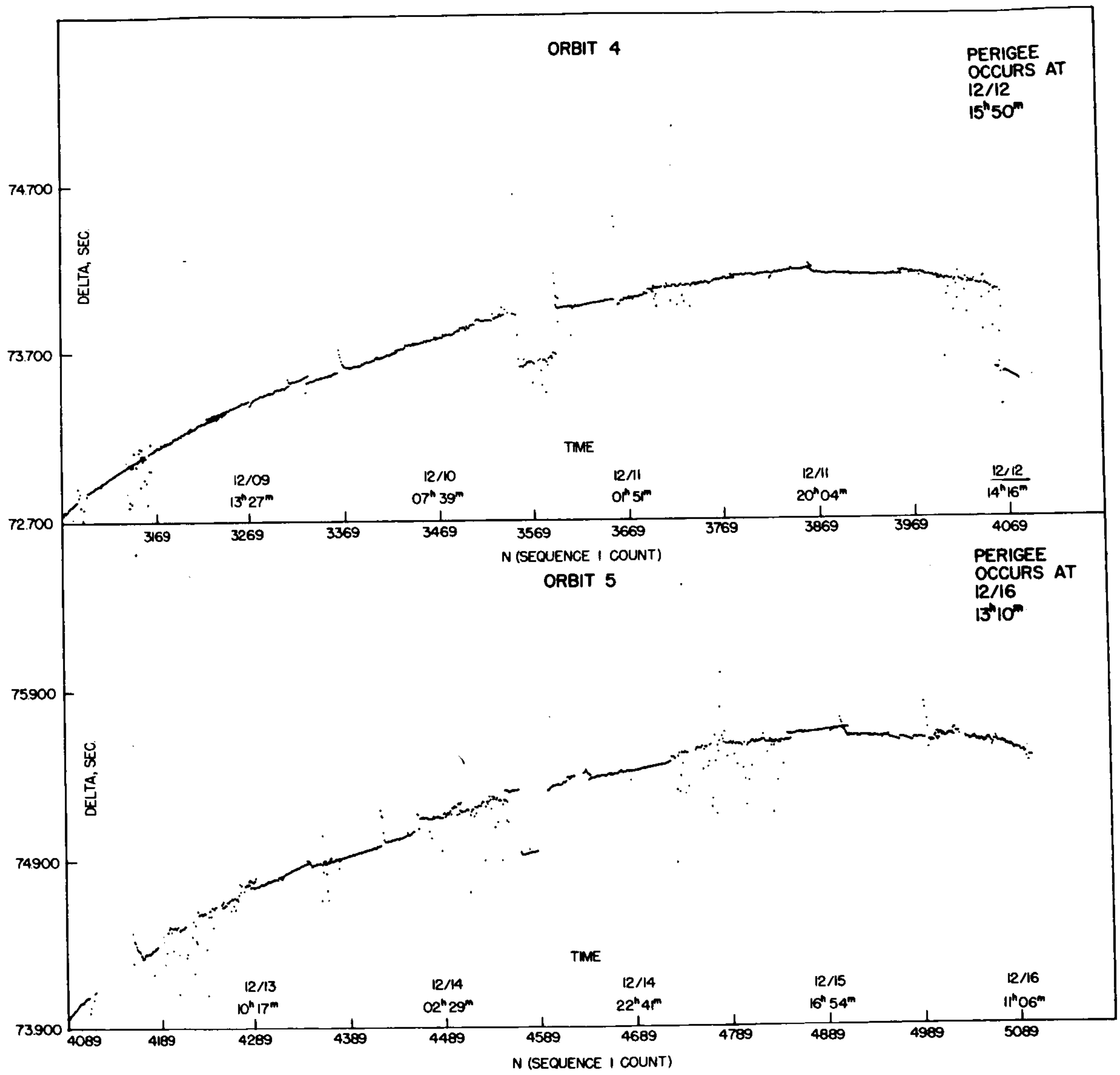
A-3-b

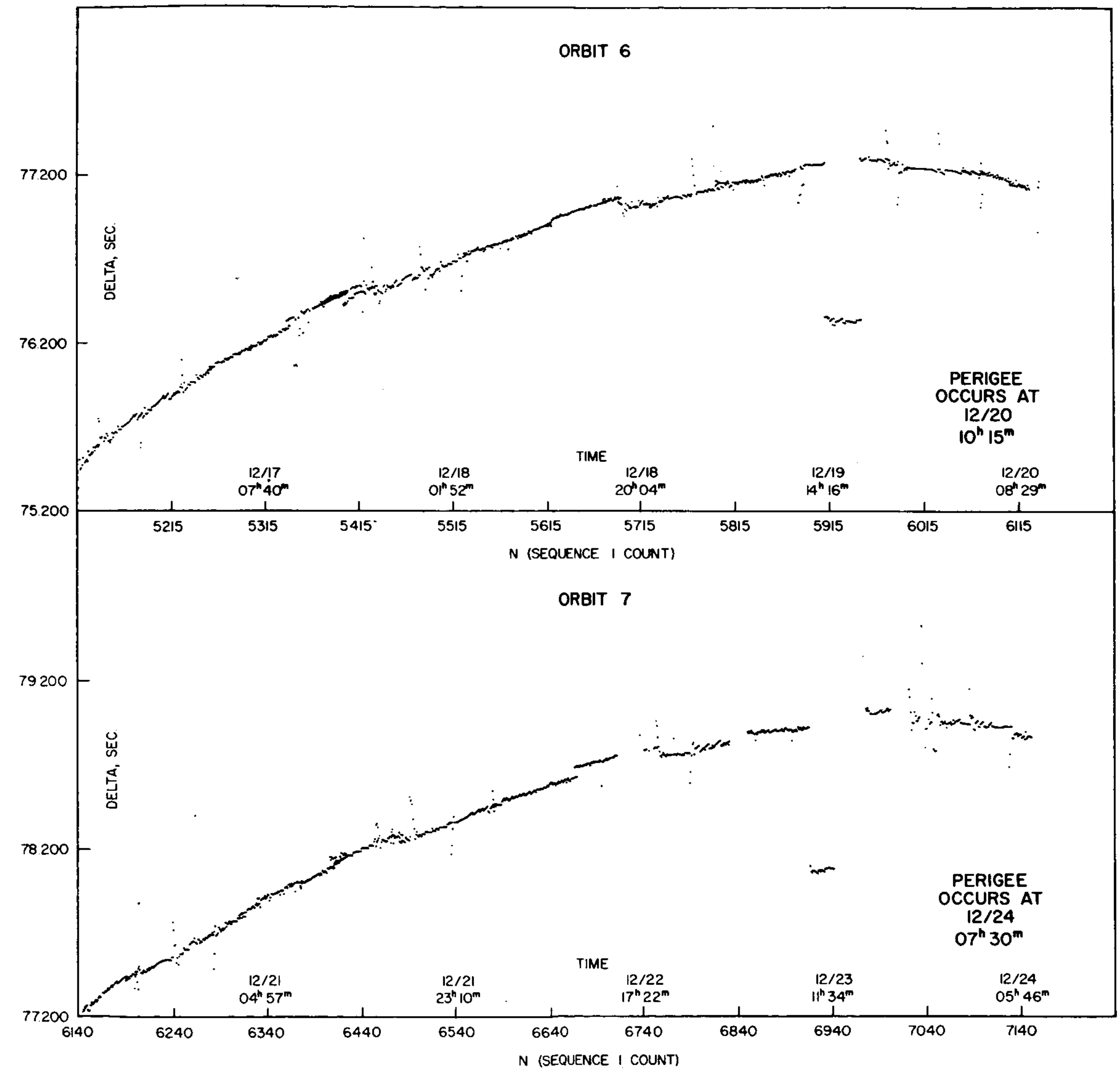


A-3-c

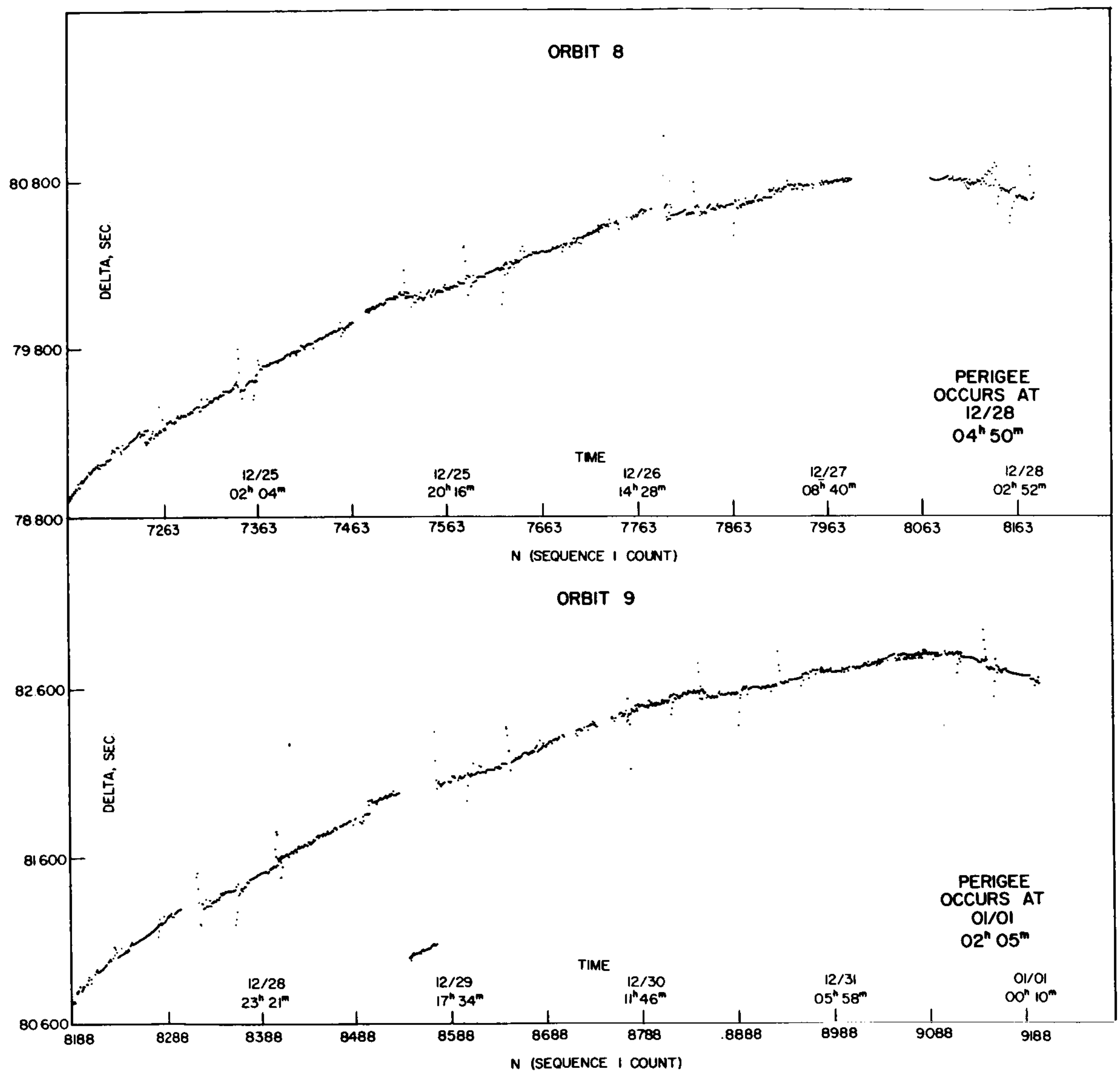



ORBIT 2
PERIGEE OCCURS AT 12/04 21h15m
DELTA, SEC
73.000
72.000
71.000
TIME
12/01 18h30m
12/02 12h42m
12/03 06h54m
12/04 01h07m
12/04 19h19m
1115
1215
1315
1415
1515
1615
1715
1815
1915
2015
N (SEQUENCE I COUNT)
ORBIT 3
PERIGEE OCCURS AT 12/08 18h 25m
DELTA, SEC
73.800
72.800
71.800
TIME
12/05 15h58m
12/06 10h11m
12/07 04h23m
12/07 22h35m
12/08 16h47m
2042
2142
2242
2342
2442
2542
2642
2742
2842
2942
3042
N (SEQUENCE I COUNT)

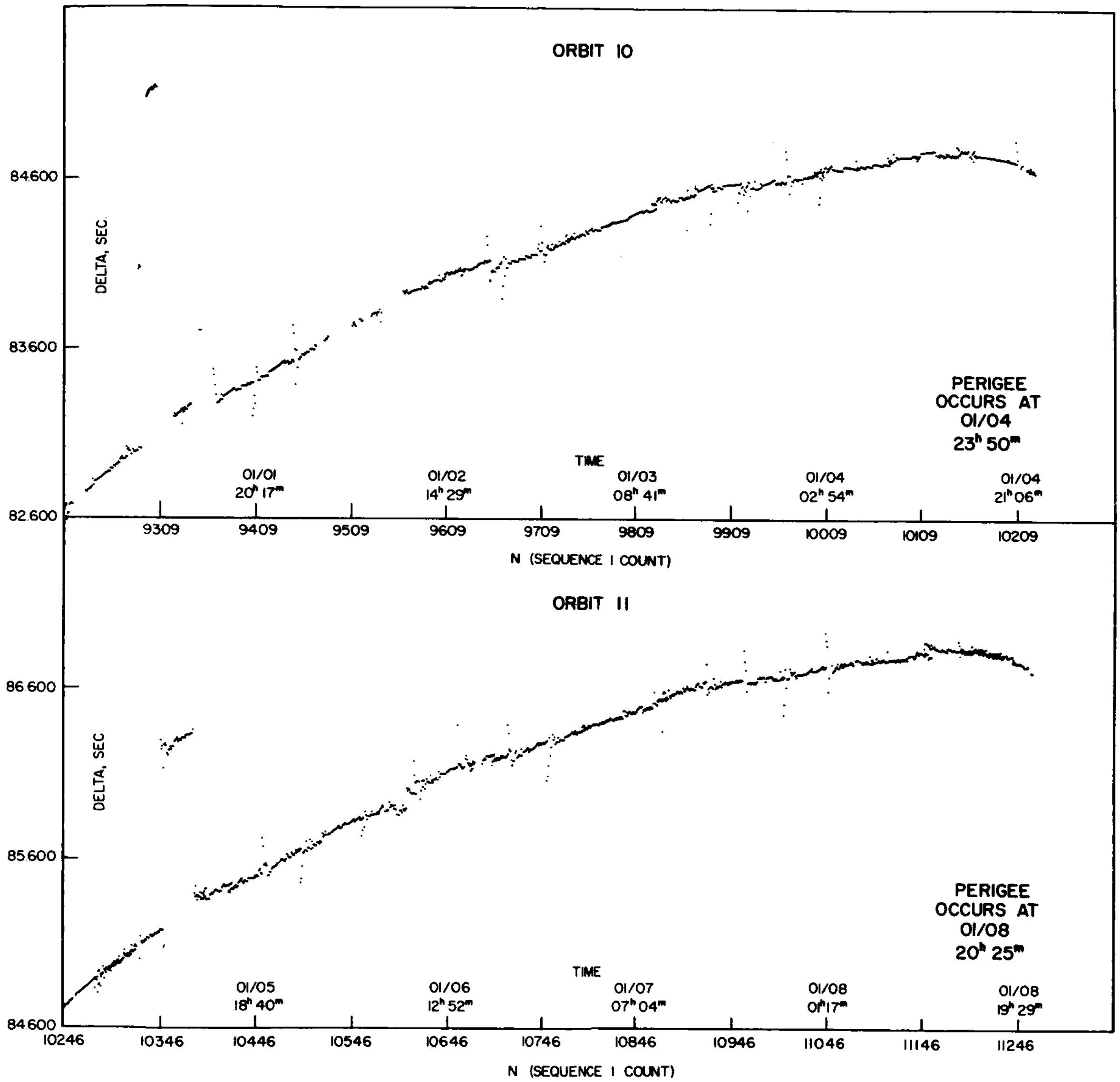

ORBIT 4
PERIGEE OCCURS AT 12/12 15h50m
74.700
73.700
72.700
DELTA, SEC.
TIME
12/09 13h27m
12/10 07h39m
12/11 01h51m
12/11 20h04m
12/12 14h16m
3169
3269
3369
3469
3569
3669
3769
3869
3969
4069
N (SEQUENCE I COUNT)
ORBIT 5
PERIGEE OCCURS AT 12/16 13h10m
75.900
74.900
73.900
DELTA, SEC.
TIME
12/13 10h17m
12/14 02h29m
12/14 22h41m
12/15 16h54m
12/16 11h06m
4089
4189
4289
4389
4489
4589
4689
4789
4889
4989
5089
N (SEQUENCE I COUNT)

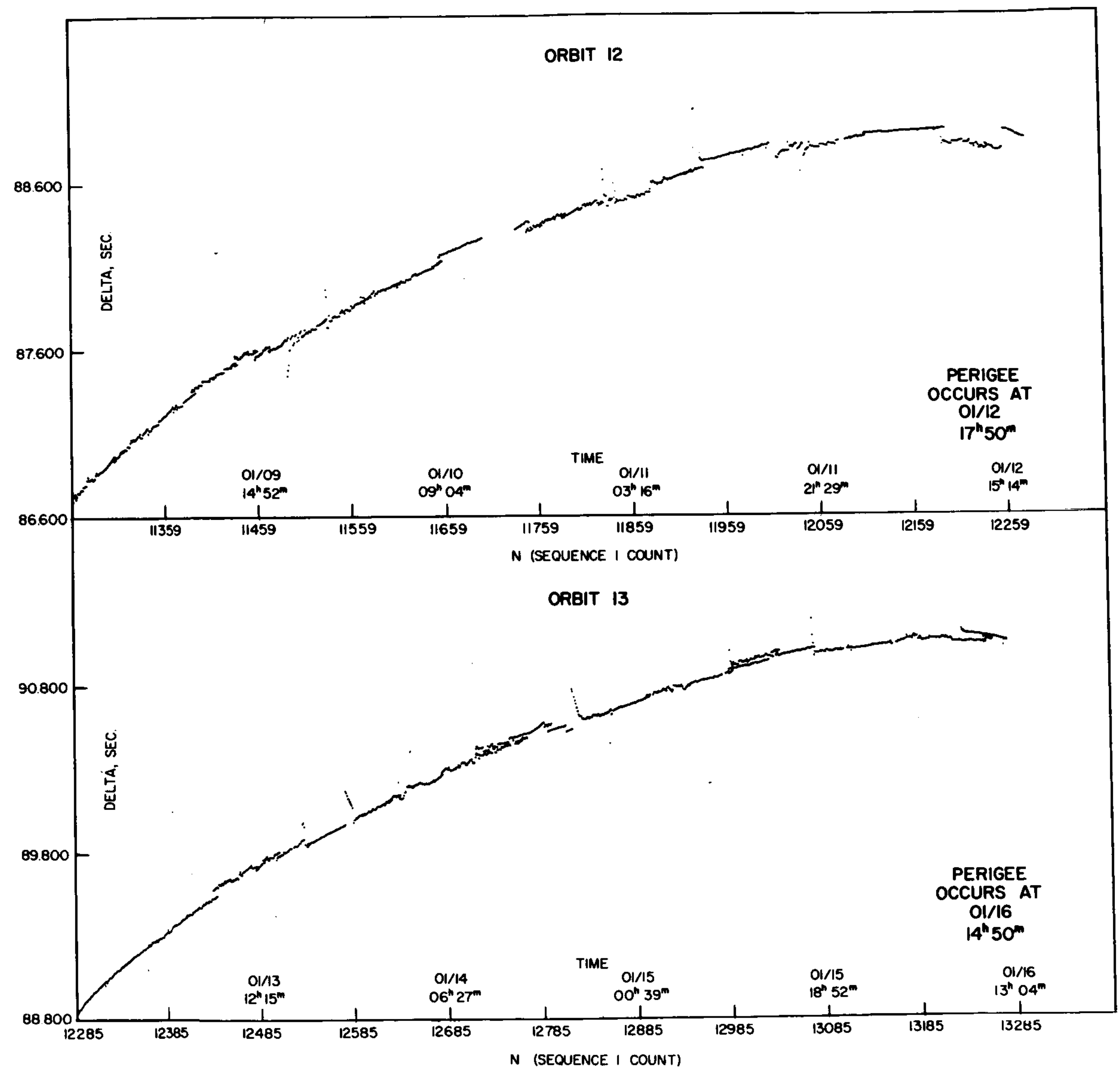


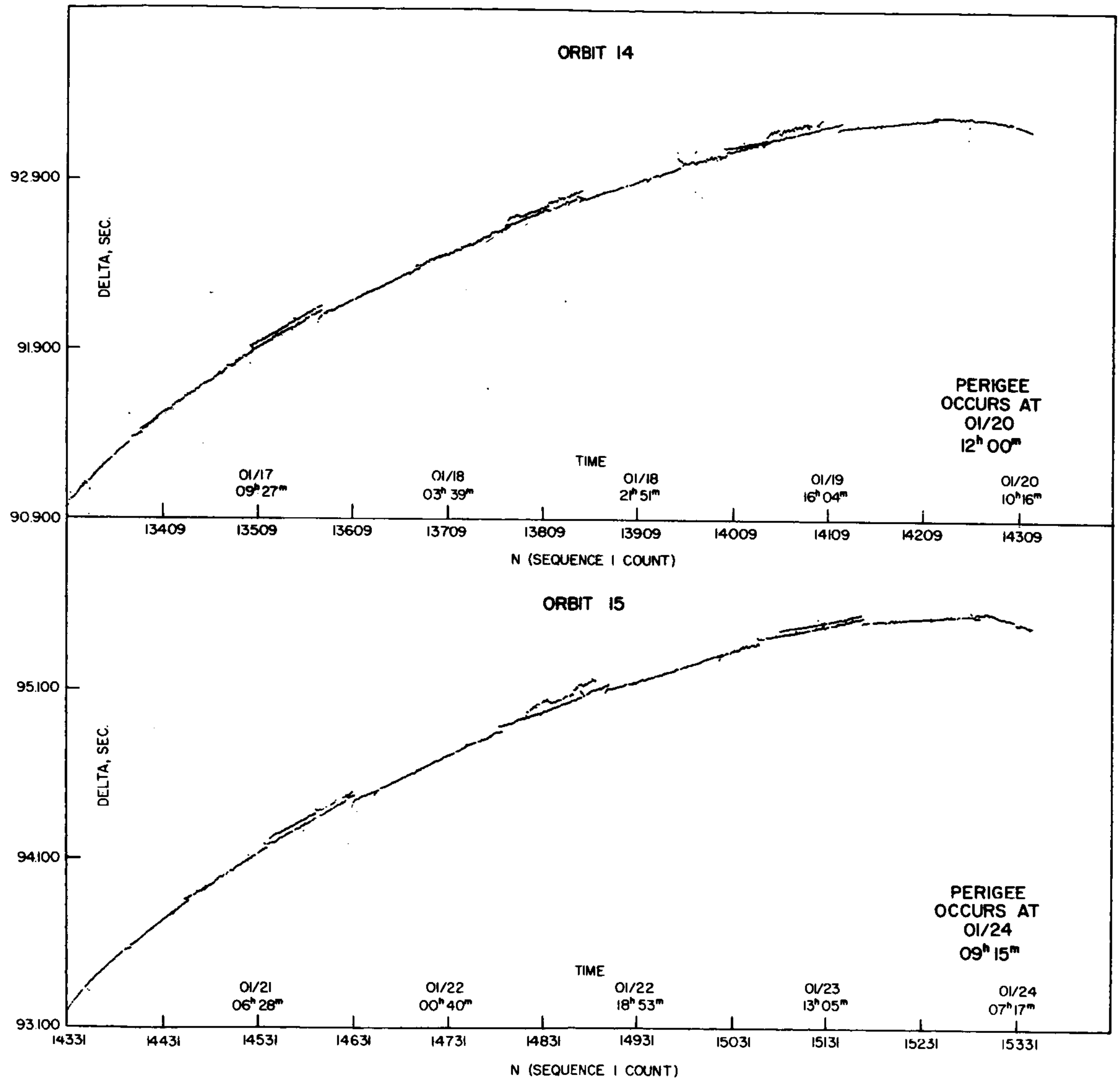
ORBIT 6
77.200
76.200
75.200
DELTA, SEC
PERIGEE OCCURS AT 12/20 10h 15m
TIME
12/17 07h 40m
12/18 01h 52m
12/18 20h 04m
12/19 14h 16m
12/20 08h 29m
5215
5315
5415
5515
5615
5715
5815
5915
6015
6115
N (SEQUENCE I COUNT)
ORBIT 7
79.200
78.200
77.200
DELTA, SEC
PERIGEE OCCURS AT 12/24 07h 30m
TIME
12/21 04h 57m
12/21 23h 10m
12/22 17h 22m
12/23 11h 34m
12/24 05h 46m
6140
6240
6340
6440
6540
6640
6740
6840
6940
7040
7140
N (SEQUENCE I COUNT)

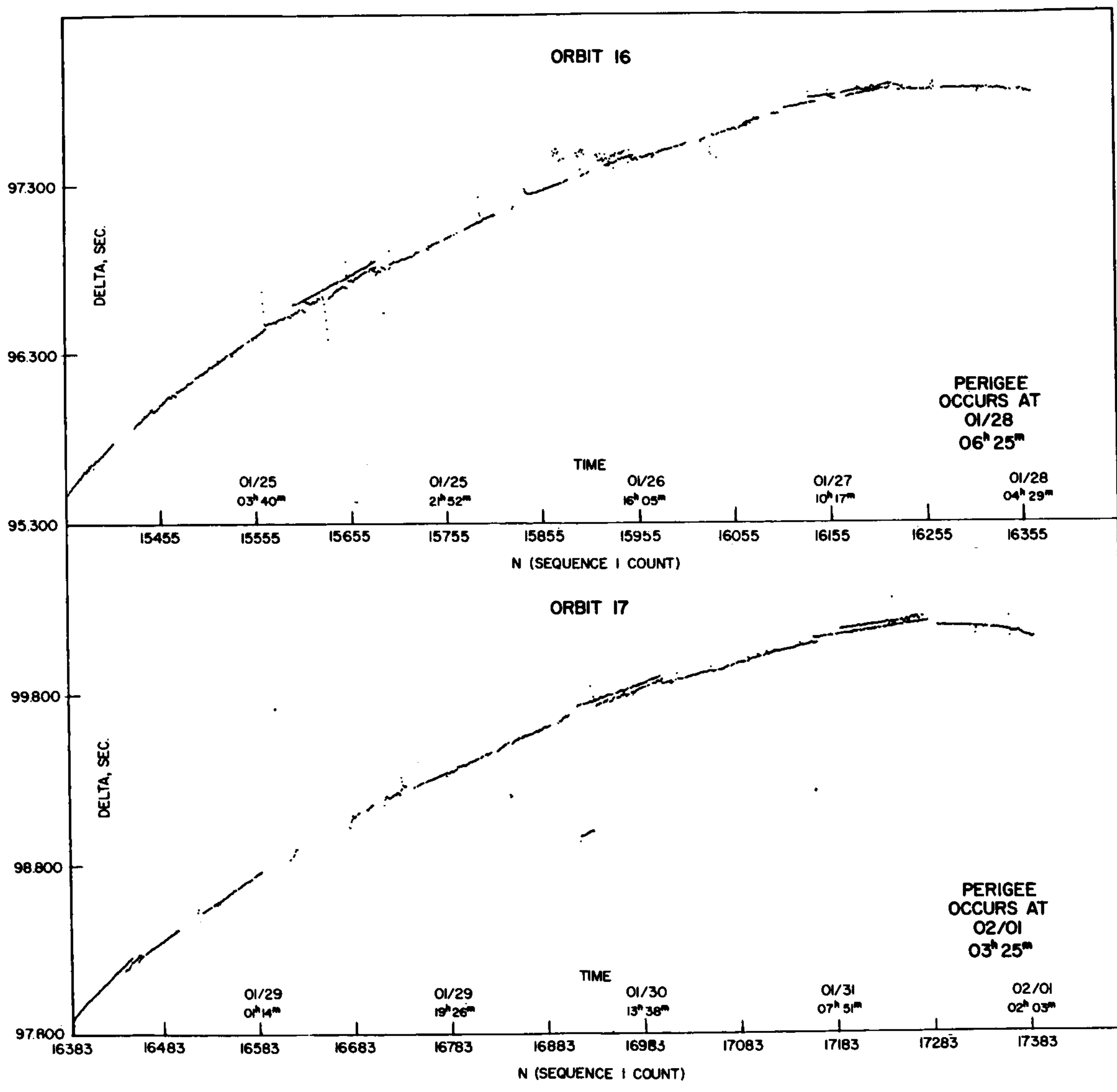


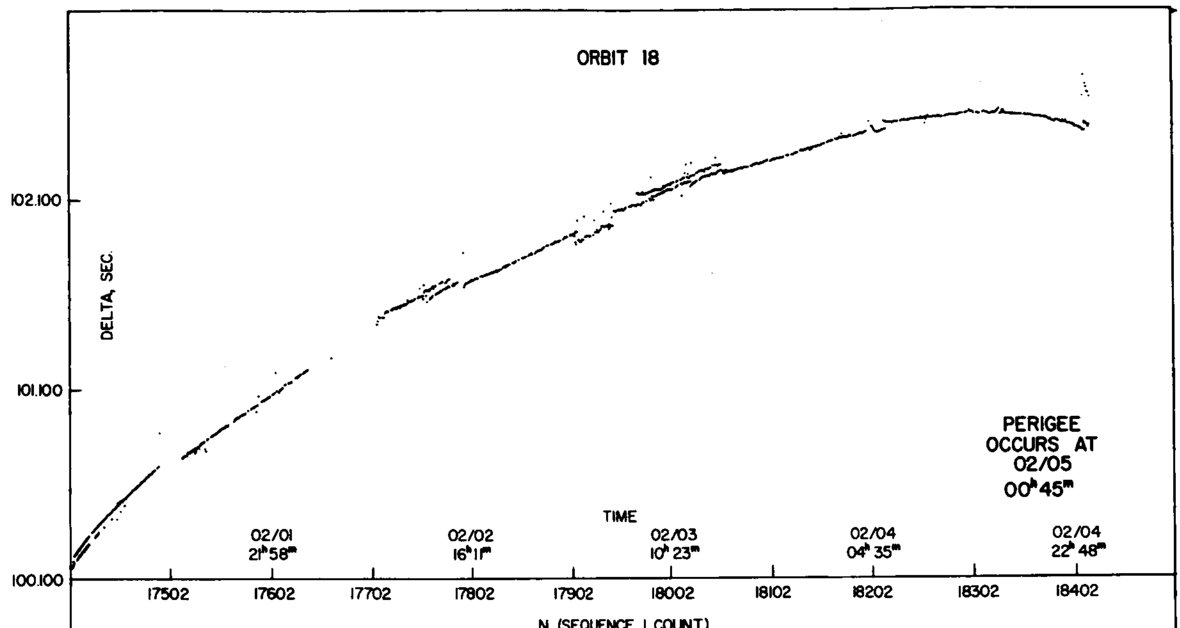
ORBIT 8
DELTA, SEC
80 800
79 800
78 800
PERIGEE OCCURS AT 12/28 04h 50m
TIME
12/25 02h 04m
12/25 20h 16m
12/26 14h 28m
12/27 08h 40m
12/28 02h 52m
7263
7363
7463
7563
7663
7763
7863
7963
8063
8163
N (SEQUENCE I COUNT)
ORBIT 9
DELTA, SEC
82 600
81 600
80 600
PERIGEE OCCURS AT 01/01 02h 05m
TIME
12/28 23h 21m
12/29 17h 34m
12/30 11h 46m
12/31 05h 58m
01/01 00h 10m
8188
8288
8388
8488
8588
8688
8788
8888
8988
9088
9188
N (SEQUENCE I COUNT)


ORBIT 10
DELTA, SEC.
84.600
83.600
82.600
PERIGEE OCCURS AT 01/04 23h 50m
TIME
01/01 20h 17m
01/02 14h 29m
01/03 08h 41m
01/04 02h 54m
01/04 21h 06m
9309
9409
9509
9609
9709
9809
9909
10009
10109
10209
N (SEQUENCE 1 COUNT)
ORBIT 11
DELTA, SEC.
86.600
85.600
84.600
PERIGEE OCCURS AT 01/08 20h 25m
TIME
01/05 18h 40m
01/06 12h 52m
01/07 07h 04m
01/08 01h 17m
01/08 19h 29m
10246
10346
10446
10546
10646
10746
10846
10946
11046
11146
11246
N (SEQUENCE 1 COUNT)

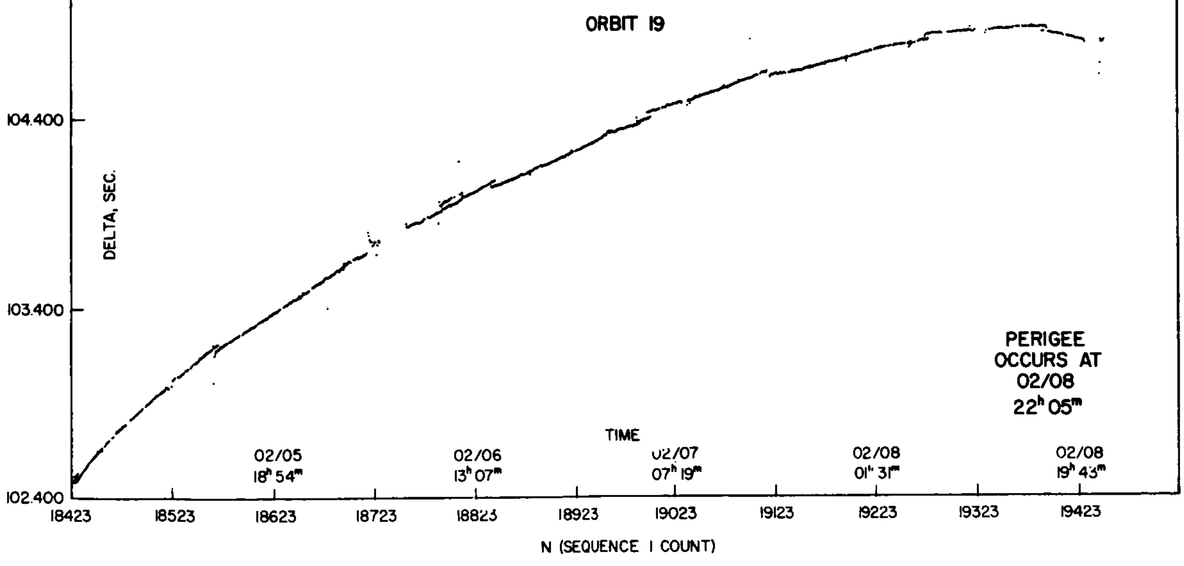

ORBIT 12
88.600
87.600
86.600
DELTA, SEC.
PERIGEE OCCURS AT 01/12 17h50m
TIME
01/09 14h52m
01/10 09h 04m
01/11 03h 16m
01/11 21h 29m
01/12 15h 14m
11359
11459
11559
11659
11759
11859
11959
12059
12159
12259
N (SEQUENCE I COUNT)
ORBIT 13
90.800
89.800
88.800
DELTA, SEC.
PERIGEE OCCURS AT 01/16 14h50m
TIME
01/13 12h 15m
01/14 06h 27m
01/15 00h 39m
01/15 18h 52m
01/16 13h 04m
12285
12385
12485
12585
12685
12785
12885
12985
13085
13185
13285
N (SEQUENCE I COUNT)


ORBIT 14
92.900
91.900
90.900
DELTA, SEC.
PERIGEE OCCURS AT 01/20 12h 00m
TIME
01/17 09h 27m
01/18 03h 39m
01/18 21h 51m
01/19 16h 04m
01/20 10h 16m
13409
13509
13609
13709
13809
13909
14009
14109
14209
14309
N (SEQUENCE I COUNT)
ORBIT 15
95.100
94.100
93.100
DELTA, SEC.
PERIGEE OCCURS AT 01/24 09h 15m
TIME
01/21 06h 28m
01/22 00h 40m
01/22 18h 53m
01/23 13h 05m
01/24 07h 17m
14331
14431
14531
14631
14731
14831
14931
15031
15131
15231
15331
N (SEQUENCE I COUNT)

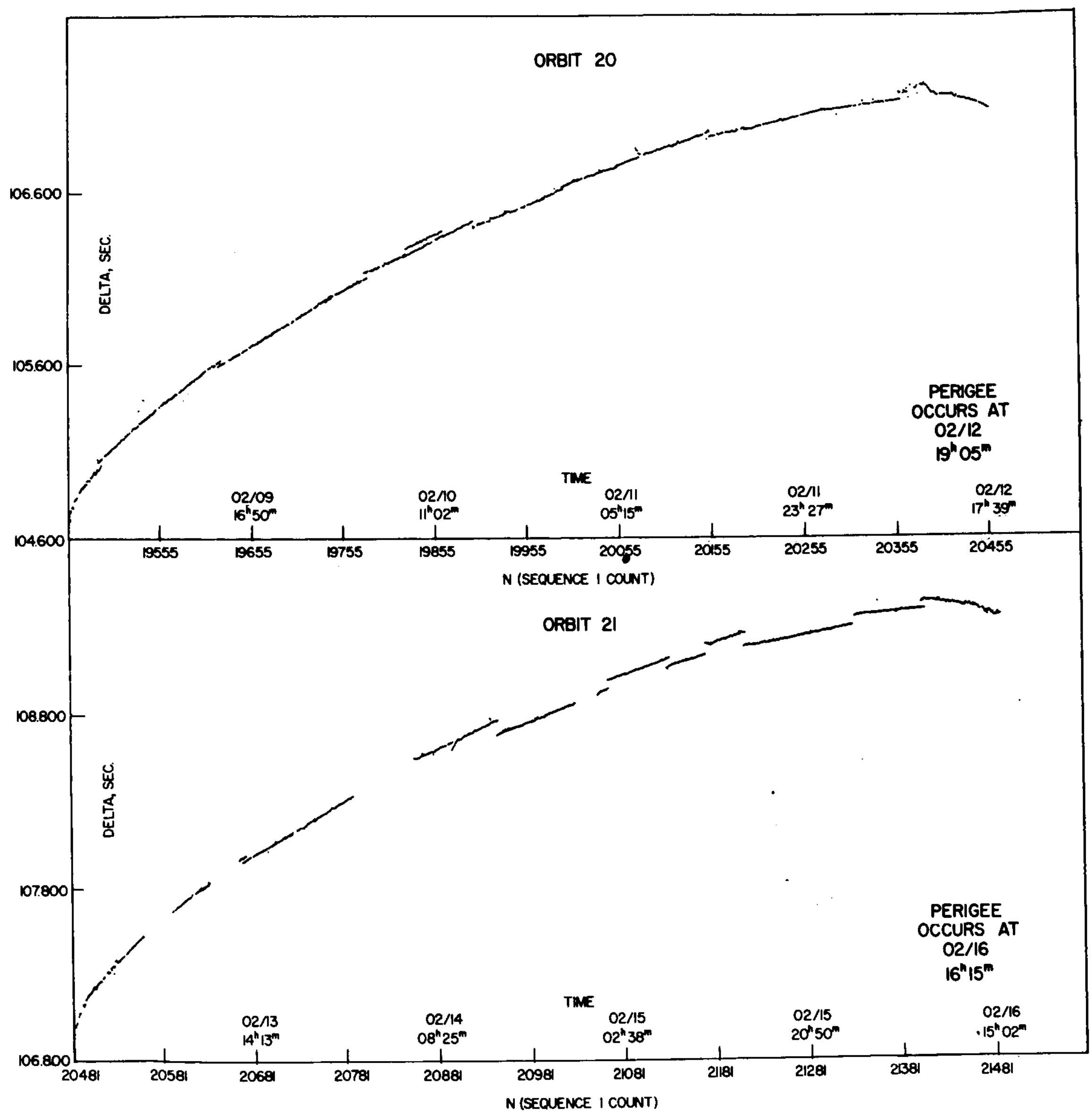

ORBIT 16
97.300
96.300
95.300
DELTA, SEC.
PERIGEE OCCURS AT 01/28 06h 25m
TIME
01/25 03h 40m
01/25 21h 52m
01/26 16h 05m
01/27 10h 17m
01/28 04h 29m
15455
15555
15655
15755
15855
15955
16055
16155
16255
16355
N (SEQUENCE I COUNT)
ORBIT 17
99.800
98.800
97.800
DELTA, SEC.
PERIGEE OCCURS AT 02/01 03h 25m
TIME
01/29 01h 14m
01/29 19h 26m
01/30 13h 38m
01/31 07h 51m
02/01 02h 03m
16383
16483
16583
16683
16783
16883
16983
17083
17183
17283
17383
N (SEQUENCE I COUNT)



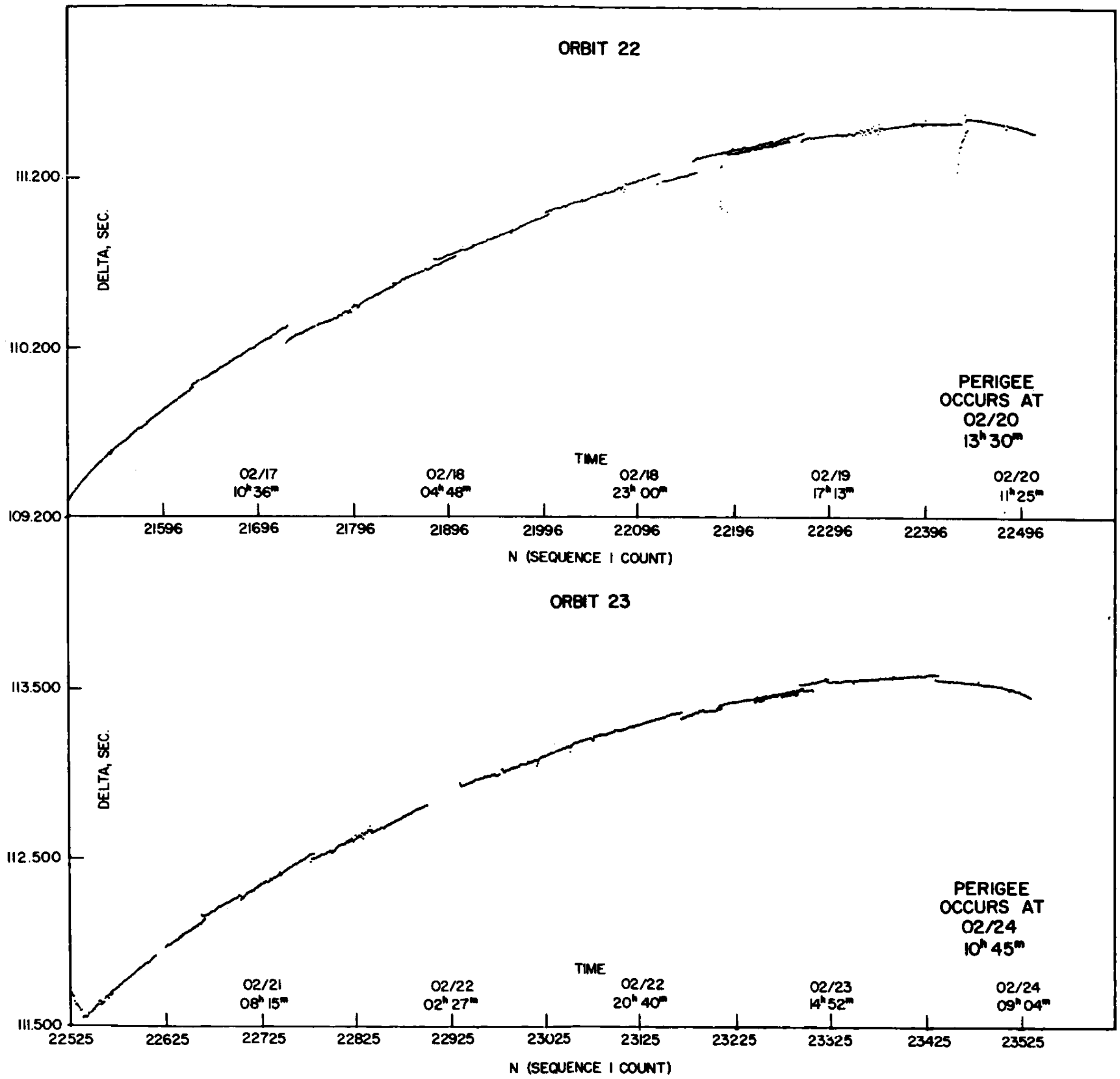
ORBIT 18
DELTA, SEC.
102.100
101.100
100.100
PERIGEE OCCURS AT 02/05 00h 45m
TIME
02/01 21h 58m
02/02 16h 11m
02/03 10h 23m
02/04 04h 35m
02/04 22h 48m
17502
17602
17702
17802
17902
18002
18102
18202
18302
18402
N (SEQUENCE I COUNT)



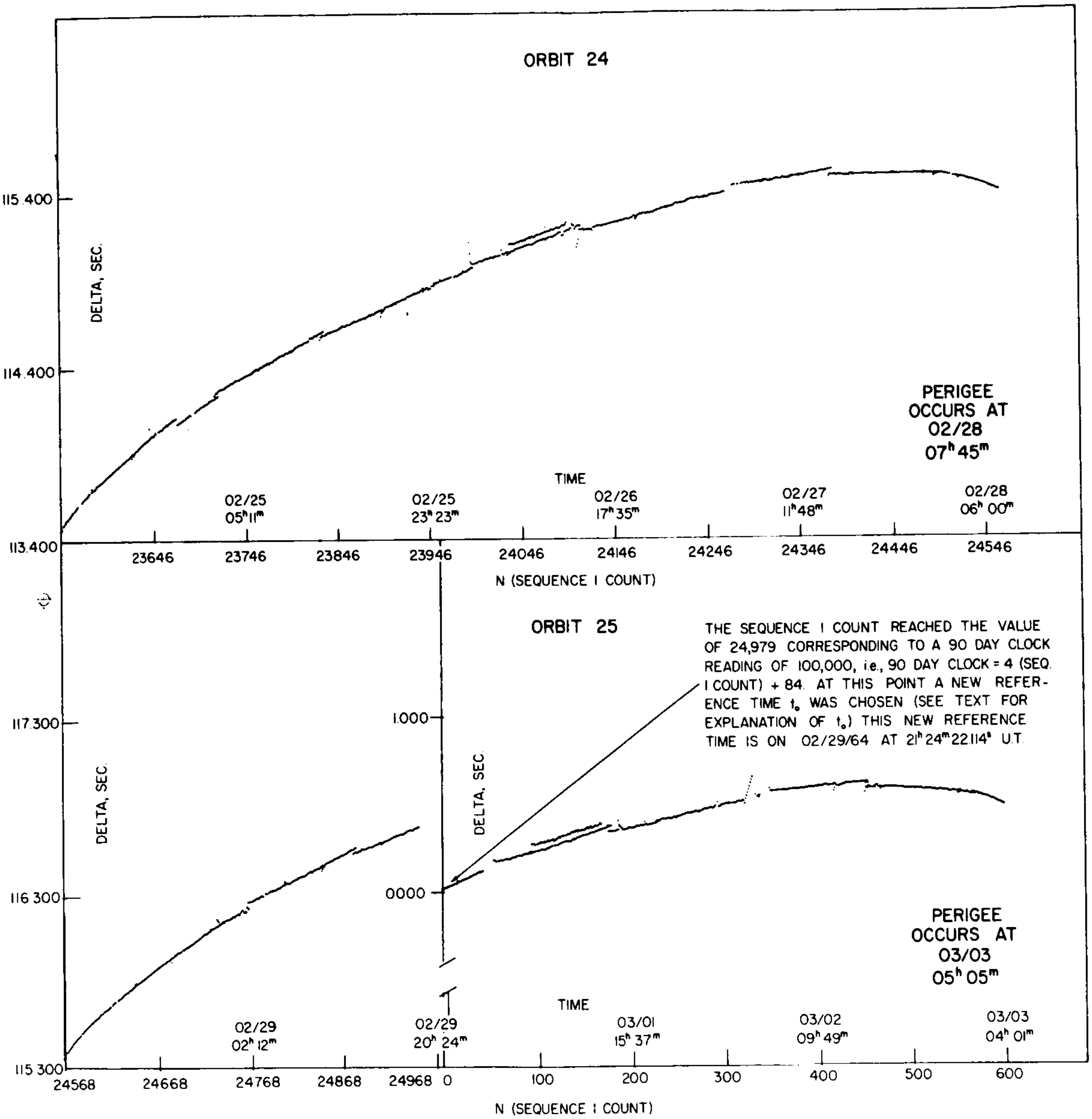
ORBIT 19
DELTA, SEC.
104.400
103.400
102.400
PERIGEE OCCURS AT 02/08 22h 05m
TIME
02/05 18h 54m
02/06 13h 07m
02/07 07h 19m
02/08 01h 31m
02/08 19h 43m
18423
18523
18623
18723
18823
18923
19023
19123
19223
19323
19423
N (SEQUENCE I COUNT)

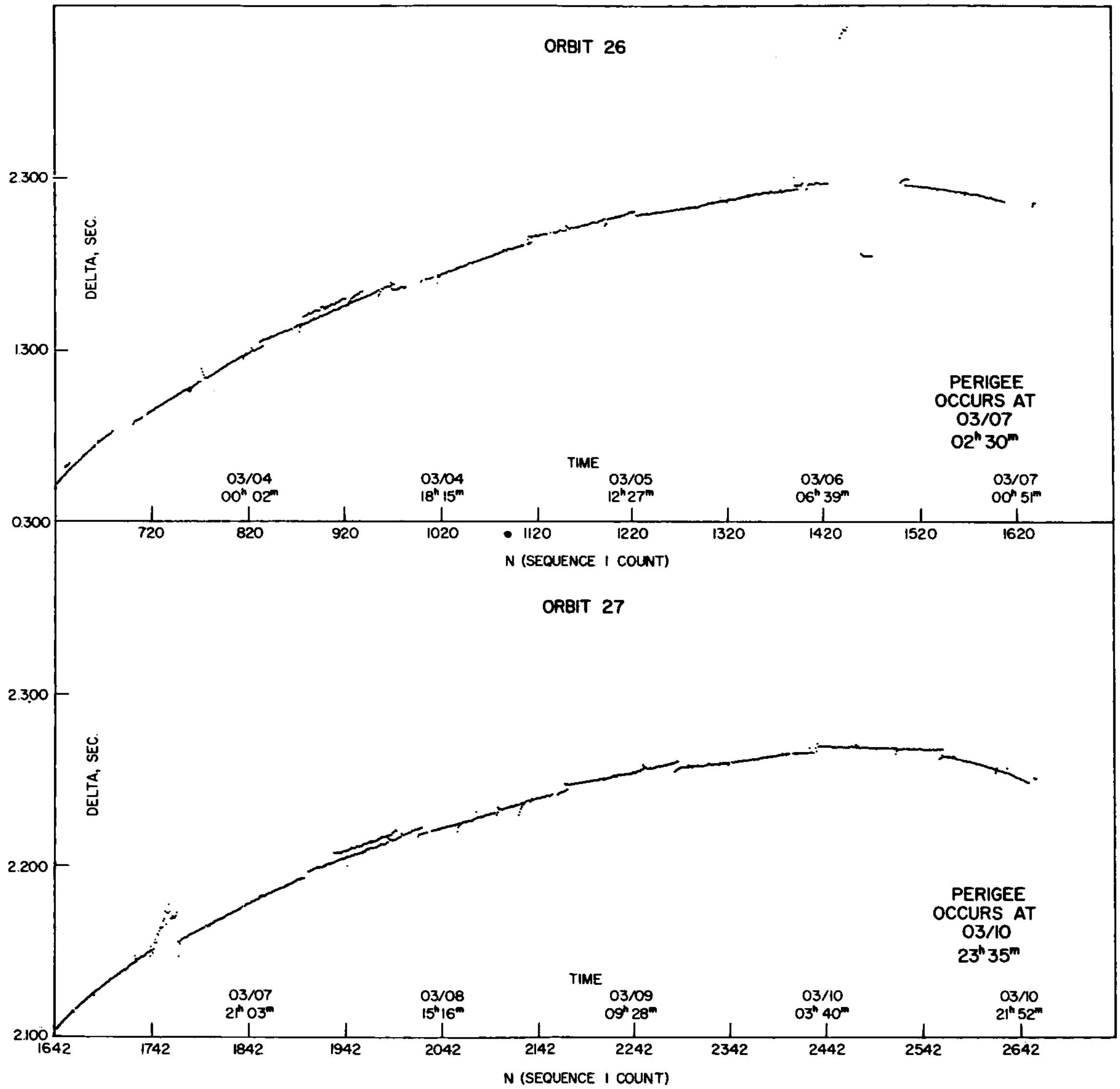


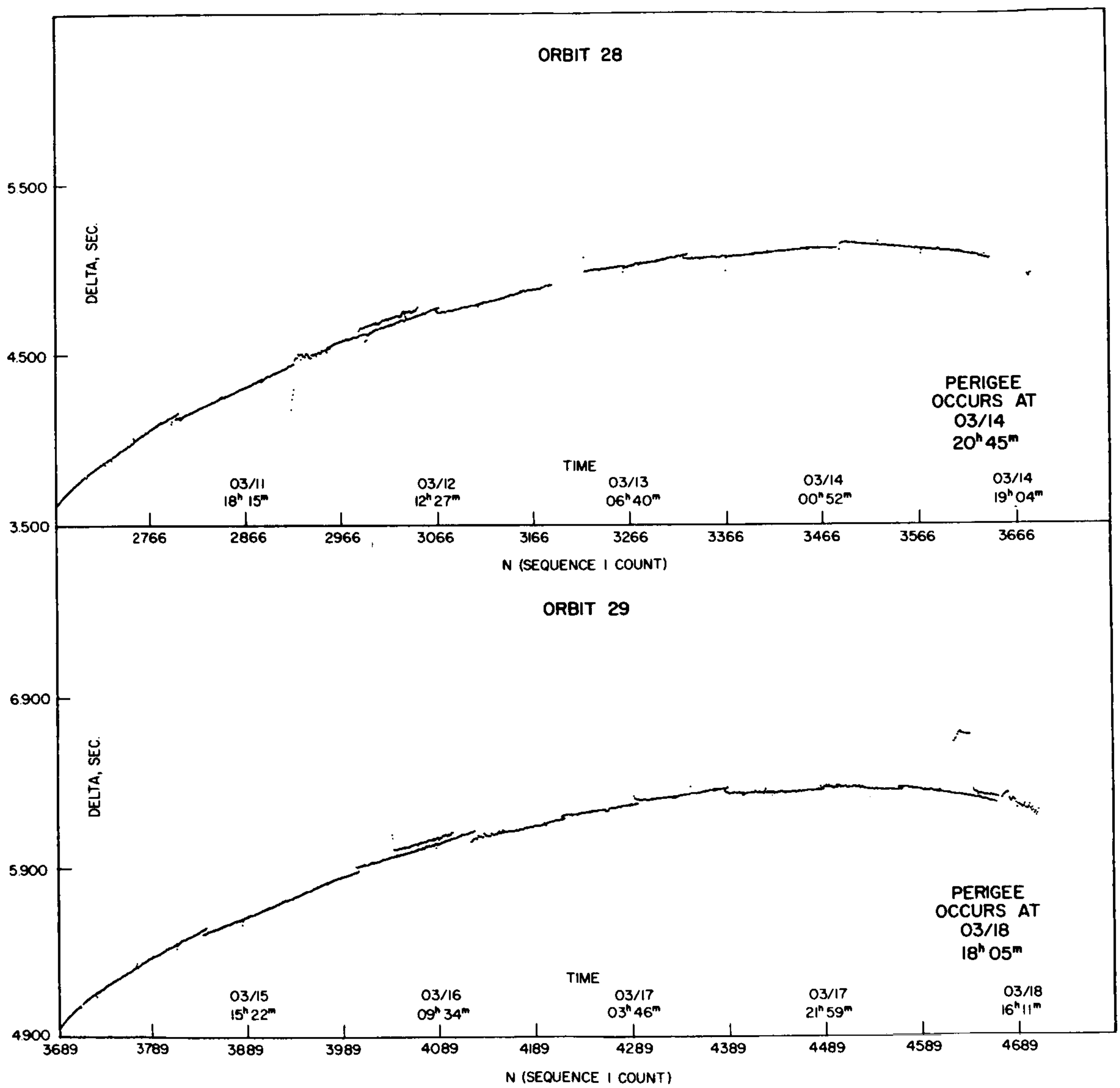
ORBIT 20
DELTA, SEC.
106.600
105.600
104.600
PERIGEE OCCURS AT 02/12 19h 05m
TIME
02/09 16h50m
02/10 11h02m
02/11 05h15m
02/11 23h 27m
02/12 17h 39m
19555
19655
19755
19855
19955
20055
20155
20255
20355
20455
N (SEQUENCE 1 COUNT)
ORBIT 21
DELTA, SEC.
108.800
107.800
106.800
PERIGEE OCCURS AT 02/16 16h15m
TIME
02/13 14h13m
02/14 08h25m
02/15 02h 38m
02/15 20h50m
02/16 15h 02m
20481
20581
20681
20781
20881
20981
21081
21181
21281
21381
21481
N (SEQUENCE 1 COUNT)

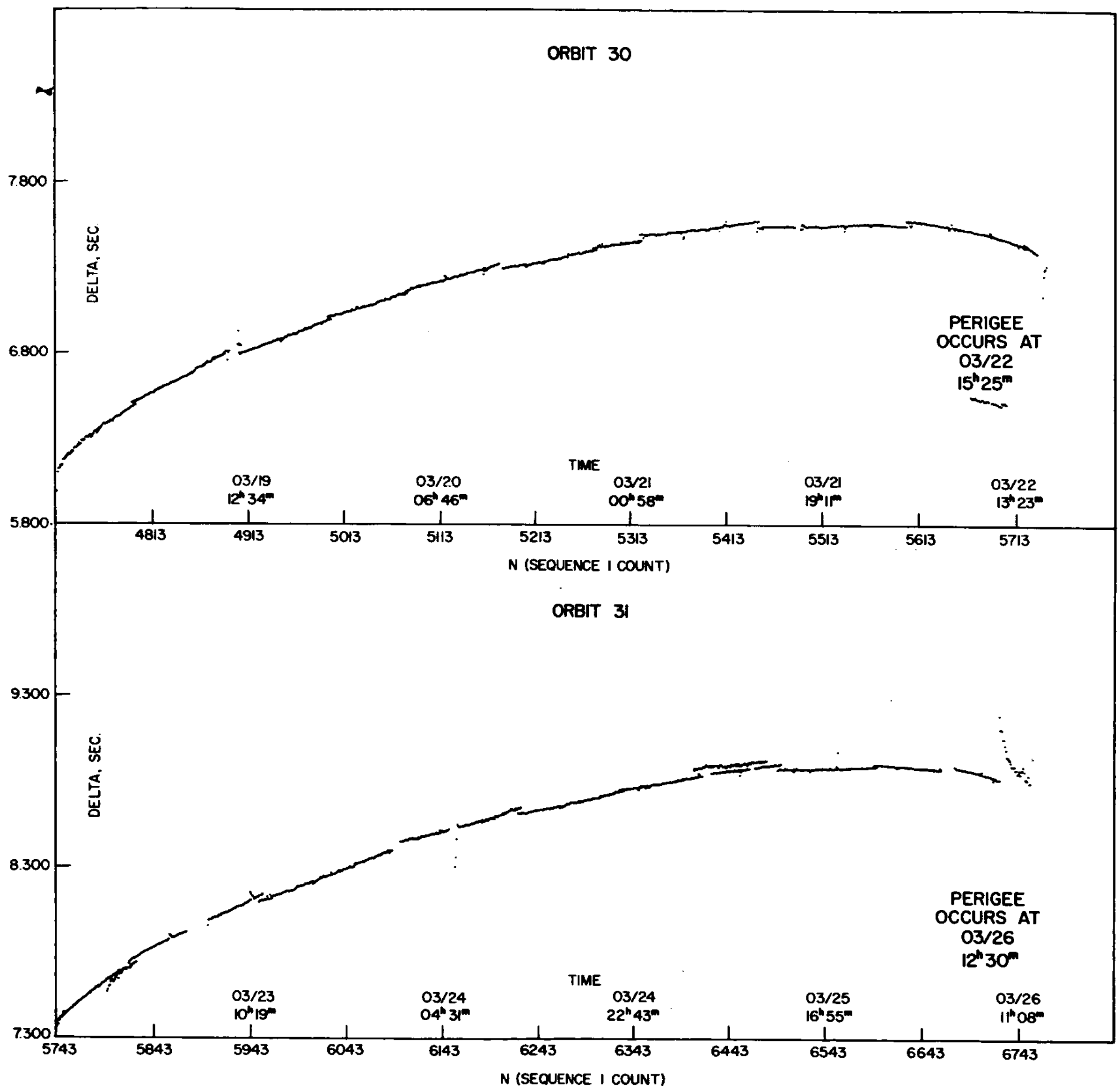


ORBIT 22
111.200
110.200
109.200
DELTA, SEC.
PERIGEE
OCCURS AT
02/20
13h 30m
TIME
02/17 10h 36m
02/18 04h 48m
02/18 23h 00m
02/19 17h 13m
02/20 11h 25m
21596
21696
21796
21896
21996
22096
22196
22296
22396
22496
N (SEQUENCE I COUNT)
ORBIT 23
113.500
112.500
111.500
DELTA, SEC.
PERIGEE
OCCURS AT
02/24
10h 45m
TIME
02/21 08h 15m
02/22 02h 27m
02/22 20h 40m
02/23 14h 52m
02/24 09h 04m
22525
22625
22725
22825
22925
23025
23125
23225
23325
23425
23525
N (SEQUENCE I COUNT)

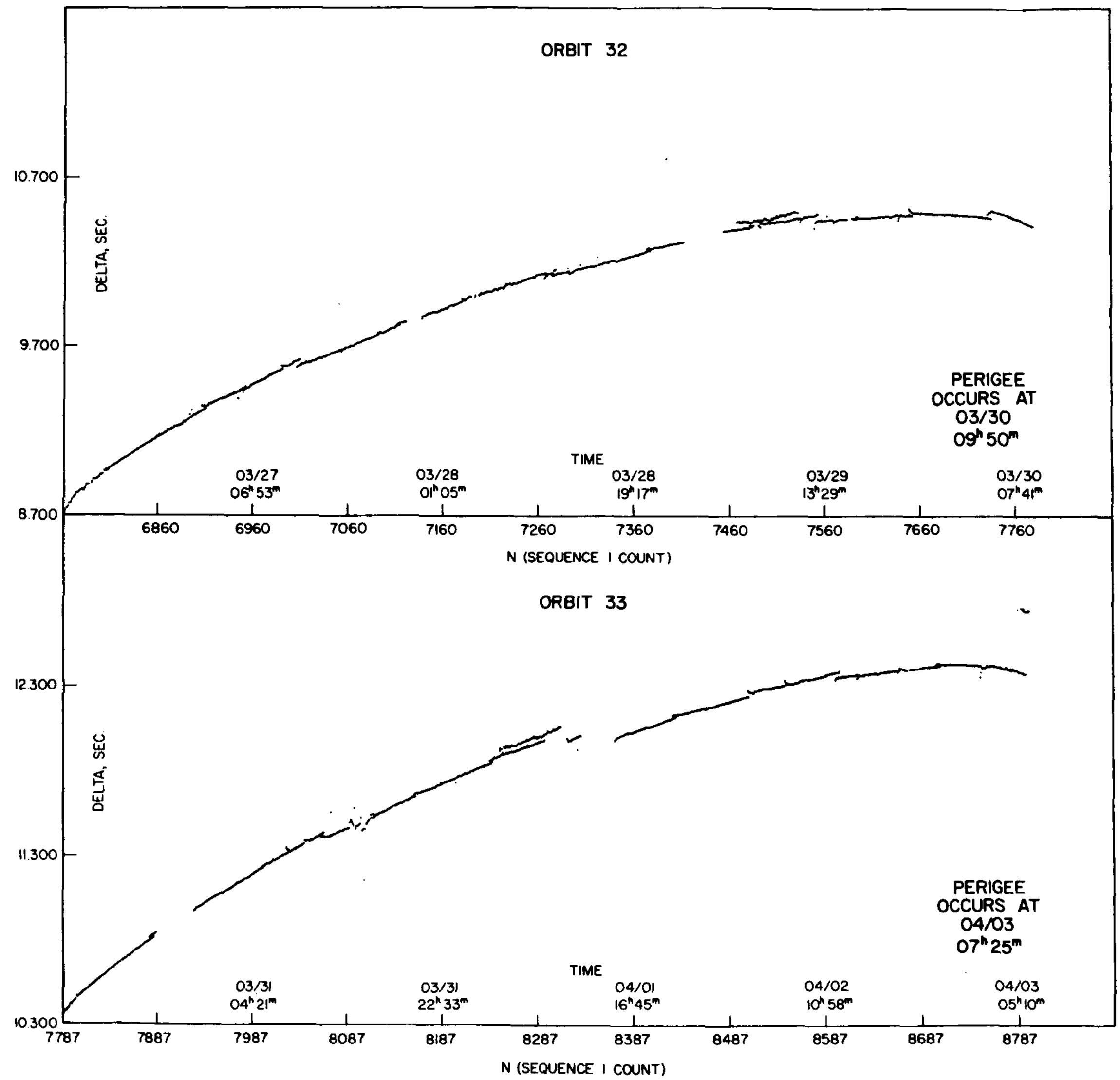

ORBIT 24
115.400
114.400
113.400
DELTA, SEC.
PERIGEE OCCURS AT 02/28 07h 45m
TIME
02/25 05h 11m
02/25 23h 23m
02/26 17h 35m
02/27 11h 48m
02/28 06h 00m
23646
23746
23846
23946
24046
24146
24246
24346
24446
24546
N (SEQUENCE I COUNT)
ORBIT 25
THE SEQUENCE I COUNT REACHED THE VALUE OF 24,979 CORRESPONDING TO A 90 DAY CLOCK READING OF 100,000, i.e., 90 DAY CLOCK = 4 (SEQ. I COUNT) + 84. AT THIS POINT A NEW REFERENCE TIME t0 WAS CHOSEN (SEE TEXT FOR EXPLANATION OF t0) THIS NEW REFERENCE TIME IS ON 02/29/64 AT 21h 24m 22.114s U.T.
117.300
116.300
115.300
1.000
0000
DELTA, SEC.
DELTA, SEC.
PERIGEE OCCURS AT 03/03 05h 05m
TIME
02/29 02h 12m
02/29 20h 24m
03/01 15h 37m
03/02 09h 49m
03/03 04h 01m
24568
24668
24768
24868
24968
0
100
200
300
400
500
600
N (SEQUENCE I COUNT)


ORBIT 26
2.300
1.300
0.300
DELTA, SEC.
PERIGEE OCCURS AT 03/07 $02^h 30^m$
TIME
03/04 $00^h 02^m$
03/04 $18^h 15^m$
03/05 $12^h 27^m$
03/06 $06^h 39^m$
03/07 $00^h 51^m$
720 820 920 1020 1120 1220 1320 1420 1520 1620
N (SEQUENCE I COUNT)
ORBIT 27
2.300
2.200
2.100
DELTA, SEC.
PERIGEE OCCURS AT 03/10 $23^h 35^m$
TIME
03/07 $21^h 03^m$
03/08 $15^h 16^m$
03/09 $09^h 28^m$
03/10 $03^h 40^m$
03/10 $21^h 52^m$
1642 1742 1842 1942 2042 2142 2242 2342 2442 2542 2642
N (SEQUENCE I COUNT)

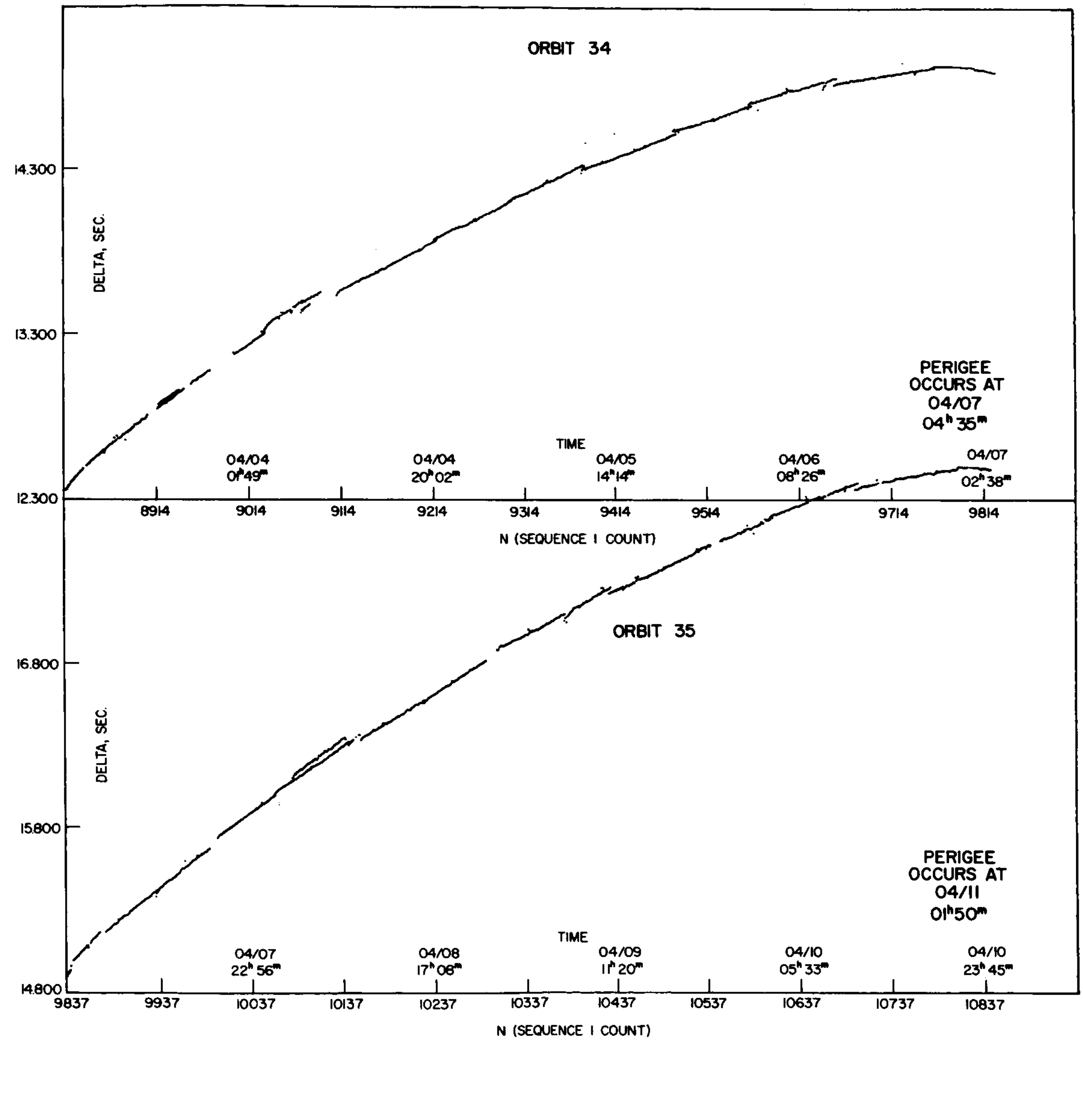

ORBIT 28
5.500
4.500
3.500
DELTA, SEC.
PERIGEE
OCCURS AT
03/14
20h 45m
TIME
03/11
18h 15m
03/12
12h 27m
03/13
06h 40m
03/14
00h 52m
03/14
19h 04m
2766
2866
2966
3066
3166
3266
3366
3466
3566
3666
N (SEQUENCE I COUNT)
ORBIT 29
6.900
5.900
4.900
DELTA, SEC.
PERIGEE
OCCURS AT
03/18
18h 05m
TIME
03/15
15h 22m
03/16
09h 34m
03/17
03h 46m
03/17
21h 59m
03/18
16h 11m
3689
3789
3889
3989
4089
4189
4289
4389
4489
4589
4689
N (SEQUENCE I COUNT)

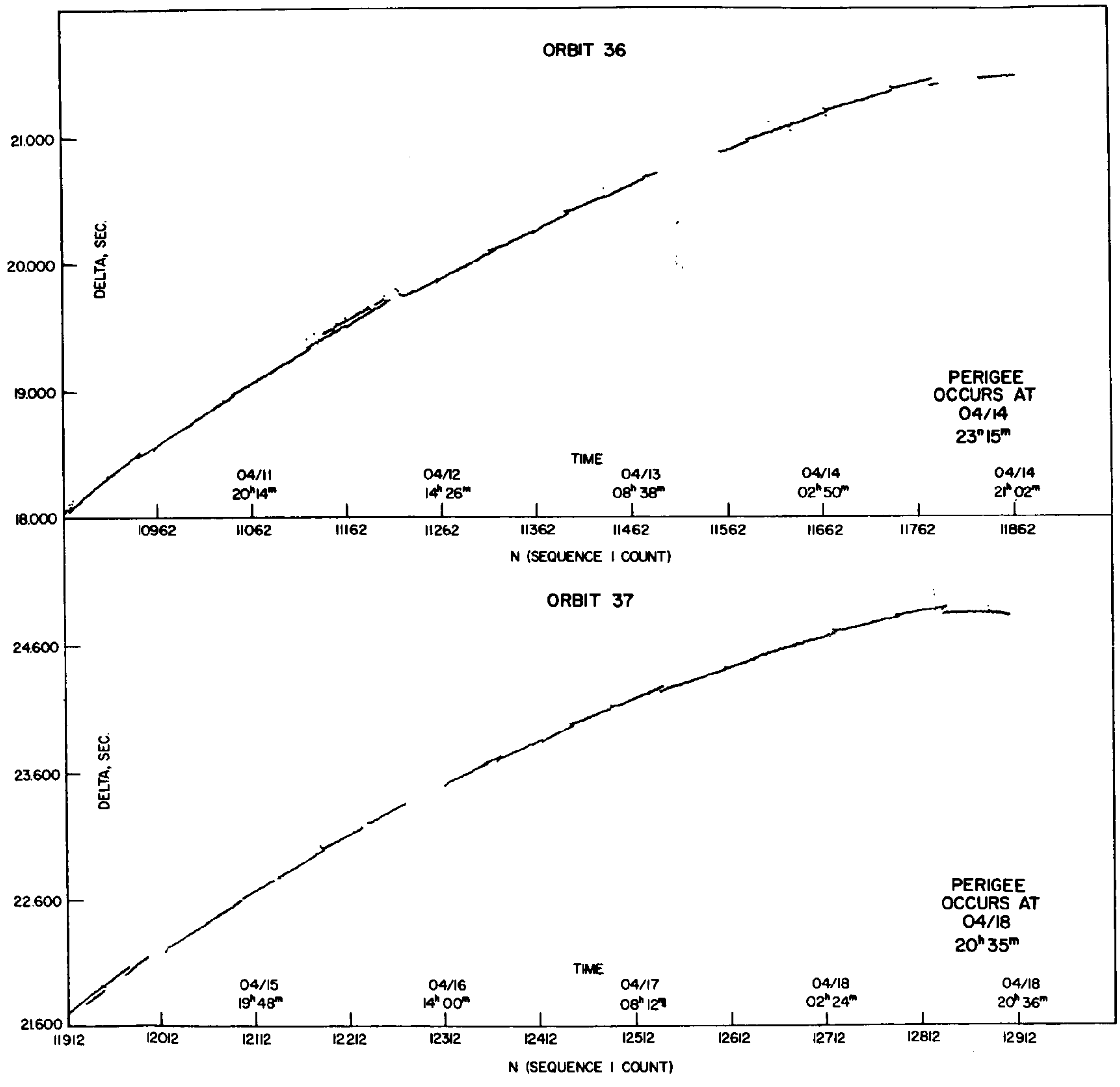


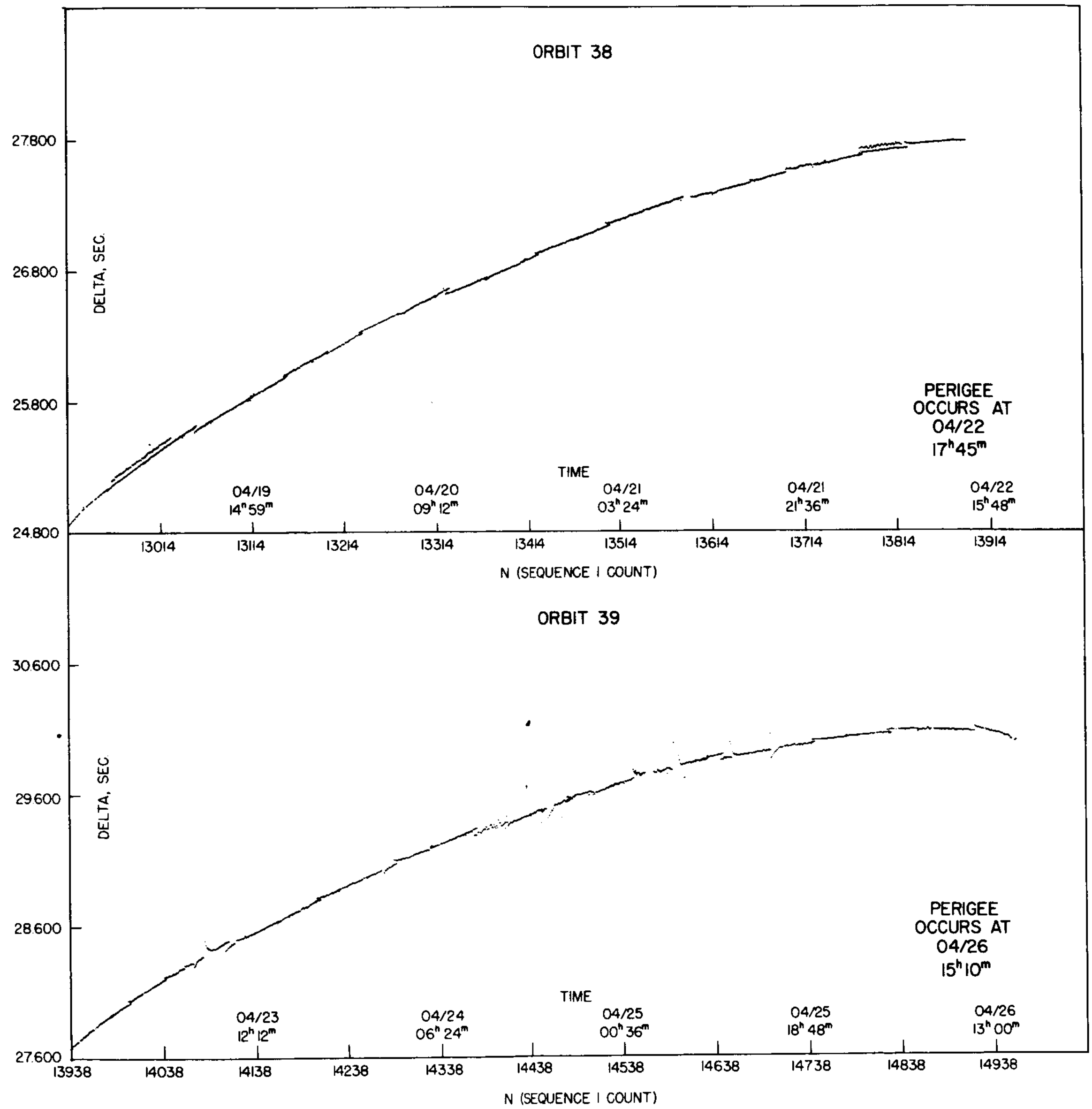
ORBIT 30
7.800
6.800
5.800
DELTA, SEC.
PERIGEE
OCCURS AT
03/22
15h25m
TIME
03/19
12h34m
03/20
06h46m
03/21
00h58m
03/21
19h11m
03/22
13h23m
4813
4913
5013
5113
5213
5313
5413
5513
5613
5713
N (SEQUENCE I COUNT)
ORBIT 31
9.300
8.300
7.300
DELTA, SEC.
PERIGEE
OCCURS AT
03/26
12h30m
TIME
03/23
10h19m
03/24
04h31m
03/24
22h43m
03/25
16h55m
03/26
11h08m
5743
5843
5943
6043
6143
6243
6343
6443
6543
6643
6743
N (SEQUENCE I COUNT)



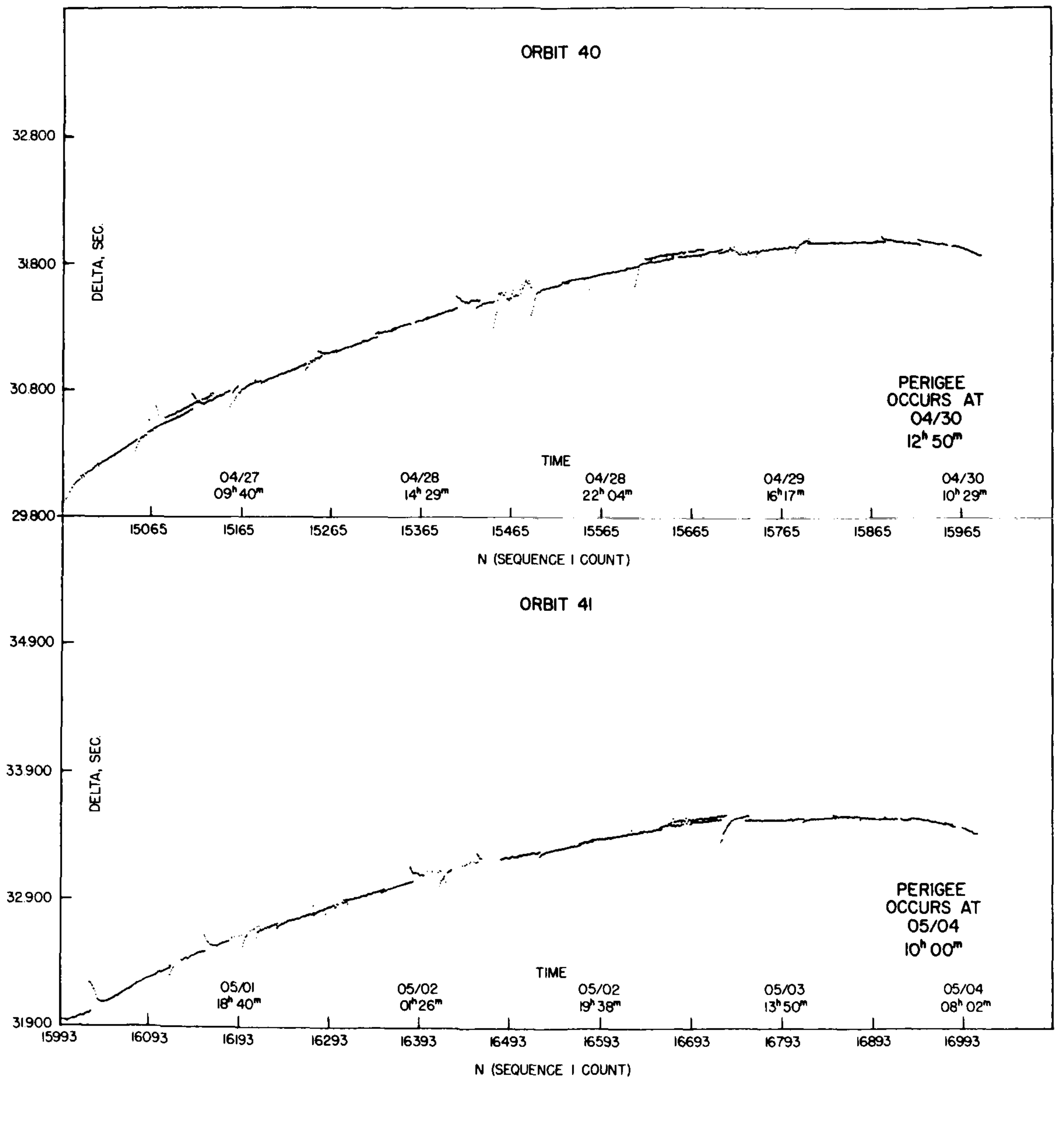
ORBIT 32
10.700
9.700
8.700
DELTA, SEC.
PERIGEE
OCCURS AT
03/30
09h 50m
TIME
03/27
06h 53m
03/28
01h 05m
03/28
19h 17m
03/29
13h 29m
03/30
07h 41m
6860
6960
7060
7160
7260
7360
7460
7560
7660
7760
N (SEQUENCE I COUNT)
ORBIT 33
12.300
11.300
10.300
DELTA, SEC.
PERIGEE
OCCURS AT
04/03
07h 25m
TIME
03/31
04h 21m
03/31
22h 33m
04/01
16h 45m
04/02
10h 58m
04/03
05h 10m
7787
7887
7987
8087
8187
8287
8387
8487
8587
8687
8787
N (SEQUENCE I COUNT)

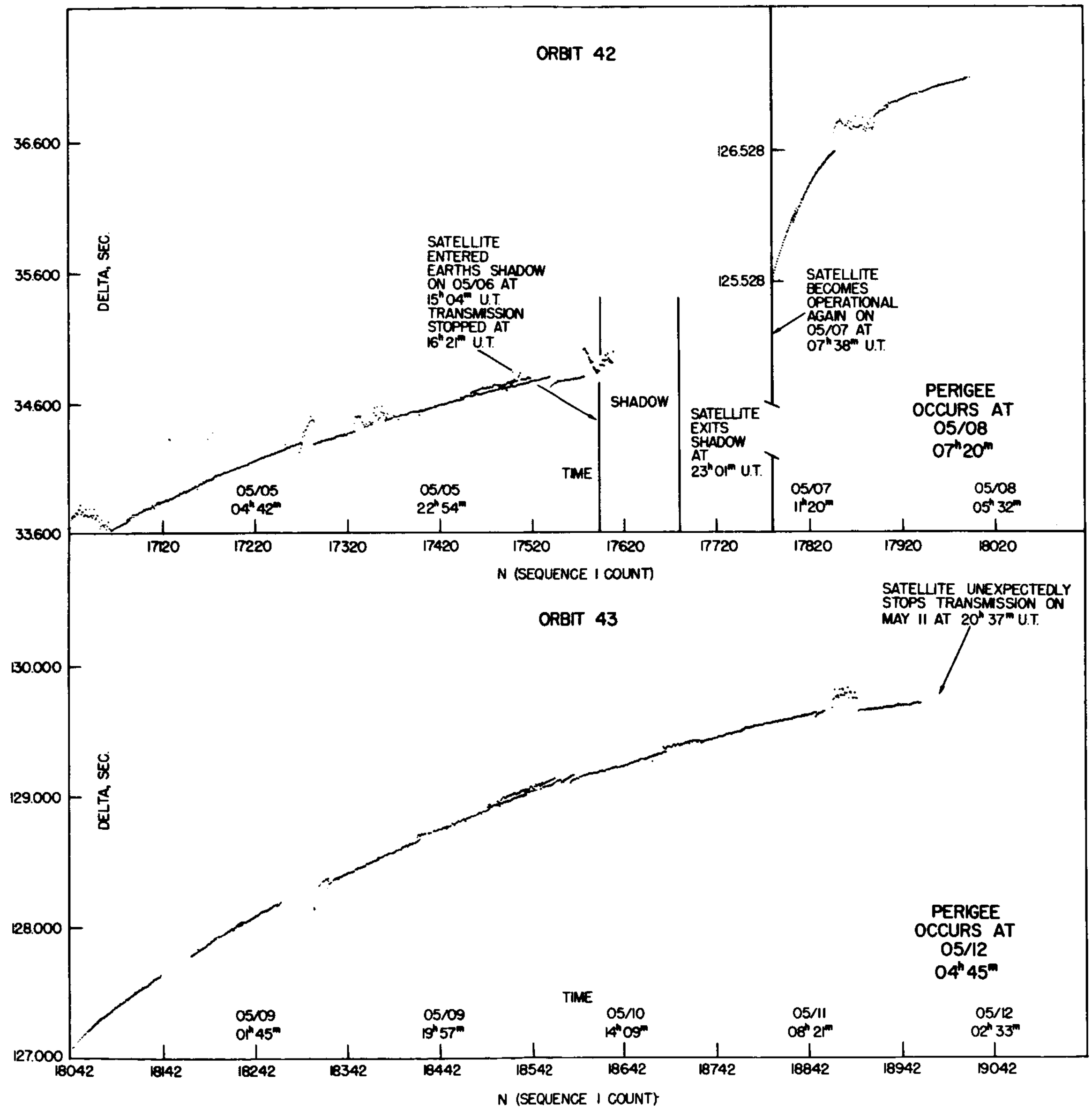

ORBIT 34
14.300
13.300
12.300
DELTA, SEC.
PERIGEE
OCCURS AT
04/07
04h 35m
TIME
04/04
01h49m
04/04
20h02m
04/05
14h14m
04/06
08h26m
04/07
02h38m
8914
9014
9114
9214
9314
9414
9514
9714
9814
N (SEQUENCE I COUNT)
ORBIT 35
16.800
15.800
14.800
DELTA, SEC.
PERIGEE
OCCURS AT
04/11
01h50m
TIME
04/07
22h 56m
04/08
17h 08m
04/09
11h 20m
04/10
05h 33m
04/10
23h 45m
9837
9937
10037
10137
10237
10337
10437
10537
10637
10737
10837
N (SEQUENCE I COUNT)


ORBIT 36
DELTA, SEC.
21.000
20.000
19.000
18.000
PERIGEE OCCURS AT 04/14 23h15m
TIME
04/11 20h14m
04/12 14h26m
04/13 08h38m
04/14 02h50m
04/14 21h02m
10962
11062
11162
11262
11362
11462
11562
11662
11762
11862
N (SEQUENCE I COUNT)
ORBIT 37
DELTA, SEC.
24.600
23.600
22.600
21.600
PERIGEE OCCURS AT 04/18 20h35m
TIME
04/15 19h48m
04/16 14h00m
04/17 08h12m
04/18 02h24m
04/18 20h36m
11912
12012
12112
12212
12312
12412
12512
12612
12712
12812
12912
N (SEQUENCE I COUNT)

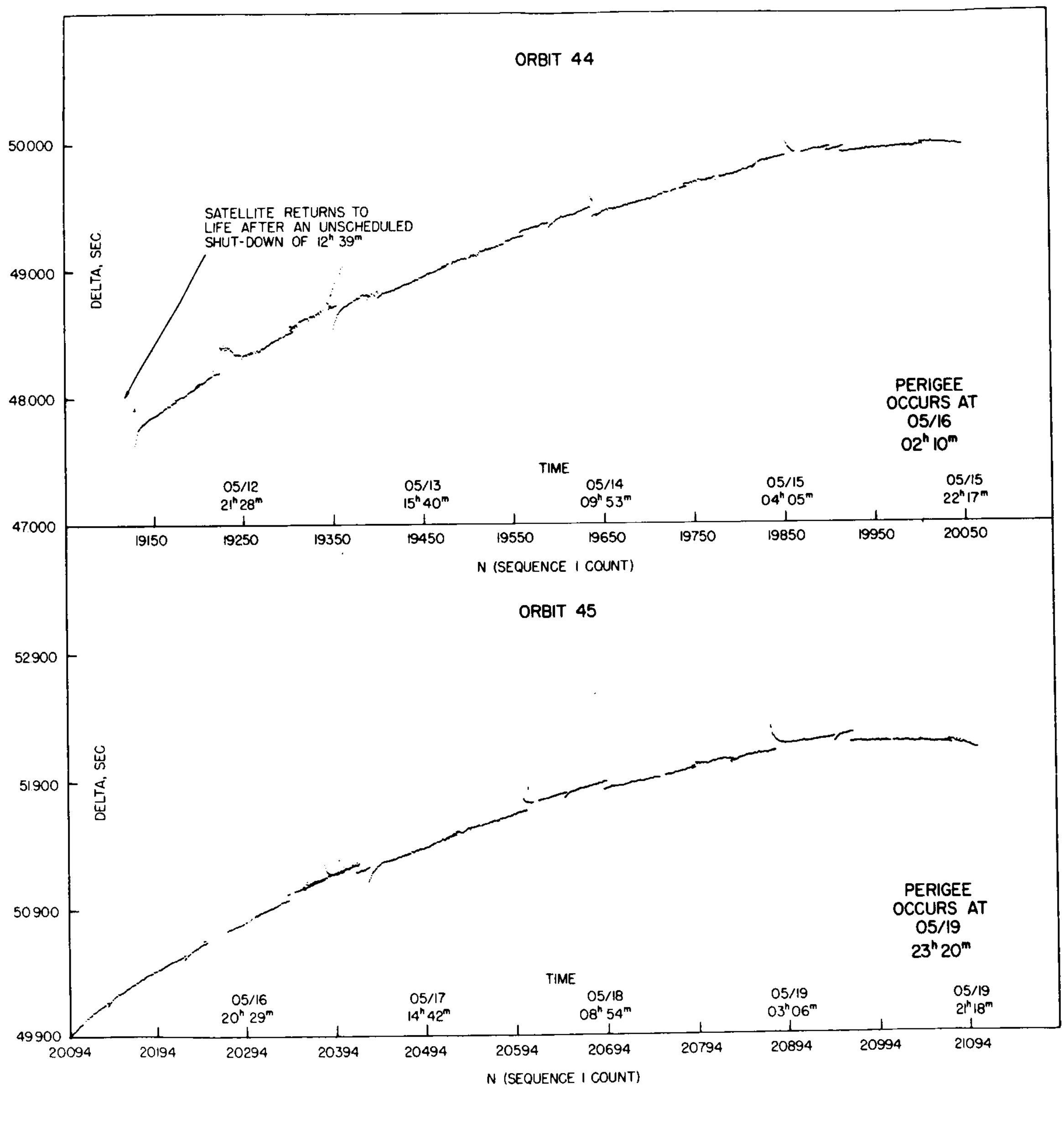


ORBIT 38
27.800
26.800
25.800
24.800
DELTA, SEC.
PERIGEE
OCCURS AT
04/22
17h45m
TIME
04/19
14h59m
04/20
09h12m
04/21
03h24m
04/21
21h36m
04/22
15h48m
13014
13114
13214
13314
13414
13514
13614
13714
13814
13914
N (SEQUENCE I COUNT)
ORBIT 39
30.600
29.600
28.600
27.600
DELTA, SEC
PERIGEE
OCCURS AT
04/26
15h10m
TIME
04/23
12h12m
04/24
06h24m
04/25
00h36m
04/25
18h48m
04/26
13h00m
13938
14038
14138
14238
14338
14438
14538
14638
14738
14838
14938
N (SEQUENCE I COUNT)

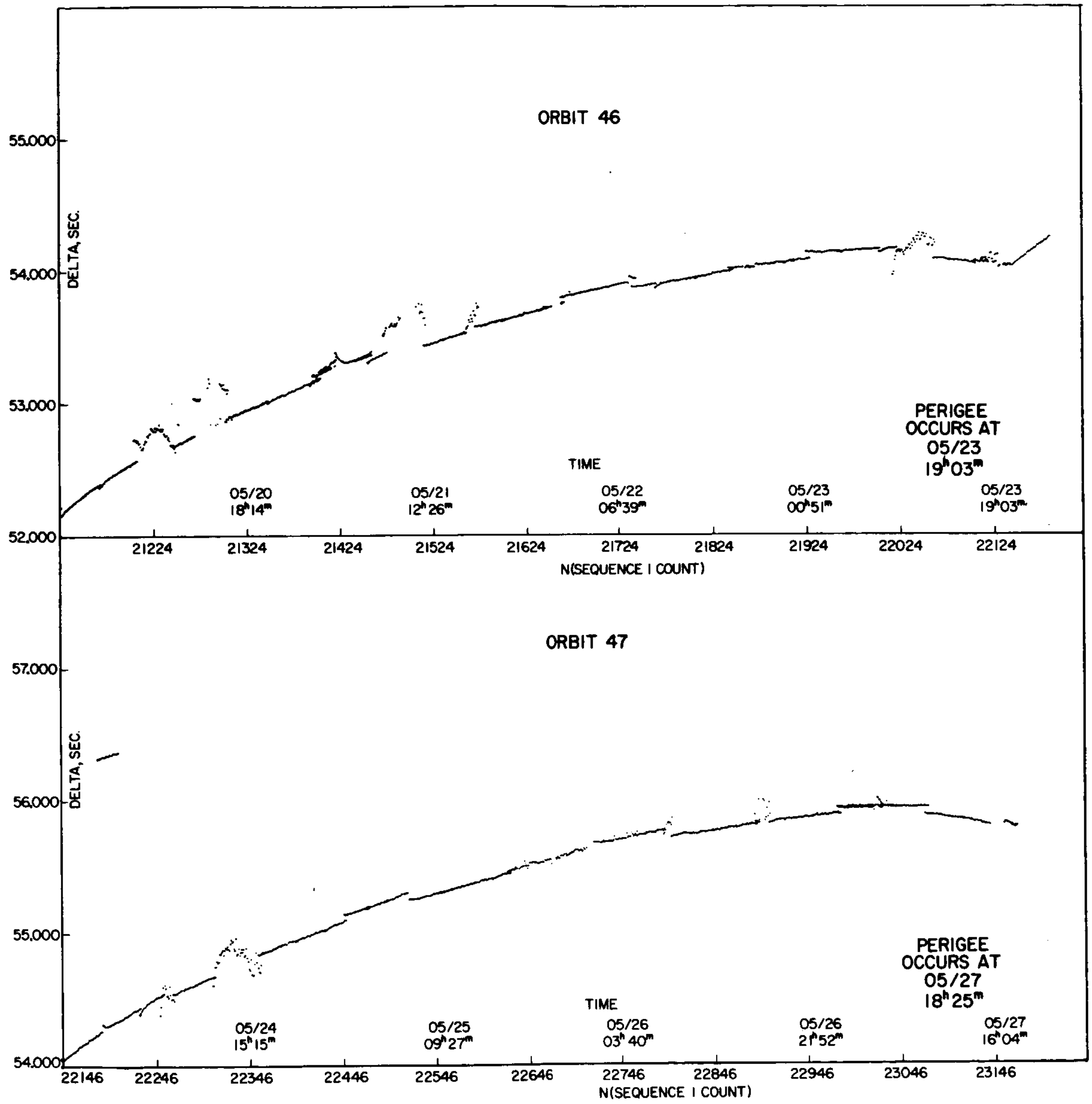

ORBIT 40
DELTA, SEC.
32.800
31.800
30.800
29.800
PERIGEE OCCURS AT 04/30 12h 50m
TIME
04/27 09h 40m
04/28 14h 29m
04/28 22h 04m
04/29 16h 17m
04/30 10h 29m
15065 15165 15265 15365 15465 15565 15665 15765 15865 15965
N (SEQUENCE I COUNT)
ORBIT 41
DELTA, SEC.
34.900
33.900
32.900
31.900
PERIGEE OCCURS AT 05/04 10h 00m
TIME
05/01 18h 40m
05/02 01h 26m
05/02 19h 38m
05/03 13h 50m
05/04 08h 02m
15993 16093 16193 16293 16393 16493 16593 16693 16793 16893 16993
N (SEQUENCE I COUNT)

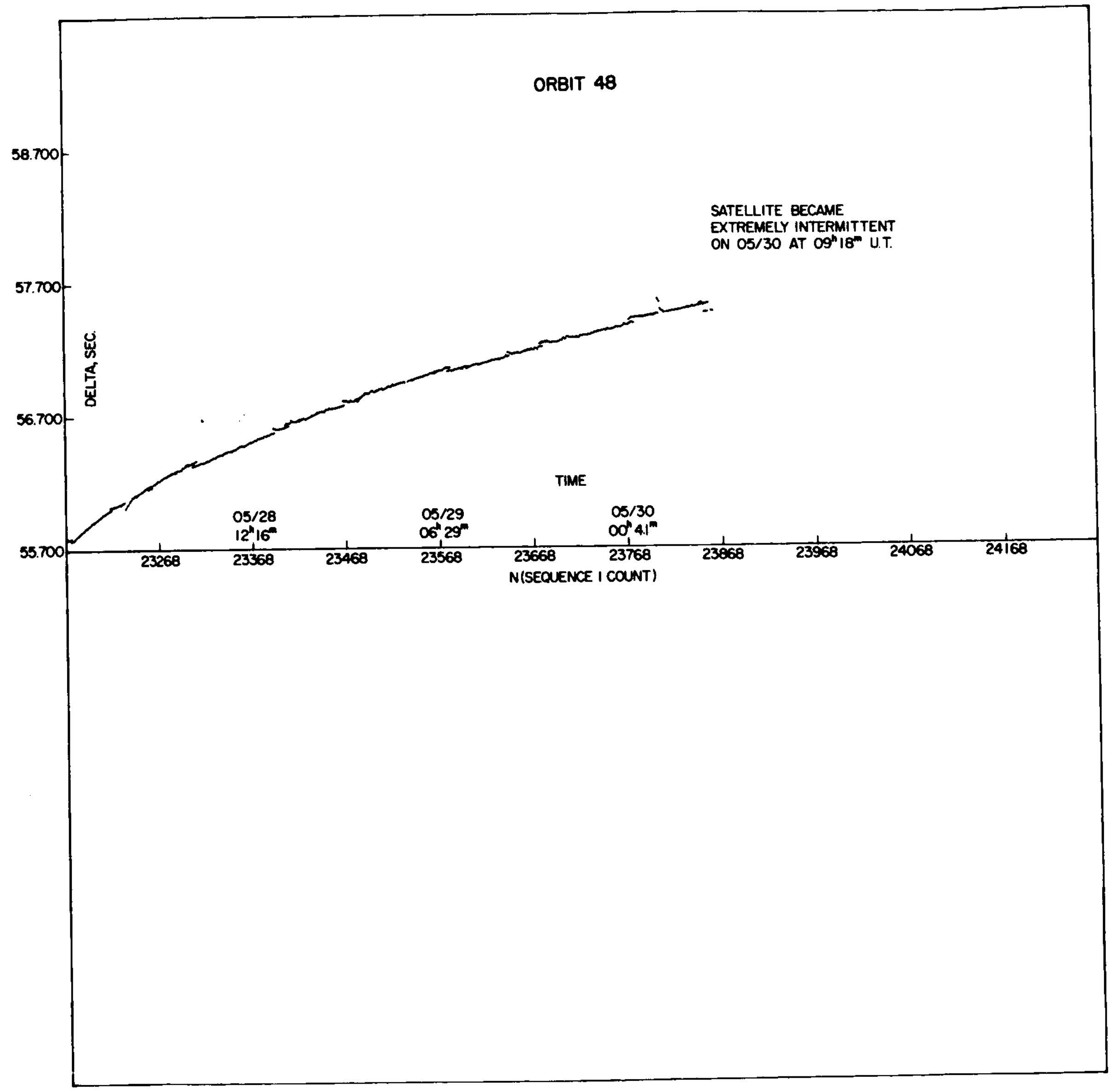


ORBIT 42
DELTA, SEC.
36.600
35.600
34.600
33.600
126.528
125.528
SATELLITE ENTERED EARTHS SHADOW ON 05/06 AT 15h 04m U.T. TRANSMISSION STOPPED AT 16h 21m U.T.
SHADOW
TIME
SATELLITE EXITS SHADOW AT 23h 01m U.T.
SATELLITE BECOMES OPERATIONAL AGAIN ON 05/07 AT 07h 38m U.T.
PERIGEE OCCURS AT 05/08 07h 20m
05/05 04h 42m
05/05 22h 54m
05/07 11h 20m
05/08 05h 32m
17120
17220
17320
17420
17520
17620
17720
17820
17920
18020
N (SEQUENCE 1 COUNT)
ORBIT 43
SATELLITE UNEXPECTEDLY STOPS TRANSMISSION ON MAY 11 AT 20h 37m U.T.
DELTA, SEC.
130.000
129.000
128.000
127.000
PERIGEE OCCURS AT 05/12 04h 45m
TIME
05/09 01h 45m
05/09 19h 57m
05/10 14h 09m
05/11 08h 21m
05/12 02h 33m
18042
18142
18242
18342
18442
18542
18642
18742
18842
18942
19042
N (SEQUENCE 1 COUNT)



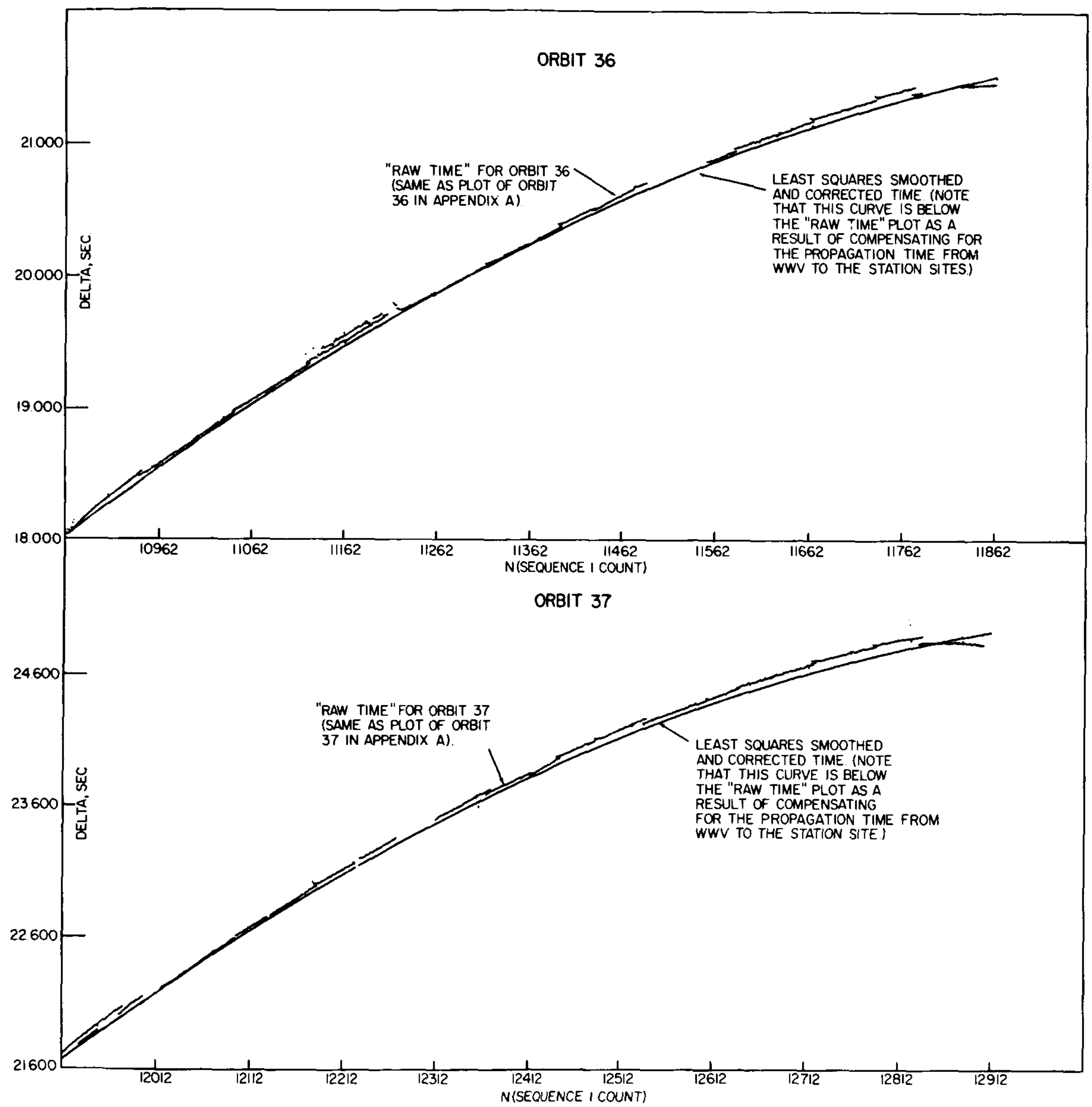
ORBIT 44
50000
49000
48000
47000
DELTA, SEC
SATELLITE RETURNS TO LIFE AFTER AN UNSCHEDULED SHUT-DOWN OF 12h 39m
PERIGEE OCCURS AT 05/16 02h 10m
TIME
05/12 21h 28m
05/13 15h 40m
05/14 09h 53m
05/15 04h 05m
05/15 22h 17m
19150
19250
19350
19450
19550
19650
19750
19850
19950
20050
N (SEQUENCE I COUNT)
ORBIT 45
52900
51900
50900
49900
DELTA, SEC
PERIGEE OCCURS AT 05/19 23h 20m
TIME
05/16 20h 29m
05/17 14h 42m
05/18 08h 54m
05/19 03h 06m
05/19 21h 18m
20094
20194
20294
20394
20494
20594
20694
20794
20894
20994
21094
N (SEQUENCE I COUNT)


ORBIT 46
55,000
54,000
53,000
52,000
DELTA, SEC.
PERIGEE OCCURS AT 05/23 19h03m
TIME
05/20 18h14m
05/21 12h26m
05/22 06h39m
05/23 00h51m
05/23 19h03m
21224
21324
21424
21524
21624
21724
21824
21924
22024
22124
N(SEQUENCE I COUNT)
ORBIT 47
57,000
56,000
55,000
54,000
DELTA, SEC.
PERIGEE OCCURS AT 05/27 18h25m
TIME
05/24 15h15m
05/25 09h27m
05/26 03h40m
05/26 21h52m
05/27 16h04m
22146
22246
22346
22446
22546
22646
22746
22846
22946
23046
23146
N(SEQUENCE I COUNT)


ORBIT 48
SATELLITE BECAME EXTREMELY INTERMITTENT ON 05/30 AT 09h18m U.T.
58.700
57.700
56.700
55.700
DELTA, SEC.
TIME
05/28 12h16m
05/29 06h29m
05/30 00h41m
23268
23368
23468
23568
23668
23768
23868
23968
24068
24168
N(SEQUENCE I COUNT)

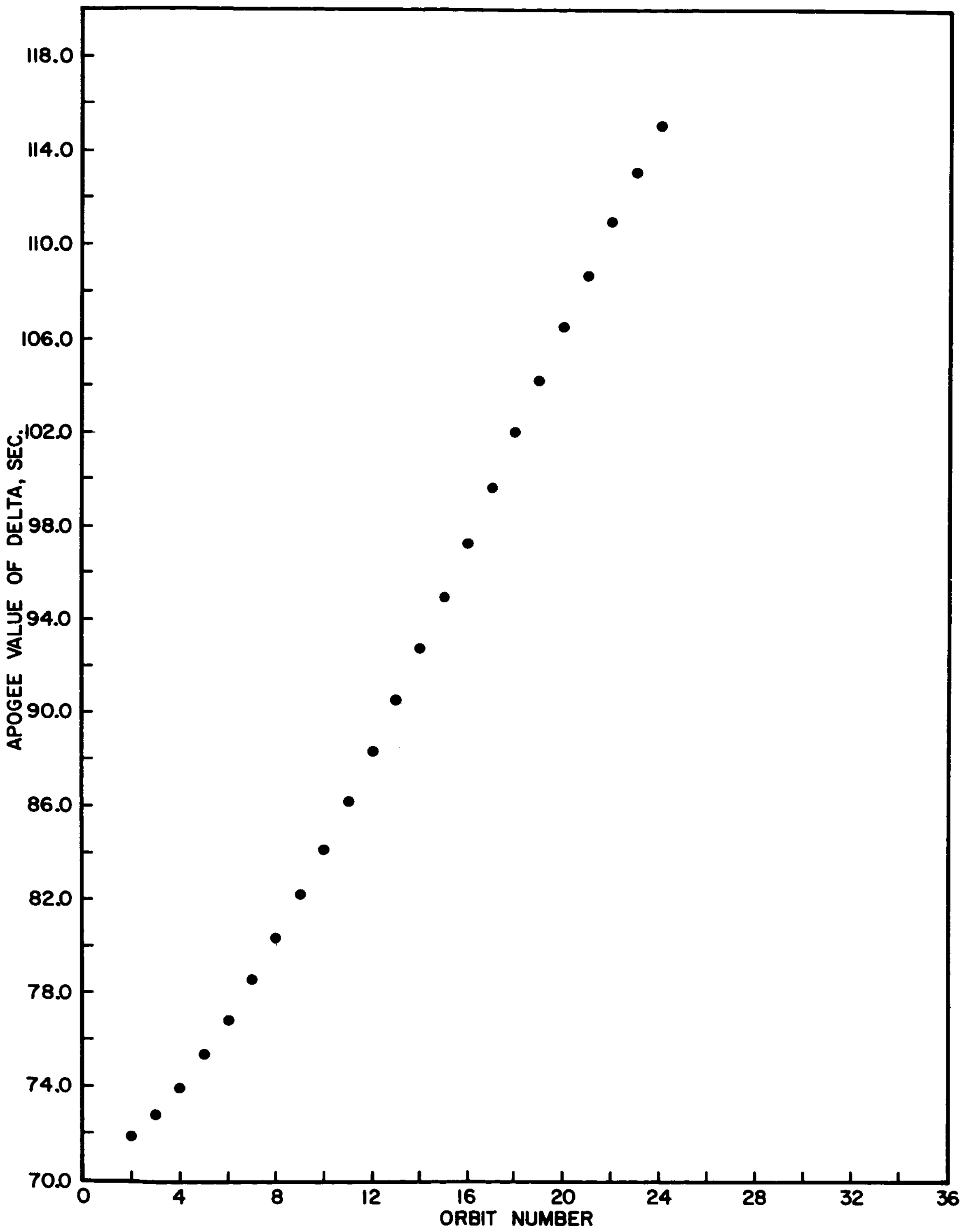
APPENDIX B

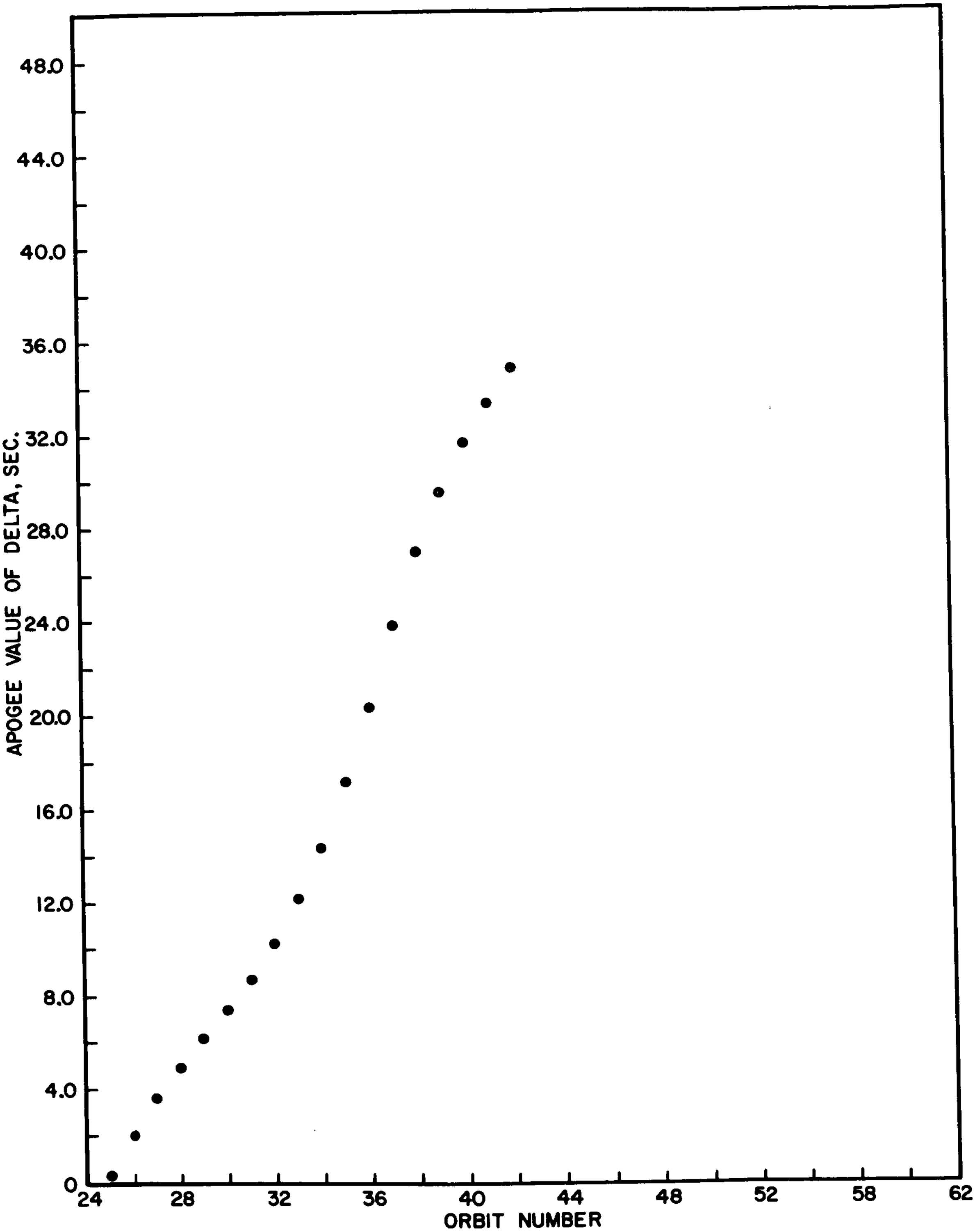
"Raw" time plots of DELTA versus N for orbits 36 and 37 compared with the corrected and smoothed plots


ORBIT 36
21.000
20.000
19.000
18.000
DELTA, SEC
"RAW TIME" FOR ORBIT 36 (SAME AS PLOT OF ORBIT 36 IN APPENDIX A)
LEAST SQUARES SMOOTHED AND CORRECTED TIME (NOTE THAT THIS CURVE IS BELOW THE "RAW TIME" PLOT AS A RESULT OF COMPENSATING FOR THE PROPAGATION TIME FROM WWV TO THE STATION SITES.)
10962
11062
11162
11262
11362
11462
11562
11662
11762
11862
N (SEQUENCE I COUNT)
ORBIT 37
24.600
23.600
22.600
21.600
DELTA, SEC
"RAW TIME" FOR ORBIT 37 (SAME AS PLOT OF ORBIT 37 IN APPENDIX A).
LEAST SQUARES SMOOTHED AND CORRECTED TIME (NOTE THAT THIS CURVE IS BELOW THE "RAW TIME" PLOT AS A RESULT OF COMPENSATING FOR THE PROPAGATION TIME FROM WWV TO THE STATION SITE.)
12012
12112
12212
12312
12412
12512
12612
12712
12812
12912
N (SEQUENCE I COUNT)

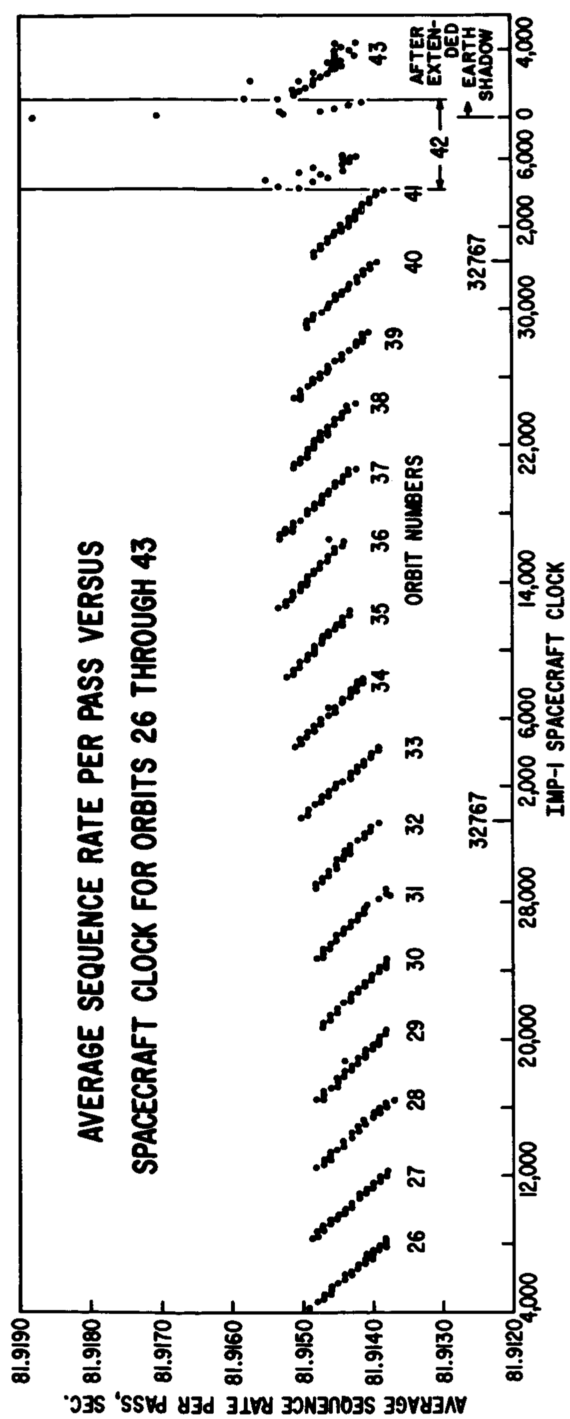
APPENDIX C

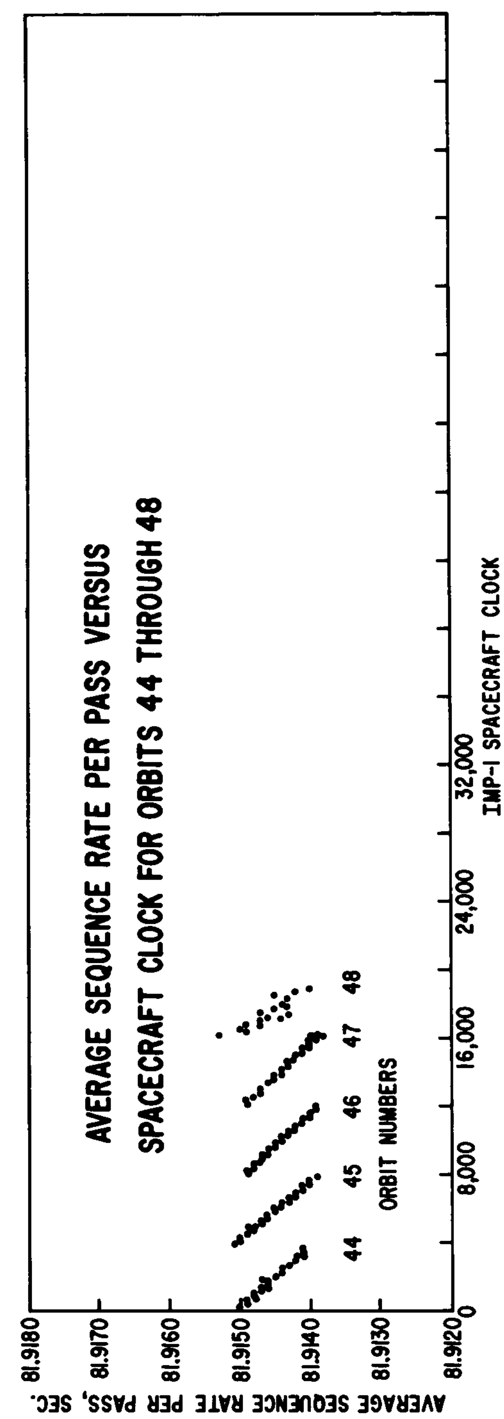
Telemetry system stability plots


118.0
114.0
110.0
106.0
102.0
98.0
94.0
90.0
86.0
82.0
78.0
74.0
70.0
APOGEE VALUE OF DELTA, SEC.
0
4
8
12
16
20
24
28
32
36
ORBIT NUMBER



48.0
44.0
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0
APOGEE VALUE OF DELTA, SEC.
24
28
32
36
40
44
48
52
58
62
ORBIT NUMBER


AVERAGE SEQUENCE RATE PER PASS VERSUS
SPACECRAFT CLOCK FOR ORBITS 26 THROUGH 43
AVERAGE SEQUENCE RATE PER PASS, SEC.
81.9190
81.9180
81.9170
81.9160
81.9150
81.9140
81.9130
81.9120
IMP-I SPACECRAFT CLOCK
ORBIT NUMBERS
32767
AFTER EXTENDED EARTH SHADOW


AVERAGE SEQUENCE RATE PER PASS VERSUS
SPACECRAFT CLOCK FOR ORBITS 44 THROUGH 48
AVERAGE SEQUENCE RATE PER PASS, SEC.
81.9180
81.9170
81.9160
81.9150
81.9140
81.9130
81.9120
0
8,000
16,000
24,000
32,000
IMP-I SPACECRAFT CLOCK
ORBIT NUMBERS
44
45
46
47
48

APPENDIX D

Propagation delay times from WWV
to the Space Tracking and Data
Acquisition Station Site

PROPAGATION DELAY TIMES FROM WWV TO THE SPACE TRACKING AND DATA ACQUISITION STATION SITE*

STATION #	STATION	PROPAGATION TIME† MILLISECONDS
Ø1	BLOSSOM POINT, MARYLAND	.5
Ø3	FORT MYERS, FLORIDA	5.8
Ø5	QUITO, ECUADOR	16.1
Ø6	LIMA, PERU	2Ø.2
Ø7	ANTOFAGASTA, CHILE	24.6
Ø8	SANTIAGO, CHILE	28.7
12	ST. JOHNS, NEWFOUNDLAND	8.1
13	FAIRBANKS, ALASKA	27.4
14	EAST GRAND FORKS, MINNESOTA	7.2
15	WINKFIELD, ENGLAND	2Ø.8
16	JOHANNESBURG, SOUTH AFRICA	45.7
17	GOLDSTONE LAKE, CALIFORNIA	12.6
18	WOOMERA, AUSTRALIA	59.1
19	GILMORE CREEK, ALASKA	27.4
2Ø	ROSMAN, NORTH CAROLINA	3.6
55	SOUTH POINT, HAWAII	28.2
56	ASCENSION ISLAND	3Ø.1
61	COLLEGE PARK, MARYLAND	Ø.Ø

*Propagation times calculated by the Network Timing Section, Network Engineering and Operations Division, Goddard Space Flight Center.

†Includes .3ms for WWV Receiver; Accurate to within ±5ms.

APPENDIX E

Timing failure rates on IMP-I
for the first 23 orbits

TIMING FAILURE RATES ON IMP-I
FOR THE FIRST 23 ORBITS*

I. STATION CLOCK SET INCORRECTLY WITH WWV.

14/855 = 1.6%

II. BCD TIME PRESENT AND ACCEPTABLE AT START OF PASS BUT FOUND DEFICIENT AT SOME LATER TIME IN THE PASS.

10/855 = 1.2%

III. BCD TIME CODE FOUND UNACCEPTABLE - PASS PROCESSED WITH SERIAL DECIMAL TIME.

1/855 = 0.2%

IV. PASS CONTAINED NO USABLE TIME CODE - PASS PROCESSED WITH RELATIVE TIME.

8/855 = 0.9%

V. A/D LINE COULD NOT SYNCHRONIZE PROPERLY WITH DATA BECAUSE OF A WEAK OR NOISY TELEMETRY SIGNAL - THIS ADVERSELY EFFECTED THE TIMING.

13/855 = 1.5%

VI. CAUSE OF UNACCEPTABLE TIMING UNKNOWN.

4/855 = 0.5%

TOTAL NUMBER OF PASSES WHICH CONTAINED A TIMING FAILURE.

50/855 = 5.8%

*Statistics compiled on a pass by pass basis, i.e., a pass is defined as one uninterrupted data recording made at a single station, not by analog tape. This policy was adopted because one analog tape can and often does contain more than a single pass.

Statistics on timing failures were compiled during the entire time the Fields and Plasmas Branch had operational responsibility for IMP-IPS, this constituted approximately the first 23 orbits.

APPENDIX F

Sample calculation for DELTA and N

Sample Calculation for DELTA and N

Sample sequence 1 recorded at Woomera, Australia on January 8, 1964 (this information obtained from the ID of the file) at $20^h\ 39^m\ 51.776^s$ U.T. during orbit number 12.

From equation (1) in text:

$$N = \left[\frac{t_n - t_o}{\Delta t}\right]$$

(Note that the brackets indicate that N has been <u>rounded</u> to an integer.)

Where:

$\Delta t = 327.656$ sec.

t_o = November 27, 1963 at $03^h\ 53^m\ 46.175^s$

t_n = January 8, 1964 at $20^h\ 39^m\ 51.766^s$

All time is referenced from January 1, 1963 thus:

$$t_o = 86{,}400\ \frac{\text{Sec.}}{\text{Day}} \times (330\ \text{Days})$$

$$+\ 3{,}600\ \frac{\text{Sec.}}{\text{Hour}} \times (3\ \text{Hours})$$

$$+\ 60\ \frac{\text{Sec.}}{\text{Min}} \times (53\ \text{Min.})$$

$$+\ 46.175\ \text{sec.}$$

$$t_o = 28{,}526{,}026.175\ \text{sec.}$$

$$t_n = 86{,}400\ \frac{\text{Sec.}}{\text{Day}} \times (372\ \text{Days})$$

$$+\ 3{,}600\ \frac{\text{Sec.}}{\text{Hour}} \times (20\ \text{Hours})$$

$$+\ 60\ \frac{\text{Sec.}}{\text{Min}} \times (39\ \text{Min.})$$

$$+\ 51.776\ \text{Sec.}$$

$$t_n = 32{,}215{,}191.776$$

$$N = \left[\frac{32{,}215{,}191.776 - 28{,}526{,}026.175}{327.656}\right]$$

$$N = 11{,}259$$

From equation (2) in text:

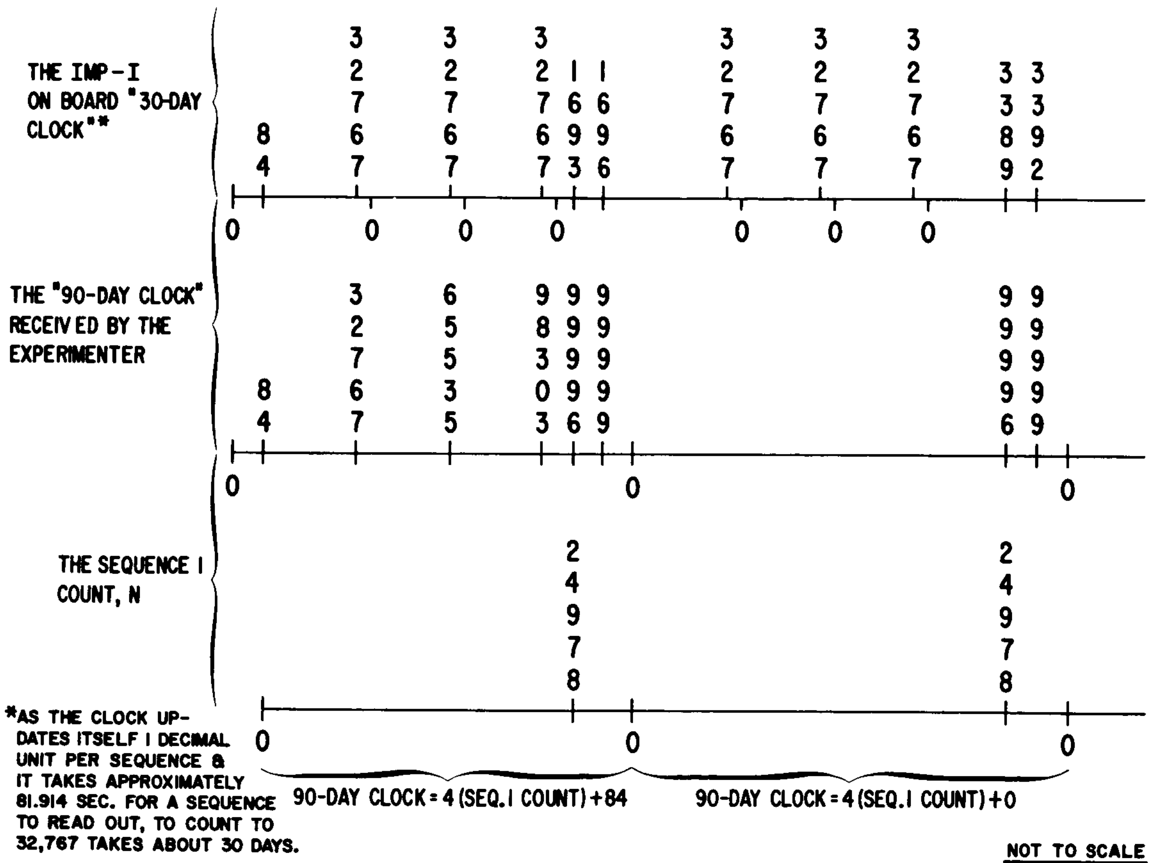
$$\text{DELTA} = \left(t_n - t_o\right) - N\,(\Delta t)$$

$$\text{DELTA} = 3{,}689{,}165.601 - 11{,}259. \times (327.656)$$

$$\text{DELTA} = +86.697 \text{ Sec.}$$

APPENDIX G

A comparison of the 30-Day
Clock, 90-Day Clock and the
Sequence 1 Count for approximately
6 months of satellite operation


THE IMP-I ON BOARD "30-DAY CLOCK"*
THE "90-DAY CLOCK" RECEIVED BY THE EXPERIMENTER
THE SEQUENCE I COUNT, N
90-DAY CLOCK = 4 (SEQ.I COUNT) + 84
90-DAY CLOCK = 4 (SEQ.I COUNT) + 0
*AS THE CLOCK UPDATES ITSELF I DECIMAL UNIT PER SEQUENCE & IT TAKES APPROXIMATELY 81.914 SEC. FOR A SEQUENCE TO READ OUT, TO COUNT TO 32,767 TAKES ABOUT 30 DAYS.
NOT TO SCALE