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

BY
WILLIAM H. MISH

OCTOBER 1964

GODDARD SPACE FLIGHT CENTER
GREENBELT, MD.
TIMING ERRORS—THEIR DETECTION AND CORRECTION IN THE IMP INFORMATION PROCESSING SYSTEM

by

William H. Mish

October 1964
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.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUMMARY</td>
<td>iii</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>APPLICABILITY OF THE IMP-I TELEMETRY FORMAT TO TIME ERROR DETECTION AND CORRECTION</td>
<td>2</td>
</tr>
<tr>
<td>IMP INFORMATION PROCESSING SYSTEM (IMP-IPS)</td>
<td>4</td>
</tr>
<tr>
<td>THE TIME ERROR DETECTION AND RECTIFICATION SOFTWARE</td>
<td>7</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>19</td>
</tr>
<tr>
<td>References</td>
<td>20</td>
</tr>
<tr>
<td>APPENDIX A</td>
<td>A-1</td>
</tr>
<tr>
<td>APPENDIX B</td>
<td>B-1</td>
</tr>
<tr>
<td>APPENDIX C</td>
<td>C-1</td>
</tr>
<tr>
<td>APPENDIX D</td>
<td>D-1</td>
</tr>
<tr>
<td>APPENDIX E</td>
<td>E-1</td>
</tr>
<tr>
<td>APPENDIX F</td>
<td>F-1</td>
</tr>
<tr>
<td>APPENDIX G</td>
<td>G-1</td>
</tr>
</tbody>
</table>
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 volumes 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 two 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
NORMAL SEQUENCE IS 16 CHANNELS x 16 FRAMES. THE SATELLITE CLOCK IS READ OUT IN CHANNELS 11, 12, 13, 14 & 15 - FRAMES 4 AND 12.

SEQUENCE 4 IS CONTINUOUS ANALOG SIGNAL. NO SATELLITE CLOCK IS PRESENT.

REPEATING PATTERN OF 4 SEQUENCES EACH SEQUENCE IS APPROXIMATELY 81.914 SECONDS IN LENGTH. TOTAL PATTERN IS APPROXIMATELY 4 x 81.914 = 327.656 SECONDS IN LENGTH.

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 updates 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 overall 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.

*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 "smoothes" 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:

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

(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
- \( \Delta t \) 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 \( t_n \))

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

\textit{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:

\[ \Delta = (t_n - t_o) - N(\Delta t) \]  \hspace{1cm} (2)

Where:

\( (t_n - t_o) \) 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.

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 affected 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 accumulator has 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 7h 57m, as is evident from the plot the spacecraft transmitted for 1h 17m after entering the Earth's shadow. It was completely shut off for a period of 15h 17m and became operational again on May 7 at 07h 38m 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.,

$$\Delta = (t_n - t_o) - N(\Delta t)$$

it would be expected that if $\Delta t$ 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 09h 18m 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 \( \Delta t \) 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 \( +86.697 \text{ sec} \). 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:

\[
+86.697 - 0.059 = 86.638
\]

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:

\[
\text{DELTA} = A_1 + A_2 N + A_3 N^2
\]

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.

*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.
References


11. Meyerson, Herbert, Fourth Fact Sheet, Explorer XIV, Greenbelt, Maryland, Goddard Space Flight Center, October 17, 1963.


16. White, Hosea, Description of IMP Edit Program FP 08A and FP 08B (Preliminary) and Appendices, Greenbelt, Maryland, Goddard Space Flight Center, January 30, 1964.


APPENDIX A

"Raw" time plots of DELTA versus N (The Sequence 1 Count) for the useful life of IMP-I
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.
ORBIT 4 PERIGEE OCCURS AT 12/12 12° 50'

ORBIT 5 PERIGEE OCCURS AT 12/16 12° 10'

A-6
PERIGEE OCCURS AT
12/20
10h 15m

PERIGEE OCCURS AT
12/24
07h 30m

A-7
ORBIT 8

PERIGEE OCCURS AT
12/28
04:50

ORBIT 9

PERIGEE OCCURS AT
01/01
02:05
ORBIT I

PERIGEE OCCURS AT
01/04
23°50'

ORBIT II

PERIGEE OCCURS AT
01/08
20°25'
ORBIT 14

PERIGEE OCCURS AT 01/20 12° 00′

TIME
01/17 09° 27″
01/18 09° 58″
01/19 10° 35″
01/20 11° 14″

N (SEQUENCE I COUNT)
13409 13509 13609 13709 13809 13909 14009 14109 14209 14309

ORBIT 15

PERIGEE OCCURS AT 01/24 09° 15″

TIME
01/21 06° 26″
01/22 00° 40″
01/22 18° 53″
01/23 13° 05″
01/24 07° 17″

N (SEQUENCE I COUNT)
14311 14431 14531 14631 14731 14831 15031 15131 15231 15331

A-11
Orbit 18

Perigee occurs at 02/05 00° 45'

Orbit 19

Perigee occurs at 02/08 22° 05'

A-13
PERIGEE OCCURS AT
02/12
15°06'
PERIGEE OCCURS AT
02/20
13° 30'

PERIGEE OCCURS AT
02/24
10° 45'
PERIGEE OCCURS AT
02/28 07h45m

PERIGEE OCCURS AT
03/03 06h05m

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 + 84 AT THIS POINT A NEW REFERENCE TIME 1_ WAS CHOSEN (SEE TEXT FOR EXPLANATION OF 1)._ THIS NEW REFERENCE TIME IS ON 02/29/64 AT 23h24m22.14s UT.
PERIGEE OCCURS AT
03/07
02°30'

PERIGEE OCCURS AT
03/10
23°35'

ORBIT 26

ORBIT 27
ORBIT 28
PERIGEE OCCURS AT 03/14 20°45'
TIME 03/12 03/13 03/14 03/14
18h 15" 12" 27" 06m40m

ORBIT 29
PERIGEE OCCURS AT 03/18 18°05'
TIME 03/15 03/16 03/17 03/17
15°22" 09°34" 03°46" 2°59"

PERIGEE OCCURS AT
03/22 15°25'
ORBIT 32

PERIGEE OCCURS AT
03/30
09°50'°

TIME
03/28 03/29 03/30
19°17' 18°49' 17°44'

N (SEQUENCE 1 COUNT)

ORBIT 33

PERIGEE OCCURS AT
04/03
07°25'

TIME
03/31 04/01 04/02
10°45' 09°58' 05°10'

N (SEQUENCE 1 COUNT)

A-20
PERIGEE OCCURS AT
O4/14
23°18’

PERIGEE OCCURS AT
O4/18
20°35’
ORBIT 38

PERIGEE OCCURS AT
04/22
17°45′

ORBIT 39

PERIGEE OCCURS AT
04/26
13°10′
PERIGEE OCCURS AT
04/30
12° 50'

PERIGEE OCCURS AT
05/04
10° 00'

A-24
SATCHEL ENTERED EARTHS SHADOW ON 05/06 AT 15°04' U.T. TRANSMISSION STOPPED AT 16°27' U.T.

SATCHEL BECOMES OPERATIONAL AGAIN ON 05/07 AT 07°38' U.T.

PERIGEE OCCURS AT 05/08 07°20' U.T.

PERIGEE OCCURS AT 05/12 04°45' U.T.

SATCHEL UNEXPECTEDLY STOPS TRANSMISSION ON MAY 11 AT 20°37' U.T.
SATellite returns to life after an unscheduled shut-down of 02° 39".

PERIGEE occurs at 05/16 02h 10m.

PERIGEE occurs at 05/19 23h 20m.

A-26
ORBIT 48

SATELLITE BECAME EXTREMELY INTERMITTENT ON 05/30 AT 09:18" U.T.
APPENDIX B

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

"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 SITE)

ORBIT 37

"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)
APPENDIX C

Telemetry system stability plots
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**

<table>
<thead>
<tr>
<th>STATION #</th>
<th>STATION</th>
<th>PROPAGATION TIME(^1) MILLISECONDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ø1</td>
<td>BLOSSOM POINT, MARYLAND</td>
<td>0.5</td>
</tr>
<tr>
<td>Ø3</td>
<td>FORT MYERS, FLORIDA</td>
<td>5.8</td>
</tr>
<tr>
<td>Ø5</td>
<td>QUITO, ECUADOR</td>
<td>16.1</td>
</tr>
<tr>
<td>Ø6</td>
<td>LIMA, PERU</td>
<td>20.2</td>
</tr>
<tr>
<td>Ø7</td>
<td>ANTOFAGASTA, CHILE</td>
<td>24.6</td>
</tr>
<tr>
<td>Ø8</td>
<td>SANTIAGO, CHILE</td>
<td>28.7</td>
</tr>
<tr>
<td>12</td>
<td>ST. JOHNS, NEWFOUNDLAND</td>
<td>8.1</td>
</tr>
<tr>
<td>13</td>
<td>FAIRBANKS, ALASKA</td>
<td>27.4</td>
</tr>
<tr>
<td>14</td>
<td>EAST GRAND FORKS, MINNESOTA</td>
<td>7.2</td>
</tr>
<tr>
<td>15</td>
<td>WINKFIELD, ENGLAND</td>
<td>20.8</td>
</tr>
<tr>
<td>16</td>
<td>JOHANNESBURG, SOUTH AFRICA</td>
<td>45.7</td>
</tr>
<tr>
<td>17</td>
<td>GOLDSTONE LAKE, CALIFORNIA</td>
<td>12.6</td>
</tr>
<tr>
<td>18</td>
<td>WOOMERA, AUSTRALIA</td>
<td>59.1</td>
</tr>
<tr>
<td>19</td>
<td>GILMORE CREEK, ALASKA</td>
<td>27.4</td>
</tr>
<tr>
<td>20</td>
<td>ROSMAN, NORTH CAROLINA</td>
<td>3.6</td>
</tr>
<tr>
<td>55</td>
<td>SOUTH POINT, HAWAII</td>
<td>28.2</td>
</tr>
<tr>
<td>56</td>
<td>ASCENSION ISLAND</td>
<td>30.1</td>
</tr>
<tr>
<td>61</td>
<td>COLLEGE PARK, MARYLAND</td>
<td>0.0</td>
</tr>
</tbody>
</table>

\(^1\)Propagation times calculated by the Network Timing Section, Network Engineering and Operations Division, Goddard Space Flight Center.

\(^1\)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 20h 39m 51.776 s U.T. during orbit number 12.

From equation (1) in text:

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

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

Where:

\( \Delta t = 327.656 \text{ sec.} \)

\( t_o = \text{November 27, 1963 at 03h 53m 46.175 s} \)

\( t_n = \text{January 8, 1964 at 20h 39m 51.766 s} \)

All time is referenced from January 1, 1963 thus:

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

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

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

\[ + 46.175 \text{ sec.} \]

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

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

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

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

\[ + 51.776 \text{ Sec.} \]

F -3
\[ t_n = 32,215,191.776 \]
\[ N = \left[ \frac{32,215,191.776 - 28,526,026.175}{327.656} \right] \]
\[ N = 11,259 \]

From equation (2) in text:

\[ \Delta = (t_n - t_o) - N(\Delta t) \]

\[ \Delta = 3,689,165.601 - 11,259 \times (327.656) \]

\[ \Delta = +86.697 \text{ Sec.} \]
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**

<table>
<thead>
<tr>
<th>Count</th>
<th>THE IMP-I ON BOARD <em>30-DAY CLOCK</em>*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>699</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>36</td>
<td>7</td>
</tr>
<tr>
<td>736</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>792</td>
<td>7</td>
</tr>
</tbody>
</table>

THE "90-DAY CLOCK" RECEIVED BY THE EXPERIMENTER

<table>
<thead>
<tr>
<th>Count</th>
<th>THE &quot;90-DAY CLOCK&quot; RECEIVED BY THE EXPERIMENTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>999</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>899</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>399</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>369</td>
<td>6</td>
</tr>
</tbody>
</table>

THE SEQUENCE I COUNT, N

<table>
<thead>
<tr>
<th>Count</th>
<th>THE SEQUENCE I COUNT, N</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

*AS THE CLOCK UPDATES ITSELF 1 DECIMAL UNIT PER SEQUENCE 8 IT TAKES APPROXIMATELY 81.914 SEC. FOR A SEQUENCE TO READ OUT, TO COUNT TO 32,767 TAKES ABOUT 30 DAYS.