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TIME CORRELATED DATA RETRANSMISSION TELEMETRY SYSTEM

by

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Summary

The paper describes techniques for the development of a time correlated burst retransmission telemetry system. The discussion covers the feasibility of a time correlated system and considerations for its implementation. The many dependent and independent parameters encountered and their effect on the overall system requirements are examined. Formatting techniques of the output link which provides the capability of extracting data and time events while maintaining a high bandwidth efficiency is presented. A three input link system (Gemini, Agena and Titan) having one output link will be examined. The advantages and disadvantages of the burst system will be evaluated resulting in the selection of the system which is most applicable to the mission requirement.

Introduction

Previous method of information management of multi-input telemetry systems have stressed data acquisition and handling with less emphasis placed on time correlation, however, ever increasing requirement of obtaining time correlated data has increased the need of techniques which can provide maximum utilization of retransmission bandwidth yet still allow timing of individual parameter to be accurately reconstructed. In a time correlated system, it is not enough that the data of one channel is correlated to its input sync, but the data must also be correlated to the retransmission channel and to all other input channels in the system. With correlation established it is only necessary to introduce a time of day word in the retransmission format. The further the time of day words are separated, the greater the bandwidth utilization. However, the separation of the time of day introduces the problem of deviation of input frequency of one or all of the input channels and to the previous indicated requirement of intercorrelation between input and output channels. Another problem introduced by the spacing of the time word is the data buffer storage requirements which is directly proportioned to the time word separation. It is the purpose of this paper to present techniques which resolve these problems and yet provide an excellent bandwidth utilization with a minimal amount of memory capacity.

General System Requirements

The time correlated retransmission system receives data from asynchronous PCM telemetry links and retransmits selected parameters via normal communication channels. Three asynchronous links considered are the Titan, Gemini and Agena which are time and data managed in order to meet the restricted bandwidth requirement of existing retransmission facilities.

The quantity of available input data far exceeds the retransmission capability, therefore, a selection of input data to be retransmitted must be made. The main considerations of the retransmission system which must provide time of occurrence along with the data parameters, are Data Time Delay and Bandwidth Utilization Efficiency. The Data Time Delay is the time between data occurrence at the output of the retransmission system and data availability to the user. Bandwidth Utilisation is a measure of maximum possible output data based on the output data rate versus the actual output data. The retransmission system selects one predetermined mix of data from the three input links, stores the data and then retransmits the data in a block format.

The analysis shows that the time and sync correlation requirements between different inputs is resolved by increasing or decreasing the data period until time correlation occurs at some whole number of input frames of every input and output link. The data selected for retransmission from any one link during the period is defined as a burst. The correlation of "N" input and output links at different data rates places definite requirements on data buffer storage capacity. Once time and sync correlation is obtained it is possible to operate each input in a continuous mode extracting the selected data as required by the programmer. In the selected system a minimum period equals 0.25 seconds, and contains three blocks, one from each input link. Each block is assembled during a 0.25 second interval and contains data selected from 5 Titan input frames, 10 Gemini input frames, and 4 Agena input frames.

The memory is required to store selected data samples until the block is read-out. Since there is some overlap where read-in and read-out
The time of day word contains units of hours, minutes, seconds, and microseconds. The time word indicates the time of occurrence, at the receiver terminal of the retransmission system, of the first input data frame in the output frame. In the case shown, it is the time of the first Titan frame in the Titan burst. Once time is established at the start of the output frame, all data within the output frame is referenced to this time. The time of the first frame of each burst is determined by a channel separation word which is a measure of the delay between the transmitted time of day word and the beginning of the first frame of each burst.

The time of occurrence of parameters, selected during subsequent input frames and assembled into a particular burst, is re-established from the Sync Tolerance Word which is a measure of the difference between the actual input sync rate and the nominal input sync rate. The address word is used to identify the prime input frame number and since the input frames following the first frame of each burst are in numerical ascending order, it is only necessary to identify the first frame.

**Design Criteria**

The optimum design and evaluation of the Block Burst Retransmission System is based on the characteristics of the input and output channels which enter and leave the retransmission system. These basic characteristics are usually given and the system must then be designed and optimized around these characteristics. The following discussion gives step-by-step the criteria which must be specified for the design of a blocked burst retransmission system, and in addition, establishes the basic equations for determining the limitations of the system. The system design criteria which must be optimized, are as follows:

1. Frame & Parameter Constraints
2. Time of Day
3. Channel Separation
4. Data Rate Tolerance Deviations
5. Sub-Frame Address
6. Memory Requirements
7. Bandwidth Efficiency

Retransmission systems, in which the total input data rate is greater than the output data rate and in which data compaction techniques are not used, requires the pre-selection of data parameters and their locations, conversely, the data parameters not selected and their locations are then also known. Location of non-selected parameters between the first selected parameter and the last selected parameter are referred to as holes and are used in determining memory storage requirements. The more important parameter which must be specified in order to fully evaluate the retransmission system are listed in Table 1.0. It is assumed the characteristics for any particular system evaluation, are held constant.

The retransmission output link contains the data parameter and the time of occurrence of the parameter. In order to provide this information with the optimum bandwidth utilization, it is necessary to devise a special format for the retransmission systems output. The output format for retransmitting input channel one contains data parameter words grouped as to prime frame number, an output time word and sync deviation word. The time and deviation words are used to locate the prime frames with respect to time. The actual parameter selection routine of the programmer determines the location of the parameter within the frame. This information must also be available at the data reduction site to properly locate the selected parameter with respect to time. In addition, address (frame) identification is provided at the beginning of the block of frames of the channel. The format for the remaining input channels is similar to the first except they contain channel separation words instead of a time of day word. The time occurrence for the first frame of each burst is determined by summing the time of day word of the first channel with the channel separation word of the channel under evaluation.

**Establishing The Burst Period**

A burst period is defined as the time in which all inputs have cycles through the smallest number of complete frames. Thus:

\[
N_1 = N_2 = N_3 = N_N = P
\]

\[
F_1 \quad F_2 \quad F_3 \quad F_N
\]

where \( N = \text{number of complete frames} \)

\( F = \text{main frame rate} \)

For the case where Titan = 20 frames/sec., Gemini = 10 frames/sec. and Agena = 16 frames/sec. an output period will contain three blocks, each selected over an integer number of input frames. Hence, \( N_1, N_2, \) and \( N_3 \) must be integers.

By inspection of the above equations, it is seen that a satisfactory solution is obtained when:

\( N_1 = 5; N_2 = 10; N_3 = 4; \) and \( P = 0.25 \) seconds

The number of parameters which can be selected from each input frame of a given input link is equal to the retransmission bandwidth allocated to that input link, divided by the input frame rate and word length.
In an output period of 0.25 seconds, the total number of words which can be transmitted is 1275. If these were all Titan words it would be possible to select 225 words per input frame; if all Gemini words, 125 words per input frame. In the case of Agena, the number of words are limited by the input rate of 128 words per input frame.

In a more representative condition, where burst from all input links are included in the output, it is evident that fewer words can be selected from each input frame. Assuming that the output capacity is equally divided between the three input links, the number of words which can be selected per input frame is then: Titan = 85; Gemini = 42; Agena = 106. It is evident that other mixes are possible.

**Sampling Rate Compensation**

The loss due to sub-commutation compensation can be controlled by the proper selection of parameters and data rates. The general PCM data system when not considering parameters priorities is arranged as follows:

<table>
<thead>
<tr>
<th>Input Parameters</th>
<th>Rates (Samples/Sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_N$</td>
<td>$S_N$</td>
</tr>
<tr>
<td>$X'_N$</td>
<td>$S'_N$</td>
</tr>
<tr>
<td>$X''_N$</td>
<td>$S''_N$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$S_N$ (lowest)</td>
<td></td>
</tr>
</tbody>
</table>

The Data Reduction Ratio is determined as follows:

$$\text{DDR} = \frac{\text{Channel 'N' input bit rate}}{\text{Output bit rate - (output bit rate for all channels other than 'N')}}$$

Max. DDR = \(\frac{R_N}{R_0 - R_0 \left( \frac{w_0 - w_N}{w_0} \right)}\) \(\rightarrow\) \(\frac{R_N}{R_0}\) \(\rightarrow\) \(\frac{R_N}{w_0} \rightarrow R_0\)

Min. DDR = \(\frac{R_N}{R_0 - R_0 \left( \frac{w_0 - w_N}{w_0} \right)}\) \(\rightarrow\) \(\frac{R_N}{R_0} \rightarrow \frac{R_N}{w_0} \rightarrow R_0\)

Consider the following:

Parameter \(S_N = \frac{I_N}{\text{DDR}} = Y + Y'_N\)

The whole number part of \(Y\) represents the number of \(S(N)\) samples per second parameters contained in the output link, converting the remainder \(Y'_N\) to the next lowest sampling rate.

Adding this number to \(S'_N\) and again dividing by the DDR

Parameter \(S'_N = \frac{X'_N + R'}{\text{DDR}} = Y' + Y'_N\)

Again the whole number part \(Y'\) represents the number of \(S'_N\) samples per second parameters contained in the output link. The above steps are repeated until all parameters rates are accounted for.

The remainder of the last conversion represents the utilization loss due to sub-prime sampling rates. The maximum parameters loss for channel \(N\) would occur when the remainder of the lowest rate approaches the magnitude of the lowest rate as a final value.

Therefore, the utilization loss per frame is determined as follows:

$$\alpha = \sum_{N=1}^{N=\infty} \left[ \frac{S_N \text{(Lowest)}}{Y_0 W_0} \right]$$

The Titan PCM data system utilizes 196 analog and 1/8 bi-level input channels arranged as follows:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rates (Samples/Sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>400</td>
</tr>
<tr>
<td>19</td>
<td>200</td>
</tr>
<tr>
<td>36</td>
<td>100</td>
</tr>
<tr>
<td>34</td>
<td>40</td>
</tr>
<tr>
<td>90</td>
<td>20</td>
</tr>
</tbody>
</table>

The bit rate is 172.8K b/s and the format is as follows. The prime frame contains 5 sub-frames and is sampled 20 times per second. Each sub-frame contains 64 words and each word contains 27 bits and is divided into three 8 bit syllables. Each 8 bit syllable represents one data sample. The 8 bit code is combined in descending order so that the first bit is most significant.

The Titan input link bit rate is faster (172.8K b/s) than the output link bit rate (40.8K b/s). The data reduction ratio is therefore, determined as follows:

Titan DDR = \(\frac{\text{Titan Input Bit Rate}}{\text{Total Output Bit - (Gemini & Agena) output rate}}\) bit rate

The minimum Titan data reduction ratio occurs when Gemini and Agena output bit rates are zero and the maximum Titan Data Reduction Ratio occurs when Gemini and Agena output bit rate equal the total output bit rate or in other words when the Titan output bit rate equals zero.
The Titan Data Reduction Ratio is

Max. DRR(T) = \frac{172K \text{ b/s}}{40.8K \text{ b/s}} = 4.25 \text{ b/s}

Min. DRR(T) = \frac{172K \text{ b/s}}{40.8K \text{ b/s}} = 4.25 \text{ b/s}

In other words the data reduction ratio may vary from 4.25 to \(\infty\). In the following example the minimum Titan data reduction ratio will be considered. The minimum DRR is not a whole number and thus not a multiple of the prime rate, therefore, a direct reduction of Titan parameters for a minimum DRR cannot be realized. Since full utilization of Titan data cannot be realized the question arises as to just how much utilization can be obtained.

The optimum format of the output link is found by dividing the highest data rate parameters by the Data Reduction Ratio and applying the remainder to the next lowest data rate. Consider the following:

Parameter (400) = \frac{19}{4.25} = 4.5

The whole number part of the above equation represents the number of 400 samples per second parameters contained in the output link, convert the remainder of .5 to the next lowest sampling rate of 200 samples per second.

Parameter (200) (R) = \frac{19 + 1}{4.25} = 1.0

Adding this to the number of parameters at the 200 samples per second rate and again dividing by Data Reduction Ratio.

Parameters (200) = \frac{19 + 1}{4.25} = \frac{20}{4.25} = 4.7

Performing similar operations on the remaining lower rates of 100, 40, and 20, the parameters of all rates can be found. The results are tabulated below:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rates</th>
<th>Samples/Sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

The remainder of .3 of the 20 sample per second rate results in a blank in the output data format every 1.66 seconds. The above arrangement may be varied in any combination such that the total number of parameters remain a whole number. The maximum loss of data for Titan would occur when the remainder of the lowest rate due to various DRR approached 1.0 as a limit resulting in a blank parameter every .05 seconds. If the five blocks of Titan in the output link were allowed to vary \(\pm 1\) parameter from each other then the utilization could be increased by a factor of five (5). This technique will be included when calculating the total utilization efficiency. However, it will not be implemented in the engineering model.

Frame Synchronization

The period of the output channel (i.e., output sync separation time) is dependent on the ability to reconstruct each data parameter, therefore, from experimental data

\[ \text{S}_0 \text{ (output sync rate)} = \frac{F_0 \text{ (output frame rate)}}{K} \]

where \(K\) is any whole number less than 10,000 which allows \(F_0\) to equal the minimum possible whole number the separation between sync for the ideal system is \(R_0/K\) where \(K = 10,000\), however, in order to synchronize the asynchronous input channels it is necessary to reduce the value of \(K\). This reduction prevents the full utilization of sync separation allowable, therefore, a sync utilization loss results. This loss is determined as follows:

\[ \text{Sync Utilization Loss (\(\alpha\)) = Sync Bits (1/K)} \]

\[ \frac{\text{per frame}}{10,000} \]

The sync utilization efficiency in percent \((\eta)\) can be determined from \(\alpha\):

\[ \eta = (1 - \alpha) \times 100 \]

Synchronous timing periods are necessary if time of occurrence data is not sent for every parameter. In order to convert the retransmission system from asynchronous to synchronous, it is necessary that the input frame rates of each channel divided by \(F_0\) equal a whole number. If the number is not a whole number then the frame rate must be increased by introducing blank frames, until it is a whole number. The resulting whole number represents the number of frames of the input channel plus blank frames which appear in each frame of the output channel. The difference between the initial rate and the new rate divided by the new rate is the frame utilization loss subtracted from unity is the frame utilization factor. The frame rate required for synchronizing the input channels to the output channel is determined as follows:

\[ F_N = \text{input frame} \times \text{'N'} \text{ / output frame} \]

\[ = F_N + \frac{(F_0 - K_N)}{F_0} \]

where \(F_N\) is the frame rate of input channel \(\text{'N'}\).

\(K_N\) is any whole number between 1 and \(F_0\) which makes \(F_N\) the smallest possible whole number.

The new effective frame rate for synchronization of the input channel to the output channel is \(F'_N\) and is determined as follows:

\[ F'_N = F_N + (F_0 - K_N) \]
The frame utilization loss is determined as follows:

\[ \alpha = \frac{N=3}{N=1} \frac{F' N}{F' N} - \frac{N=1}{N=1} \frac{F N}{F N} = 1 - \frac{N=3}{N=1} \frac{F N}{F N} = 1 - \frac{r}{T} \]

The frame utilization efficiency in percent (\( \gamma_F \)) can be determined from:

\[ \gamma_F = \left( \frac{N=\infty}{N=1} \frac{F N}{F' N} \right) x 100 = \frac{F_T}{T} x 100 \]

\[ = (1 - \alpha) \times 100 \]

The system designer should exercise care wherever possible in the selection of the input and output channel parameters in a multi-channel system. The selections should be made to optimize the sync and frame utilization efficiency. Consider the frame rates for three known input links, Titan, Gemini and Agena and a 40.8K b/sec output link.

\[ F_0 = \frac{40,800}{10,000} = 4 \]

\[ P (\text{Titan}) = \frac{F_T + F_0 - K_N}{F_0} = 5 \]

\[ P (\text{Gemini}) = 10 \]

\[ P (\text{Agena}) = 4 \]

\[ F = \frac{F_T + F_0 + F_A}{F_T + F_0 + F_A + \sum_{N=1}^{N=3} [F_0 - K_N]} \]

Since

\[ \sum_{N=1}^{N=3} [F_0 - K_N] = 0 \]

then

\[ \gamma_F = 1.0 \]

Consider a second example where the input frame rates are 13, 20 and 28 samples/second and the output rate is 28,000 bits/second.

\[ F_0 = \frac{R_0}{N} = \frac{28,000}{9,333} = 3 \]

\[ P_1 = \frac{13 + (3 - K_1)}{3} = 5 \text{ where } K_1 = 1 \]

\[ P_2 = \frac{20 + (3 - K_2)}{3} = 7 \text{ where } K_2 = 2 \]

\[ P_3 = \frac{28 + (3 - K_3)}{3} = 10 \text{ where } K_3 = 2 \]

\[ \sum_{N=1}^{N=3} \frac{R_N}{R' N} = 0.94 = \frac{61}{65} \]

\[ \gamma_F = 94\% \]

\[ \alpha = 0.06 \]

The ratio of 61/65 can be stated that for every 65 input frames in the output format only 61 will represent true input frames and 4 will contain no data.

The effective sync separation utilization must also be considered. It was noted that the optimum sync separation must be reduced in order that \( F_0 \) be a prime number so that synchronization can be obtained. The sync separation utilization is therefore,

\[ S = \frac{\text{Sync Separation}}{\text{Max. Sync. Separation Allowable}} = \frac{1}{10,000} \]

The \( S \) for the first case is 1.0 and the second case \( S \) is 0.93. In order to relate the frame and sync utilization to the overall system, it is necessary to convert them to a bandwidth utilization factor. The effect sync bit utilization loss for the first case is zero and for the second case is \( 3 \times 10^{-5} \).

**Time Word**

The time of occurrence of the first sync within the period is detected and used to generate the time word. The time word will contain units of hours, minutes and seconds and will be measured to an accuracy of one microsecond. The number of bits required for the complete time word is 37. The number of bits is based on a maximum number of 24 hours, 60 minutes, and 60 seconds. Since the primary interest is in transmitting the maximum data within a period rather than standardizing the time format, the system which uses the least number of output data bits will be considered.

The bandwidth utilization efficiency in percent (\( \gamma_{time} \)) due to the time word is:

\[ \gamma_{time} = (1 - \frac{T}{K}) \times 100 \]

where \( T = \text{Time Word} \)

The bandwidth utilization loss (\( \alpha_{time} \)) due to the time can be determined in terms of \( \gamma_{time} \):

\[ \alpha_{time} = \frac{T}{K} = (1 - \gamma_{time}) \times 100 \]
An incorrect data parameter should not be considered critical enough to endanger the mission or cause a serious loss of intelligence. It may not even be necessary to know that a parameter error has occurred during an output frame, however, since it is relatively easy to place an overall parity bit in the output format, a parity bit is added. More important consideration is given to time and address data since an uncorrected error in this data could result in the misinterpretation or loss of a complete output frame of data, therefore, not only is it necessary to detect an error but the bit in error should be corrected. The correction bits, when considering bandwidth utilization efficiency or loss are included as a part of the data words.

\[ \alpha_e = \frac{\text{Time and Address Correction Bits}}{\text{Total Output Bits}} = \frac{K_p K_a}{K} \]

Channel Separation Considerations

The maximum time separation of sync difference between the first Titan sync and the first Gemini sync and between the first Titan sync and the first Agena sync is approximately 250,000 microseconds. The minimum difference between the first Titan sync and the first Gemini or Agena sync approaches zero as a limit. Thus, the bits needed for time correlation for an input channel would decrease from 36 \((T \rightarrow 1/4 \text{ sec.})\) to zero \((T \rightarrow 0)\). Since the two cases mentioned, that is \((T \rightarrow 1/4 \text{ sec.})\) and \((T \rightarrow 0)\) are extreme cases, it is worthwhile to consider a more general case. The approximate time difference between the first Titan sync and the first Gemini or Agena sync is the time difference measured between the Titan burst and the Gemini or Agena burst of the output link, \(T_f\) is the time difference between Titan and Gemini sync and \(T_m\) is the difference between Titan and Agena sync.

Consider the case where

\[
\begin{align*}
W_T \text{ (Titan)} &= 55 \times 5 = 275 \\
W_G \text{ (Gemini)} &= 50 \times 10 = 500 \\
W_A \text{ (Agena)} &= 125 \times 4 = 500
\end{align*}
\]

\[
T_f = \frac{8}{40.5 K_b} \times 275 = 53,900 \text{ usec.}
\]

and \(T_m = \frac{8}{40.5 K_b} \times (275 \times 500) = 152,000 \text{ usec.}\)

The numbers of bits needed for \(T_f\) is 15 and for \(T_m\) is 18 or a total of 33 bits versus a total of 36 for the worse case. It is obvious that only in the extreme cases will any saving occur with respect to sync difference and, therefore, when weighed against the added program needed to save these extra bits it would indicate that a fixed number of bits be reserved for sync difference and tolerance and this number be such that it covers the worst case.

\[ T_p \text{ (Period)} = \frac{K}{R_0} \]

The channel separation word should have the capability of handling the maximum time separation.

The maximum bits required for a channel separation word is determined as follows:

\[ I = \log \frac{R_p}{2} \]

\[ T_p = 2^I \]

\(T_p\) is the closest larger whole number.

The bandwidth utilization efficiency in percent \(\eta_c\) due to the channel separation word is

\[ \eta_c = 100\left(1 - \sum_{N=2}^{\infty} \frac{N}{N!} \log \frac{2}{2} \right) \]

The bandwidth utilization loss \(\alpha_c\) due to the address can be determined in terms of \(\eta_c\)

\[ \alpha_c = 100 \left(1 - \frac{\eta_c}{100}\right) \]

Effect of Input and Output Link Tolerance

Considering the case where only the Titan link is implemented, if the data input period is less than the assigned data output period, then the difference in time multiplied by the input selected data rate (not to exceed 255 words/frame) would be the data over-flow. If the data input period is greater than the data output period, then the difference in time multiplied by the output data would be the data under-flow. Lastly, the third and most ideal case is when the data under-flow or data over-flow equals zero, however, tolerances of the input and output links makes this condition for all practicable purposes impossible. Since under-flow of data is allowable (no loss of data occurs), the maximum number of words selected must be based on the maximum input data rate and the minimum output data rate.
The Titan input link has a rate tolerance of ± .05% or ± 90 bits/seconds and the output link has a rate tolerance of ± .01%, since it is a ground link, or ± 4.0 bits/seconds. For all practical purposes the tolerance of the output link can be neglected as insignificant. In a condition where the incoming data rate is a minimum, the maximum data loss due to rate tolerance is the difference between the maximum input data rate and the minimum input data rate multiplied by the ratio of the output data rate and the maximum input data rate or 11 bits/output frame.

The above discussion has only considered the Titan link, however, it can be readily seen that the combinations of Titan, Gemini, and Agena utilization loss will be less than the utilization loss of Titan alone.

Consideration of Data Rate Tolerance Deviations

Once time is established at the start of a block it is only necessary to determine the deviation in the known input data rate in order to determine "time of occurrence" at the beginning of any frame. The data rate tolerance of the Titan link is assumed to be ± .05% when expressed in terms of time is ± .05% of the .05 second data sync input period. The data rate tolerance for the sync expressed in microseconds is 25. Over a full burst period the tolerance is 125 microseconds determined by multiplying the sync tolerance by the number of sync periods per output period. If we assume this tolerance is a fair representation of all channels, then the maximum deviation between the start of a period and the end of a period is 125 microseconds.

The time deviation of sync from normal for a given frame is formulated and placed at the beginning of the given data frame. The maximum time Titan data frame 2 can be displaced from frame 1 is ± 25 usec., therefore, only 6 time deviation bits are needed, one for sign and 5 for quantity. Frame 3 can be displaced up to ± 50 usec. from frame 1 or time of day and so on for frames 4 and 5. All Gemini and Agena frames other than the first are formatted in the manner similar to the Titan blocks.

If the tolerance is reduced then the sync time deviation bits could be reduced, however, the amount of reduction would be small in comparison to the reduction in tolerance. As an example, consider an input channel tolerance of .01% instead of .05%, the words needed for time correlation decrease from 21 to 20. It is obvious that the time correlation words for the proposed system is relatively independent of input channel sync tolerance.

In order to determine the deviation in time between the time or channel separation word and a particular frame, it is only necessary to multiply the deviation per frame by the number of frames between the time or channel separation word and the frame in question. The number of bits required for the time deviation word is determined as follows:

$$I_T = \log \left( \frac{\text{deviation word}}{2} \right)$$

The normal amount of bits required for deviation words are extremely small when compared to the bits required for time of day words, however, since the deviation words is directly related to the bit rate tolerance and the number of frames per block, it is essential that the system designer strive to keep the input rate tolerance tight and the prime frame rate to some common multiple of a low prime number. The bandwidth utilization efficiency in percent due to bit rate tolerance is:

$$\eta_T = 100 \left[ 1 - \left( \frac{I_2 + I_3 + I_4 + \cdots + I_N}{K} \right) \right]$$

The bandwidth utilization loss ($\alpha_T$) due to bit rate tolerance can be determined in terms of $\eta_T$.

$$\alpha_T = \sum_{N=2}^{\infty} \log \frac{D_N}{K \log 2} = 1 - \frac{\eta_T}{100}$$

Techniques For Address Correlation

The basic requirement of an asynchronous link system is to be able to determine which data parameter is being sent and its time of occurrence. In order to provide some form of identification of an input parameter in the output link it is necessary to provide address or identification data in the output data train. If a parameter occurs at the prime frame rate or some multiple of the prime frame rate it is only necessary to identify the sync time of the prime frame. However, in cases where the sampling rates are slower, it is necessary to determine which prime or main frame contains the data sample.

If only time of the prime frame occurrence were known, it would be impossible to determine which parameter is being sent. In order to locate the slower or sub-frame parameters it is necessary to place an identification word or bit in the prime frame containing the slower speed sampling data.

In the Titan link the slowest sampling rate occurs at the prime frame rate therefore, no frame identification is necessary. However, in the Gemini and Agena links, there are sampling rates slower than the prime frame rate. Therefore,
identification bits are necessary. The slow-
est sub-frame of the Gemini link is .16 samples
per second, therefore, identification must be
provided.

Number of Gemini prime frames for one input sub-frame

In a similar manner the number of Agena prime frames for one input sub-frame is 6t. The total number of tag bits required is the sum of the Gemini and Agena tag bit.

For the general case the number of input prime frames for one input sub-frame is:

\[ P_N = \text{input prime frame rate} \div \text{lowest input sub-frame rate} \]

The number of bits required for address (frame) identification is

\[ I_A = \log \frac{P_N}{\log 2} \]

The number of bits required for address (frame) identification is

\[ I_A = \frac{\log P_N}{\log 2} \]

The bandwidth utilisation efficiency in percent due to the address word is:

\[ \eta_A = 100 \left[ 1 - \frac{1}{K} \sum_{N=1}^{\infty} \left( \frac{\log P_N}{\log 2} \right) \right] \]

The bandwidth utilisation less \( \alpha_A \) due to the address can be determined in terms of \( \eta_A \):

\[ \alpha_A = \frac{\sum_{N=1}^{\infty} \frac{\log P_N}{\log 2}}{N} = 1 - \frac{\eta_A}{100} \]

\[ \eta_A = 100 \left( 1 - \alpha_A \right) \]

The effect of \( \alpha_A \) will be small when com-
pared to other losses, however, the system
designer should consider sub-prime commutation
rates which cause I to be equal to or slightly
less than a whole number for if I is slightly
larger than a whole number then the next larger
whole number must be used.

Memory Requirements

Since the selected input period is a common
multiple of all channels it is possible to move
the frame slots in phase and still be in synchro-

ous. This indicates that the start of the trans-
mission period would occur at some time other
than the leading edge of a frame or the first
frame after input channel sync. \( \beta, B = \phi \) is
the phase shift between the first sync of each
channel burst and the phase lock time and \( \beta' \),
\( B' = \phi' \) is the phase shift between the sync
prior to phase lock of each channel and the
phase lock time. The period of complete cycles
of all channels is \( \gamma \). It can be seen that

though the storage is dependent only on the input
word rate and the number of input words per
frame, extra storage for buffering because of
different channels rates is not necessary as long
as each channel has a frame rate which is some
multiple of the output frame rate for any one
program, Constant but non-related block sizes
allow the input channels to be phased locked
thus all channels will track together and over-
flow or underflow of any one channel will be a
function of variation in the input rate of that
channel and constant overflow or underflow of
all channels equally will be a function of the
variation in the output rate only.

The total storage required for \( N \) input
channels not considering overlap of memory
access between input and output, is determined
as follows:

\[ M_N = \sum_{N=1}^{\infty} \left( T_N + \frac{P_N}{R_N} \right) \]

where

\[ \left( \frac{N-1}{R_N} \right) \left( \frac{R_N - R_O}{R_N} \right) \]

and

\[ \frac{T_N R_N}{R_O} + \frac{P_N}{R_N} \left( \frac{R_N - R_O}{R_N} \right) \leq W_N \]

\[ \frac{N-1}{R_N} = W_N \]

\[ \frac{T_N R_N}{R_O} + \frac{P_N}{R_N} \left( \frac{R_N - R_O}{R_N} \right) \leq W_N \]

\[ T_N = \frac{T_N R_N}{R_O} + \frac{P_N}{R_N} \left( \frac{R_N - R_O}{R_N} \right) \]

\[ T_N = \frac{K}{R_O} + \frac{1}{S_N} + \frac{8W_N P_N K}{R_O^2} \]

Where \( T_N \) is the time between the start of
data storage of channel \( N \) and the start of data
read out, \( T'_N \) is the whole number part of \( T_N \)
while \( T''_N \) is the remainder. The parameter \( T''_N \)
is determined from the following equation:

\[ T_N = T_P + T_X + \left( T \text{ (slip)} - T_T \right) \]

Where \( T_P \) is the period time, \( T_X \) is the time
between the end of the input data block of channel
'\( N \)' and the end of the retransmission block of
channel '\( N' \)', \( T \text{ (slip)} \) is the input frame granu-
laritiy and \( T_T \) is the output time of input data
channel \( N \).

The worse case occurs when the selected
input data words occurs in a burst at the leading
edge of the data frame, here again this condi-
tion is a function of operational control and
therefore, must be taken into account in the de-
termination of buffer storage requirements.

\[ T_X = \frac{8W_N \left( \frac{1}{R_O} - \frac{1}{R_N} \right) \frac{H_N}{R_N}}{R_N} \]

\[ T_T = \left( \frac{8W_N P_N K}{R_O^2} \right) \]

394
combining and solving for \( T_n \)

\[
T_n = \frac{K}{R_0} + 8 \left[ \frac{W_n}{R_0} \left( \frac{1}{R_0} - \frac{1}{R_n} \right) - \frac{H_n}{R_n} \right] + \frac{1}{F_n} \\
+ \frac{6W_n F_n K}{R_0^2}
\]

for a selected mixture of 735 Titan, 500 Gemini

\( M_T = 1040 \) words

Bandwidth Utilization Efficiency

The total bandwidth utilization loss is determined by summing the utilization loss due to formatting and compensating factors, determined in previous paragraphs.

\[
\alpha_{\text{Total}} = \alpha_R + \alpha_S + \alpha_T + \alpha_{\text{Time}} + \alpha_E + \alpha_C + \alpha_T + \alpha_A
\]

where

- \( \alpha_R \) is the sub-commutation compensation utilization loss
- \( \alpha_S \) is the sync synchronous loss
- \( \alpha_T \) is the time word utilization loss
- \( \alpha_E \) is the error correction utilization loss
- \( \alpha_C \) is the channel separation utilization loss
- \( \alpha_D \) is the data overflow compensating utilization loss
- \( \alpha_T \) is the rate tolerance deviation utilization loss
- \( \alpha_A \) is the address utilization loss

The total bandwidth efficiency is determined as follows:

\[
\text{Bandwidth (total)} = (1 - \alpha_{\text{Total}}) \times 100
\]

For the Titan, Gemini and Agena case:

- Format
- Data Underflow Compensation
- Sampling Rate Compensation

296 bits
11 bits
9 bits

316 bits or
1040 words

Bandwidth Utilization Efficiency = \( \frac{1275 - 1040}{1275} \times 100 \)

= 96.2%

Conclusion

The data storage required of a Time Correlated Retransmission System for the selected data mixture under consideration is 1040 words. The programming requirement for the system is less complex not only in programming for parameter timing but also in programming for memory access. The system provides the mission programmer versatility in the selection of parameters and their sampling rates. The programmer may select any configuration of Titan, Gemini or Agena parameters with a negligible loss in bandwidth utilization. The bandwidth utilization efficiency of the proposed Titan - Gemini - Agena System has been calculated at 96%. Other combinations of input channels will have bandwidth utilization efficiency based on the characteristics of the input and output channels.

Overall, it is felt that the increase storage requirements versus less complex programming balance out. The versatility and high bandwidth efficiency occurs at the expense of real time response. Though the data of the proposed system is delayed, a possible 0.25 seconds, the actual time of data occurrence is transmitted with the data making it possible to reconstruct the data as a function of time. The actual delay in real time must be measured against mission requirements.

### TABLE 1.0

<table>
<thead>
<tr>
<th>Specified Parameters of the Retransmission System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>Input 1</td>
</tr>
<tr>
<td>Input 2</td>
</tr>
<tr>
<td>Input 3</td>
</tr>
<tr>
<td>Input N</td>
</tr>
<tr>
<td>Output</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FIGURE 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTPUT FROM SOURCE</td>
</tr>
</tbody>
</table>

395