MICROSECOND RESOLUTION TELEMETRY[1]

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Introduction This paper is concerned with the measuring and telemetering of event occurrence times with a 1 to 2 microsecond accuracy. There are three basic approaches presented, all of which can be used in different applications for one event up to several hundred events. The factors involved in the choice of a system are presented from the encoding viewpoint with little emphasis on the actual RF link problems.

Definition of the Problem The difficulty of obtaining the microsecond resolution depends to a large extent on the constraints used in defining the problem. The assumptions made are of a general nature, but may not be valid in some isolated cases. When a particular problem does not follow the constraints, then a complete review of the techniques for additions or deletions would be a necessity. The problem will be limited to RF links in which information retrieval is not possible some finite time after data occurrence.

There are two major constraints placed on the specific problem. First, it must be capable of handling any sequence in which the events occur (including simultaneous occurrence of a set), and supply 1 to 2 microsecond resolution. Second, the data should be recovered as soon as possible after the event has occurred. This latter constraint can be one of the more important factors in the choice of a particular system. For example, in impact measurements where the RF link will be destroyed soon after the last event occurrence.

The event occurrence time is defined az the time a threshold value is reached. The number of events that can be handled by the system will be defined as “N”. The success of a particular technique is de-pendent on the value of N.

Explanation of the Three Techniques General - There are two parts of the data to be transmitted; they are the recognition of one particular event and its occurrence time. The three techniques presented in this paper obtain the data in three basic methods designated as real time, delayed time, and a hybrid approach called hybrid time.

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Real Time Systems A real time system yields the information as it occurs. Examples of such systems would be an FM-FM system where a, function is continuously monitored, and even a commutated channel where a particular segment represents a signal during its allotted time. Of course, a signal directly modulating the transmitter would also be considered real time.

There are two major subdivisions of real time systems; they are True Real Time and Coded Real Time. A True Real Time system transmits both the event identification and the event occurrence time simultaneously. The analog level will identify the event, and the time when this level appears is the occurrence time. The Coded Real Time uses a binary, tertiary, quaternary or etc. code to identify the event, and the time of the codes first character transmission as the event occurrence time. Figure 1 shows an example for 4 events on True Real Time and Coded Real Time.

Both systems are limited by the components; however, within this limitation there are certain advantages and disadvantages of each. Referring to Figure 1, the True Real Time system can transmit event and occurrence time as fast as the system can respond; but if a number of signals are placed on the same data link then many levels must be distinguished and a good signal-to-noise ratio is required. The Coded Real Time system is limited to event occurrence times that are separated at least by the length of the coded word; however, because of the discrete levels it can tolerate more noise.

Delayed Time Systems A delayed time system stores a particular event occurrence in a pre-addressed storage location and telemeters it at some later or delayed time. An example of such a system could be where data is recorded on a flight tape recorder and then played back on command. Also, the data could be stored independent of real time in a coded format and then multiplexed into the RF link. Such a method is shown in Fig. 1. The length of the coded word for each event would depend on the type of code (binary, tertiary, quaternary, etc.) used and the total elapsed time that must be encoded. To better explain this point consider the following specific example.

Example 1: Requirements exist for 4 events to be monitored with 1 microsecond resolution on the occurrence time. The total time that can elapse from the first event to the last event is 320 microseconds.

Solution - A 1 MHz clock could be gated into 4 9-bit binary counters by the event occurrence times. A counter would be controlled by a specific event in the following manner. When any one of the events occur then all counters are enabled and receive pulses from the clock; each counter is then disabled by the occurrence of the event which controls the disable gate. The counter corresponding to the first event would have no count shown as it has the enable and disable signal pulses applied simultaneously. Using an 18-bit sync word then the total frame length would be 64 bits. The frame would be multiplexed continuously at the highest rate the components or bandwidth will tolerate. There are many other factors that could affect the use of such a system, but this example serves to explain the delayed time approach.

The advantage of the delayed time system is that each event is identified by the position on the frame, and the stored occurrence time can be completely independent of all other events. This allows for simultaneous occurrence. The disadvantage is that the entire frame data must be transmitted after the last event. That is, two adjacent frames must be the same in data content to assure accurate data. In some cases the amount of time required for this transmission may be longer than the expected life of the telemetry system. Impact measurements could impose this latter condition.

Hybrid Time Systems As the name suggests, the Hybrid Time System is a combination of the Real Time and Delayed Time characteristics. The system would transmit event occurrence time as it happens by a change in level and the event sequence as a delayed time coded word, as per Fig. 1. The Hybrid Time System is limited in resolution to the speed of the telemetry system, but the length of the coded word is determined by the number of possible sequences that can occur. If a binary coded word is used then

$$2^m = N!$$

where m is the number of bits required to code N events happening in random order but not simultaneously. The number of bits required increases substantially if simultaneous occurrence is considered.

System Determining Factors There are many factors that determine which approach should be taken. Some of the more important factors will be reviewed in the following list. Many of these terms are cross-related, but some are independent of others.

1. BW_1 - The bandwidth capabilities of the system.
2. BW_2 - The allowable bandwidth that can be used.
3. N - The number of signals required to be handled.
4. R - The resolution required i.e., one part out of how many.
5. T_1 - Minimum time spacing between events (it might be 0 or perhaps 1 second).
6. T_2 - The maximum time that can elapse between the first event occurrence and the last event.
7. T_3 - The minimum amount of time available for transmission of data after the last event occurrence.
8. S/N - Signal-to-noise ratio.
9. C - Cost of the system permitted.
10. REL - Reliability required of the system.

For the purpose of this paper the response time of the entire system to a step function will be considered as the capability with very little presented on true bandwidth considerations. The term used will be RT for Rise Time.

It would be possible to obtain a formula which equates the type system to some function of these variables. This has not been performed in this paper because time and experience is needed to determine if these are all of the variables that should be considered. Also some weighing factor would have to be assigned to things like cost and reliability, which would not be valid in general.

A System Requirement Solved Using Delayed Time Technique Recently a program requirement was presented for a Mach 6 sled test to make event occurrence measurements at impact. The general requirements were 100 time events to be monitored with a 1 to 2 microsecond accuracy, and limited volume and weight available for any telemetry package. The amount of time available after the last event occurrence was estimated to be a minimum of 300 microseconds. The amount of time that can elapse between the second event occurrence and the la-st event occurrence wa,s estimated at a maximum of 200 microseconds. The first event could occur 200 microseconds prior to all other events. Thus

$N = 100$
$R = 1/200$
$T_1 = 0$
$T_2 = 200 \times 10^{-6}$ sec.
$T_3 = 300 \times 10^{-6}$ sec.

The evaluation of some new P-Band transmitters revealed that when used with a 1.5 MHz bandwidth receiver a maximum rise time (RT) of 1 microsecond for pulse modulation on the RF link was feasible. Thus

$RT = 1 \times 10^{-6}$ sec.

The signal-to-noise ratio was believed to be favorable to analog or multilevel signals at near impact locations.

The resolution could possibly be obtained by a Real Time System. The Delayed Time System would require an 8-bit word for each event. The event identification becomes extremely difficult for Real Time, while relatively simple in Delayed Time because the 100 8-bit word locations would identify the event. Likewise, if a Hybrid system were used then a 100! combination must be considered (even eliminating the simultaneous occurrence modes). The logic to perform this would be very extensive.

It appeared that the Delayed Time System was the best, but with 8-bits for 100 words then 800-bits must be transmitted. The bit time period could be 1 microsecond at a miniimim thus 800 microseconds were required if only one RF link was used. If four RF links were used, then only 200 microseconds would be used. Also, if a quaternary code instead of a binary code were used, then only 100 microseconds are required. The system design revealed that 2 to 4 microsecond character periods were more compatible with components and transmission capabilities. A period of 2.5 microsecond was chosen so the total transmission time required is 250 microseconds when four transmitters and a quaternary NRZ-C code are used. The encoding package is called ISMAC for Integrated System of Multiplexing and Counting. The main subsystems are:

1. 1 megahertz clock
2. Master Delay Circuit
3. Synch Generation
4. Start and Stop Gates
5. 96 8-bits binary counters
6. Multiplexer

The operation of the system as shown functionally in Figure 2 is as follows: The clock is running and all other circuits are reset. The counters are not receiving pulses. When the first event occurs, called T_0, the master delay circuit is activated. After the preset delay time of 0 to 255 microseconds, the start signal is applied so that all counters begin to receive pulses. As an event occurs it supplies a. stop signal to its corresponding counter. The number of pulses, up to 255, are then stored in the counters. The 8-bit output of ea-ch counter is translated by binary to quaternary converter into four quaternary coded outputs. The multiplexer samples the four quaternary coded outputs from each counter and directs it to four transmitters.

The system design and packaging revealed that 96 channels were easier to package than 100, thus the limitation to 96 counters. The entire ISMAC was packaged in a 9" x 7" x 2-7/8" package and weighs less then 20 pounds.

Conclusion The basic approaches to microsecond resolution telemetry were presented and classified as

1. Real Time Systems
2. Delayed Time Systems
3. Hybrid Time Systems

An explanation of each technique was given so that a general understanding could be obtained. There was nothing presented on actual circuit design. The purpose of the paper was to present the methods in a, general view so that others might be able to find applications. Some of the factors that would influence the choice of a particular system are presented without detailed explanation.

A specific problem where the techniques were considered as a solution and which yielded a slightly modified delayed time system was presented.

It is possible that many applications exist for MRT (Microsecond Resolution Telemetry) in which these techniques could be utilized. Currently, circuits are being designed on the Hybrid Time and Delayed Time Systems for handling 4 events. These systems should be capable of replacing much larger and more expensive equipment presently being used for obtaining resolution of 10 to 20 microseconds.

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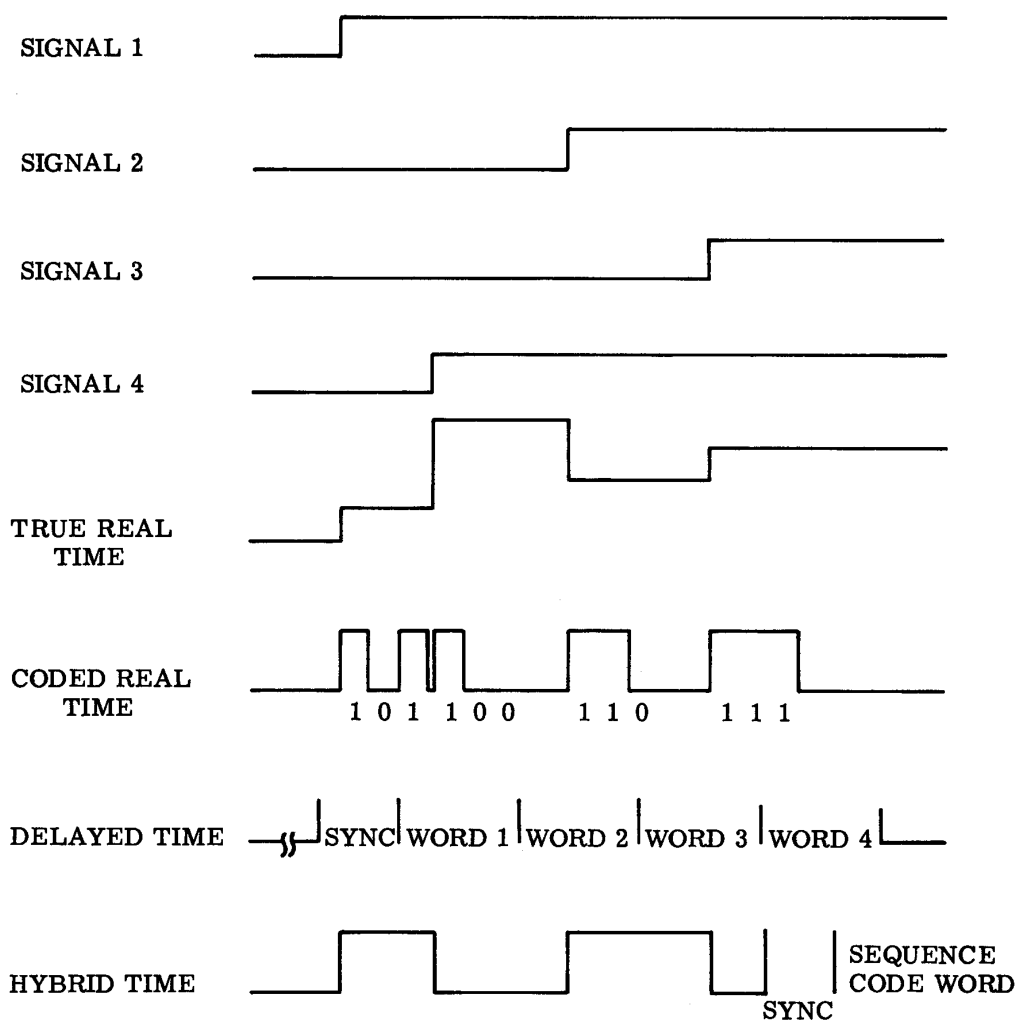

Figure 1 - Example of MRT Techniques

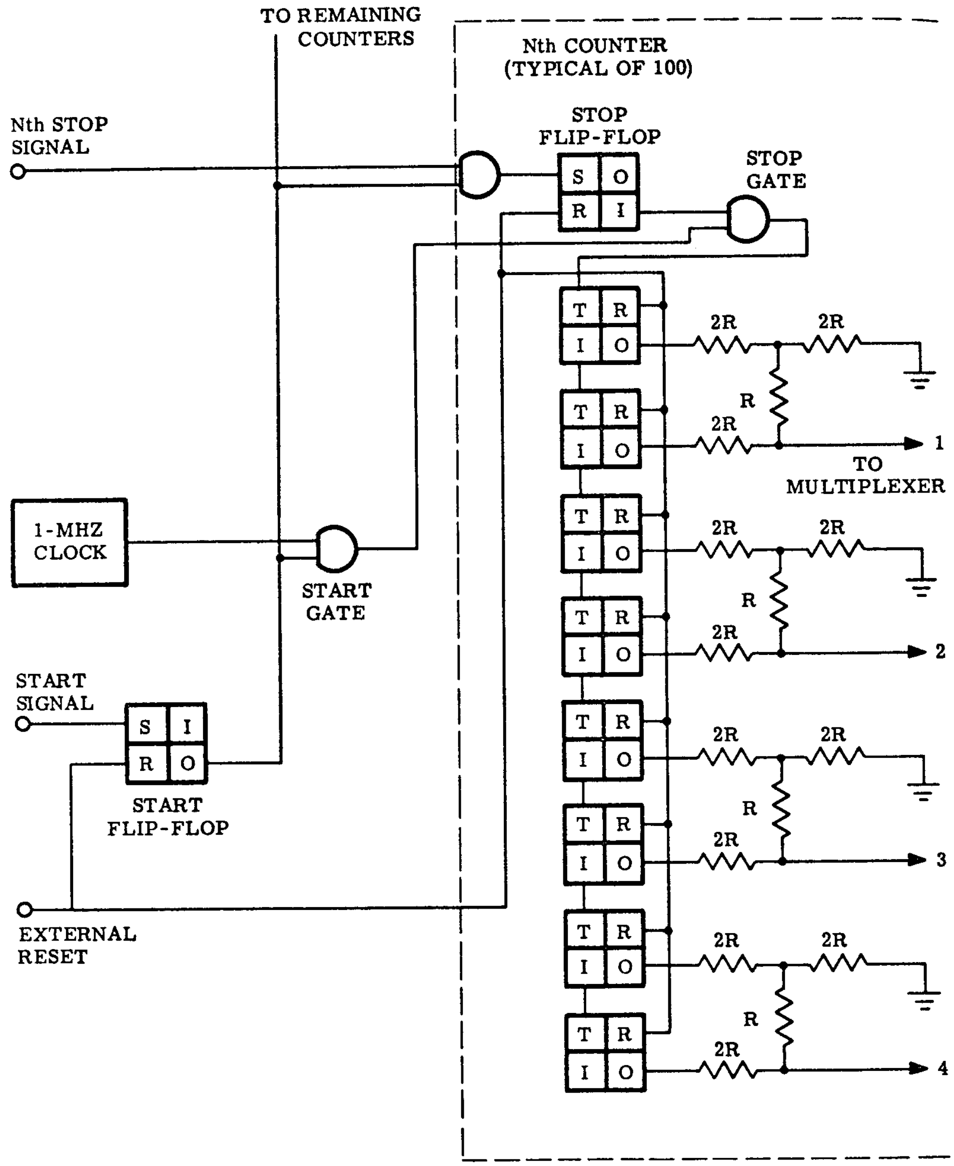

Figure 2 - ISMAC Counter and Control