IRIG 106 Chapter 10 Standardizes MIL-STD-1553 Data Recording

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Abstract

In an effort to reap the benefits of standardization for data recorder file formats, the Range Commanders Council (RCC) and others in the US Air Force instrumentation community developed the IRIG 106 Chapter 10 standard. IRIG 106 Chapter 10 provides interoperability for such applications as test range telemetry, flight test instrumentation, mission recorders, video/data servers; surveillance and reconnaissance; health and usage monitoring; mission planning, debriefing, and training; and flight operations. In addition to file formats, Chapter 10 defines the operation of various recorder and removable media (data cartridge) interfaces. IRIG 106 Chapter 10 includes specific formats for several types of flight data, including MIL-STD-1553 buses, PCM, analog, computer-generated data, images, discretes, UARTs, IEEE 1394, parallel, IRIG time, video, and voice. In addition, Chapter 106 provides standardization of time bases.

The focus of this paper is on the formatting of data monitored from MIL-STD-1553 buses. IRIG 106 Chapter 10 defines packets, which can encapsulate one of more 1553 messages. Within these packets, all messages are tagged with either a 48-bit relative or 64-bit absolute time stamp. For each message, there is also a block status word, which includes indications of bus channel and message validity, and identifies specific errors. The 1553 format also defines indications of response time, plus storage of all 1553 Command, Status, and Data Words, in the order received. For the storage of 1553 monitored data, there are different strategies that may be used, involving either fixed-sized or variable-sized blocks. In addition, some IRIG 106 Chapter 10 1553 monitors leverage DMA techniques for transferring data between a 1553 monitor and host space.

Introduction

A confluence of several trends has engendered a need for standardization in military data recording. Factors include the emergence of network centric warfare, the migration from analog to digital recording techniques; recent reductions in cost, and increases in density and reliability of solid state storage, in particular relative to magnetic media; and the benefits of standardization. Standardized data recording brings economies and benefits in multiple areas, including improved data accuracy, eliminating the need for developing custom hardware and software, providing a stable infrastructure for application software; and benefits for system integrators, including ease of data copying and distribution, along with reductions in risk, training, and overall cost and time.

These factors motivated the Range Commanders Council (RCC) and others in the US Air Force instrumentation community to demand common file formats and interfaces for digital data recorders. The IRIG 106 Chapter 10 standard was developed by the RCC, manufacturers, and others in order to meet these needs. While the initial goal for IRIG 106 Chapter 10 was to provide interoperability for test range telemetry, additional applications benefiting from this standard include flight test instrumentation, mission recorders, video/data servers; surveillance and reconnaissance; health and usage monitoring; mission planning, debriefing and training; and flight operations.

Chapter 10 defines how airborne data is captured, recorded, analyzed, and distributed. The standard's central focus is a recording format targeted towards random access digital media; i.e., solid state memory. In addition to defining overall file structures, Chapter 10 delineates specific formats monitored from MIL-STD-1553 buses, PCM, analog, computer-generated data, images, discretes, UARTs, IEEE 1394, paralleled, IRIG time, video, and voice.

In addition, Chapter 10 enables inoperability by defining the operation of various recorder and removable media (data cartridge) interfaces. These include RS-232 and RS-422 serial interfaces for recorder control and status; Fibre Channel and/or IEEE 1394B recorder data download interfaces; and IEEE 1394B data interfaces for removable media. A recent update draft of standard also includes an option for an Ethernet recorder data interface.

Time Stamping

IRIG 106 Chapter 10 provides two different options for the time stamping of packets and individual messages. These two formats are a 48-bit relative time, or a 64-bit absolute time. Both methods provide a common time base for stamping of all data stored by a data recorder, regardless of the data type. Further, using the absolute method, it is possible to correlate the times of data events for data stored across *all* data recorders at a specific location, or across multiple locations.

For each packet stored, the selection of which method is used is indicated by flag bits in the respective packet header. Both formats assume use of a local 10 MHz clock, thereby providing a time resolution of 100 nS/LSB.

The absolute time format is a "hypothetical times that either runs at the same rate for all the observers in the universe or the rate of time of each observer can be scaled to the "absolute time" by multiplying the rate by a constant"[1]. In the case of U.S. DoD test ranges and facilities, and other government agencies such as NASA, the reference for time is Coordinated Universal Times (UTC), which is referenced to the United States Naval Observatory (USNO) Master Clock.

The 64-bit absolute time stamping method is defined by IRIG Standard 200 for Time Distribution. Under this method, an update is sent out once per second by means of an analog pulse stream, and the time is clocked once per millisecond. The implies, assuming a worst case tolerance of ±0.01% (100 PPM) for a receiver's oscillator (which is the tolerance for MIL-STD-1553B transmission rate) for an absolute time user, a worst case error of ±100 nS, or precisely one "tick" of a 10 MHz clock.

Relative time is determined by the output of a free-running 48-bit 10 MHz binary counter. If relative time is used, it is distributed to all channels within the same data recorder, thereby providing a local common time base for all stored data, regardless of the data type. When relative rather than absolute time is used, the standard requires that it be accurate to within ±100 µS of absolute time, with a recommended accuracy of µS.

For MIL-STD-1553 messages, the 48-bit time value corresponds to a specific bit indicated in the MIL-STD-1553 Channel Specific Data. This time may correspond to the time of either the start or end of the first word, or the end of the last word of the 1553 message (See Figure 4).

Overall Data Packet Format

The partitioning of IRIG 106 chapter 10 data is performed on a packet basis, with all of the data within an individual packed associated with a specific channel (e.g., "4") and data type (e.g., "MIL-STD-1553"). Figure 1 illustrates the general format of an IRIG 106 Chapter 10 packet. Each packet begins with a defined packet header which identifies channel number and data type; an 8-bit sequence number, which gets incremented for each packet for the respective channel; packet length information; an indication of the channel's relative time for the first data bit of the packet; and a checksum. The packet header is followed by an optional packet secondary header, a packet body, and an optional packet trailer.

The format of the first packet of any IRIG 106 Chapter 10 data recording is called the "Computer Generated Data Packet, Format 1 Setup Record". This packet "describes the hardware, software, and data channel configuration

[1] [1], page 10-2

used to produce the other data packets in the file”[2]. The size of this packet is limited to 134, 217,728 (2^{27}) bytes.

There are two limitations on all other packets following the Setup Record: (1) they are limited to a maximum size of 524,288 (2^{19}) bytes. This total size includes the Packet Header, Packet Body, Packet Trailer, and optional Packet Secondary Header if enabled; and (2) the maximum time that may be represented by a single packet is 100 mS. For channel recordings that exceed either or both of these constraints, the channel data must be stored in multiple packets using the packet sequence counter.

PACKET SYNC PATTERN	Packet Header
CHANNEL ID	
PACKET LENGTH	
DATA LENGTH	
HEADER VERSION	
SEQUENCE NUMBER	
PACKET FLAGS	
DATA TYPE	
RELATIVE TIME COUNTER	
HEADER CHECKSUM	
TIME	Packet Secondary Header (Optional)
RESERVED	
SECONDARY HEADER CHECKSUM	
CHANNEL SPECIFIC DATA	Packet Body
INTRA-PACKET TIME STAMP 1	
INTRA-PACKET DATA HEADER 1	
DATA 1	
:	
INTRA-PACKET TIME STAMP n	
INTRA-PACKET DATA HEADER n	
DATA n	
OPTIONAL FILLER, OPTIONAL CHECKSUM	Packet Trailer

Figure 1. IRIG 106 Chapter 10 General Packet Format

The following paragraphs provide descriptions of the various fields within the general packet data structure.

The **Packet Sync Pattern** marks the start of a packet. It is a 16-bit pattern containing a fixed value of ‘EB25’h. The **Channel_ID** provides an identifier for the specific data channel being monitored and recorded, with all channels in a system required to have unique Channel_ID values, and the value ‘0000’h being reserved. For example, for an 8-channel 1553 data recorder, the respective channels of Channel_ID could have values ‘0001’h through ‘0008’h.

The **Data Length** and **Packet Length** fields are four bytes each, and indicate the number of bytes in a packet. For a given packet, the Data Length indicates the number of bytes in all of the Channel-Specific Data, Intra-Packet Time

[2] Ibid, page 10-71

Stamp, and Intra-Packet Data Header fields that are contained in the overall packet. The value of the Packet Length field equals the value of the Data Length field plus the number of bytes in the Packet Header, optional Secondary Packet Headers (if used), and Packet Trailer (if used). Assuming that the Secondary Packet Header and Packet Trailer (Filler and/or Data Checksum) fields are not used, the value of the Packet Length field will equal the value of the Data Length field plus 24.

The **Header Version** field is a one-byte indication of the applicable release of the IRIG 106 Chapter 10 standard. The single-byte **Sequence Number** represents the packet sequence number. Its value increments by one for each packet processed by the respective channel, and rolls over from ‘FF’h to ‘00’h following every 256 packets processed for the respective channel.

The one-byte **Packet Flags** field provides information regarding the format of the data packet. The bits in this field relate to the use of the optional Packet Secondary Header, formatting of the time stamp, indications of data overflow error; along with an indication about the data checksum field; that is, whether or not it is used, and if so, its width, which may be 8, 16, or 32 bits.

The value of the single byte **Data Type** field indicates the type of format of data contained within the packet. As of Revision 6, IRIG 106 Chapter 10 defines and/or reserves up to 112 different types of data. This includes eight (8) codes for each of the following 14 broad classes of data: Computer Generated Data, PCM, time, MIL-STD-1553, analog, discrete, message data, ARINC 429, video, image, UART, IEEE 1394, parallel, and Ethernet. Many of these codes are reserved for future use. For example, the code values for MIL-STD-1553 are defined as follows:

- ‘18’h – MIL-STD-1553 Data, Format 0 (Reserved for future use)
- ‘19’h – MIL-STD-1553 Data, Format 1 (MIL-STD-1553B Data)
- ‘1A’h – MIL-STD-1553 Data, Format 2 (16PP194 Bus)
- ‘1B’h – ‘1F’h – MIL-STD-1553 Data, Formats 3 – 7 (Reserved for future use)

The **Relative Time Counter** field provides a 48-bit (6-byte) representation of the Relative Time Counter. This value represents the output of free-running counter that is clocked by an internal 10 MHz oscillator, and is common to all channels. The method for time stamping of monitored data streams is defined specifically for each individual data type. The two-byte **Header Checksum** provides an integrity check of the overall packet header by providing the 16-bit arithmetic sum of all 16-bit words in the header, excluding the Header Checksum Word.

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The **Packet Secondary Header** is an optional 12-byte field. If used, this header may include a 48-bit time stamp value for the packet, along with a two-byte checksum for the time value.

The Packet Secondary Header (if used) or the Relative Time Counter (if the Packet Secondary Header is not used) is followed by one or more instances of **Packet Body**, as described in the following paragraphs. The size and duration of each Packet Body are constrained by the 524,588-byte and 100mS limitations mentioned above.

The optional **Packet Trailer** follows the last Packet Body of the Packet. If used, the Packet Trailer may contain either a **Filler,** a **Data Checksum**, or both the Filler and the Data Checksum. The Filler field is provided for two purposes: (1) to keep all packets aligned on 32-bit (4-byte) boundaries and (2) to optionally keep all packets for a particular data channel the same length. As a result, there will be some applications where the Filler field is not required. If used, the value for all Filler bytes must be either ‘00’h or ‘FF’h.

As indicated in the Packet Flags, the Data Checksum may either be not used, or be 8, 16, or 32 bits wide. The Data Checksum is computed as the 8, 16, or 32-bit arithmetic sum of all bytes, words, or double words respectively in the Channel Specific Data, Data and Filler; but *not* the 24 bytes of Packet Header Words, Packet Secondary Header (if enabled), and the Data Checksum Word itself.

General Packet Body Format

The format of the packet body field is defined specifically for each individual data type. The first field within the packet body is the **Channel Specific Data**, which is a variable length field, depending on the data type. There is only one Channel Specific Data field for each data packet. The Channel Specific Data field is followed by one or more variable-sized representations of monitored channel **Data**.

Each Data representation sub-packet consists of one or more data bytes (the number of bytes is data type-specific), and *may* be preceded by a structure called an Intra-Packet Header. The Intra-Packet Header consists of an optional

Intra-Packet Time Stamp and/or an optional **Intra-Packet Data Header**. If used for a particular data type format, the Intra-Packet Time Stamp provides either 48-bit Relative Time or 64-bit absolute time, as indicated by the Packet Flag bits. The Intra-Packet Data Header is also defined specifically for each data type, and provides additional status and format information for the data bytes that follow.

MIL-STD-1553B Packet Body Format

As mentioned, the format of the Packet Body is specific for each type. Figure 2 illustrates the format of an overall MIL-STD-1553 Format 1 (Data Type field = ‘19’h, “MIL-STD-1553B”) Data Packet.

PACKET HEADER
CHANNEL SPECIFIC DATA
INTRA-PACKET TIME STAMP FOR MESSAGE 1
INTRA-PACKET DATA HEADER FOR MESSAGE 1
MESSAGE 1
INTRA-PACKET TIME STAMP FOR MESSAGE 2
INTRA-PACKET DATA HEADER FOR MESSAGE 2
MESSAGE 2
:
INTRA-PACKET TIME STAMP FOR MESSAGE n
INTRA-PACKET DATA HEADER FOR MESSAGE n
MESSAGE n
PACKET TRAILER

Figure 2. MIL-STD-1553 Data Packet, Format 1 (MIL-STD-1553B)

With this format, the first field of the packet body (i.e., immediately after the Packet Header) is the 4-byte “MIL-STD-1553 Packet Channel Specific Data” field, as shown in Figure 3. This consists of a 24-bit message count, along with two bits to specify one of three different options for the time tagging of individual 1553 messages.

MSB 31 30	29 24	23 LSB 0
TTB	RESERVED	Message Count

Figure 3. MIL-STD-1553B Channel Specific Data

As illustrated in Figure 4 for a BC-to-RT transfer message, bits 31 and 30 define three options for message time tagging:

- Last bit of the last word of a message
- First bit of the first word of a message

- Last bit of the first word of the message

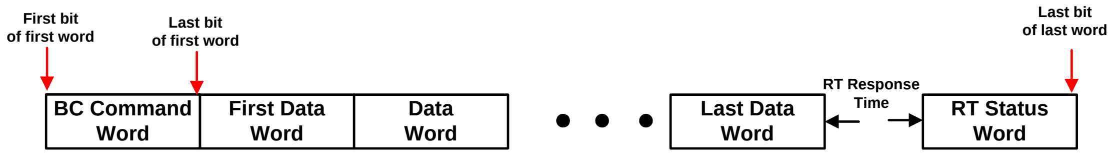

Figure 4. MIL-STD-1553B Intra-Packet Time Stamping Options

The Message Count sub-field, bits 23 through 0 of the MIL-STD-1553B Channel Specific Data, indicates the total number of MIL-STD-1553B messages stored in the packet.

Within each Data Packet, the message words for each MIL-STD-1553B message are preceded by an Intra-Packet Header. Each Intra-Packet Header consists of an Intra-Packet Time Stamp and an Intra-Packet Data Header. The Time Stamp field is 8 bytes, and contains either 48-bit Relative Time of 14-bit Absolute time, as indicated by bits in the Packet Flag field. For the case of the Relative Time Stamp, the upper 16 bytes are zero-filled, and in either case, the resolution of the Time Stamp is 100 nS/LSB.

The length of the MIL-STD-1553B Intra-Packet Data Header is 6 bytes, and is formatted as shown in Figure 5.

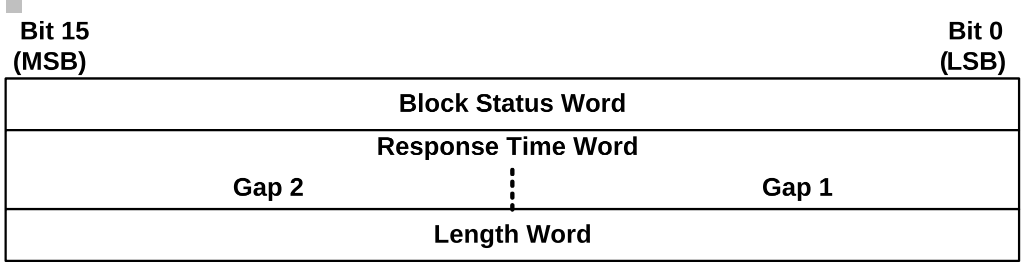

Figure 5. MIL-STD-1553B Intra-Packet Data Header

For each message, the 16-bit Block Status Word provides indications of which bus channel (A or B) a message was received on, a bit to indicate whether a message was an RT-to-RT transfer, and six bits that denote when various error conditions have occurred. The Block Status Word bit descriptions are shown in Figure 6.

Bit	Description
15 (MSB)	Reserved
14	Reserved
13	Bus_ID: 0 = Channel A, 1 = Channel B
12	Message Error
11	RT-to-RT Transfer Message
10	Format Error
9	Response Timeout: an RT either didn't respond, or its response time was greater than 14 µS
8	Reserved
7	Reserved
6	Reserved
5	Word Count Error: indicates that the number of data words in the message was different than from the Word Count field in the Command Word .
4	Sync Type Error
3	Invalid Word Error: indicates either a Manchester or Sync encoding error, incorrect number of bits in a word, or a parity error.
2	Reserved
1	Reserved
0 (LSB)	Reserved

Figure 6. MIL-STD-1553B Block Status Word Bit Descriptions

The third and fourth bytes of the Intra-Packet Data Header contain RT response time information. For all messages except RT-to-RT transfers, the RT response time is provided by the Gap 1 sub-field. As shown in Figure 7, for RT-to-RT transfer messages, the response time gap field contains two time values, with Gap 1 indicating the response time of the transmitting RT, and Gap 2 providing the response time of the receiving RT.

For all cases, the MIL-STD-1553B response time is measured from the mid-parity bit zero crossing of the Command Word or last Data Word to the mid-sync zero crossing of the responding RT's Status Word. The resolution of the Gap fields is 100 nS/LSB, thereby providing a maximum indication of 25.5 µS.

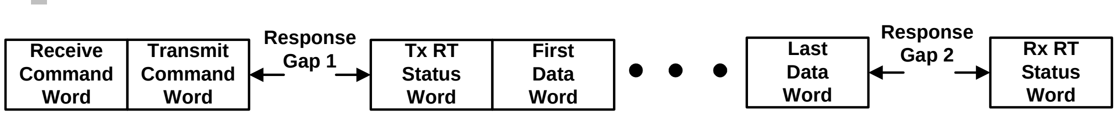

Figure 7. 1553 RT-to-RT Transfer Message, Showing Response Gap 1 and Response Gap 2

Following the Response Time Word is the Length Word. This provides an indication of the number of bytes in a message, which includes all command words, data words, and status words. The value of this field will range from a minimum of two, for a broadcast mode command with no data; up to a maximum of 72, for an RT-to-RT transfer of 32 data words.

For each message, the Length Word is followed by the values of the message's 1553 command, data, and status words, in the order that they were received. For all 1553 messages, the first word stored will always be a command word.

In theory, the 24-bit Message Count sub-field can support packets with up to 16,777,215 messages. However, this value is significantly larger than the maximum number of 1553B messages that could actually occur in a single packet of time. The maximum number of messages in a packet would occur for the case of a bus controller continuously transmitting back-to-back broadcast mode code commands with no data, each with the minimum allowable intermessage gap time of 4 µS (i.e., 2 µS bus "dead time"). This would result in a message transmitted every 22 µS, which equates to 4545 messages transmitted every 100 mS, which is the maximum allowable time interval for an IRIG 106 Chapter 10 packet.

Another IRIG 106 Chapter 10 limitation is the maximum number of bytes in a packet, which is 524,288. For MIL-STD-1553B, assuming the optional Secondary Packet Header and Trailer fields are not used, the total number of bytes in a packet includes:

- The 24 bytes of the Packet Header, including the Header Checksum.
- The 4 bytes of Channel Specific Data.
- For each 1553 message in the packet:
  - The 8 bytes of the Intra-Packet Time Stamp
  - The 6 bytes of the Intra-Packet Data Header
  - The bytes of the 1553 command, data, and status words. This will be in the range between 2 and 72

That is, the total number of bytes in the packet, or packet length (PL) may be computer by:

$$PL = 28 + \sum_{i=1}^{M} \left(14 + B_i\right),$$

Where M = the number of message in the packet, and B_i = the number of bytes in the i^{th} message of the packet.

The maximum number of words in a MIL-STD-1553B packet will occur for the case described above, that is for a bus controller continuously transmitting back-to-back broadcast mode code commands with no data, each with the minimum allowable intermessage gap time of 4 µS. For this case, M = 4545 and all B_i = 2. The total number of bytes in the packet = 28 + (4545 • (14+2)) = 72,648, which is "comfortably" below the maximum IRIG 106 Chapter 10 packet size of 524,288 bytes.

For the case where all messages in a packet are BC-to-RT transfers of 32 data words with minimum intermessage and response time gaps of 2 µS "dead time", M = 100 mS/684 µS = 146, all B_i = 68, therefore the total number of bytes = 28 + (146 • (14+68)) = 12,000. Similarly, for the case where all messages in a packet are RT-to-RT transfers of 32 data words with minimum intermessage and response time gaps of 2 µS, M = 100 mS/726 µS = 137, all B_i = 72, and the number of bytes = 28 + (137 • (14+72)) = 11,810, slightly less than for the case of BC-to-RT transfer messages.

Storage of MIL-STD-1553 Packet Bodies

In addition to providing standardization of MIL-STD-1553 monitored data, IRIG 106 Chapter 10 defines a packet format for which all elements representing 1553 messages are combined into consolidated structures. This not only includes the 1553 command, status, and data words; but also time stamping, response time, and block status information. In comparison to methods using separate structures for data, message timing, and status, this provides the advantage of accelerating the time for offline workstations to retrieve monitored messages.

For the storing of individual MIL-STD-1553 messages (packet bodies), IRIG 106 Chapter 10 specifies the use of variable length message blocks. If a fixed length allocation scheme were to be used, this would entail the storage of filler bytes for messages with less than 72 total bytes (for an RT-to-RT transfer of 32 data words). By comparison to a fixed-length allocation strategy, the use of variable sized message blocks provides the major advantage of minimizing storage space.

An IRIG 106 Chapter 10 implementation variable entails determining packet completion conditions. Depending on the application, packet completion may be determined based on one specific condition, or a combination of multiple conditions. These conditions may include: after a fixed number of 1553 messages are stored, after a fixed amount of time since the last packet completion (up to 100 ms), triggered by a specific value of absolute or relative time stamp, following a fixed number of data bytes stored in a packet, occurrence of a specific event, or immediately following a host command. In all cases, the packet will always include an integral number of 1553 messages.

1553 Monitor Performance

The occurrence of a programmed condition or combination of conditions may be used to issue a host interrupt. Upon receipt of this interrupt, the host may either access shared memory itself in order to transfer the latest 1553 data packet or, if the monitor includes a PCI Initiator with DMA burst capability, to program the monitor to write the packet to a specified area in PCI (host) address space. In general, DMA is a highly useful mechanism for minimizing the level of host resources for transferring data.

For 1553 monitors, the use of various “hardware assist” mechanisms improves monitor performance in the areas of host processor and PCIbus utilization. These include:

- Multi-message on-board packet assembly for each 1553 monitor channel
- The issuance of interrupts, based on programmable conditions, to indicate that a complete packet has been assembled
- The use of on-board DMA engines in conjunction with a PCI Initiator interface to transfer packets from the monitor memory to PCI host space.
- The issuance of interrupts to indicate the completion of PCI DMA write bursts to host space

Using the mechanisms, monitored 1553 packets may be stored to circular buffer data structures in host space. By means of semaphores, “zero-copy” techniques involving “loaning” of kernel data buffers to user application software, and separate completion queues for each 1553 channel, the monitor hardware and low-level software post lists of packets that have been written to host space.

The following “real world” example is representative of the level of performance that is possible for an IRIG 106 Chapter 10 MIL-STD-1553 monitor. This example indicates the time required to transfer a packet containing 100 MIL-STD-1553B messages, which are processed at a rate of 1 message per mS, with each message containing 32 data words:

- The monitor issues a host interrupt indicating packet completion. For the purpose of this example, this time is referenced as “zero”(0).
- At 3.2 µS (after the issuance of the interrupt), the host interrogates the 1553B monitor, and initiates the monitor card’s PCI indicator.
- At 10.8 µS, the monitor begins its DMA transfer to PCI host space.
- At 68 µS, the monitor issues a DMA Complete interrupt.
- At 73.8 µS, the host has completed its interrupt service routine acknowledging DMA completion.

Based on this example, PCI utilization = (68 µS – 10.8 µS)/100 mS = 0.057%. Assuming a monitor with eight 1553 channels processing the same message profile and packet size, this equates to a total PCIbus utilization = 8 • (0.057%) = 0.46%.

Conclusion

For data recorders, IRIG 106 Chapter 10 provides a highly standardized and robust means for storing monitored MIL-STD-1553B messages. This standard defines a common overall packet structure, along with specific data formats for MIL-STD-1553B as well as other types of recorded data.

For MIL-STD-1553B, the defined Chapter 10 packet structure delineates the storage of all 1553 message words, along with indications of message validity or errors, response time information, and either a 48-bit relative time stamp or 64-bit absolute time stamp for each message stored. Efficient implementations of Chapter 10 MIL-STD-1553B bus monitors employ hardware-assist mechanisms such as interrupts, DMA engines, and PCI Initiator interfaces, as means to minimize host processor resources and PCIbus utilization.

As a result, IRIG 106 Chapter 10 enables the Range Commanders Council (RCC) and others in the US Air Force instrumentation community to realize the myriad benefits of standardization for MIL-STD-1553B data recorders. These benefits include interoperability among equipment suppliers, software developers, and users; along with economies of scale in hardware, software, and training.

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Data Device Corporation is recognized as an international leading supplier of high-reliability data interface products for military and commercial aerospace applications since 1964 and MIL-STD-1553 products for more than 25 years. DDC's design and manufacturing facility is located in Bohemia, N.Y.

References

[1] IRIG 106 Chapter 10, Draft 06 Release; Range Commanders Council U.S. Army White Sands Missile Range, New Mexico 88002-5110

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