PCM TELEMETRY DOWNLINK
FOR IRIG 106 CHAPTER 10 DATA

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Abstract: Since both airborne and ground applications are able to handle and process IRIG 106, Chapter 10 standard data (further referred to as C10) from files or from live streaming UDP network data, it is a logical extension of the standard to telemeter network data from the air to the ground support systems with little or no modification. This paper describes a method to transport C10 compliant packets over a Class II, telemetry stream (C10 TMDL) which is fully compatible with existing encryptors, transmitters, receivers, and decryptors.

Keywords: IRIG 106 Chapter 10, Networking, Asynchronous Telemetry Downlink

1. Introduction

The best predictors for technology evolutions that will occur in the telemetry world can be found by observing what is occurring in the commercial market space. Evolutions occurring such as merging of technologies (video, communications, data) and utilization of new commercial technologies will continue to advance into the telemetry space. The best examples of these phenomena are: infiltration of network technology into Data Acquisition Units (DAU), utilization of commercial standard high speed serial asynchronous interfaces on-board the aircraft, and utilization of broadcast HD Video.

With all this said, it is clear that networks will play an ever increasing roll in telemetry. The Test and Evaluation (T&E) community does not have the funding to drive development of new technologies, thus will continue to adapt new commercial technologies to telemetry applications. Utilization of commercial high speed asynchronous data busses and networks on the test platform is increasing. High speed asynchronous data types continually challenge the ability to adequately time sample data into a PCM stream. The ability to asynchronously downlink network data and asynchronous data sources along with the other legacy analog and digital data types is very desirable without having to periodically sample each data source.

For T&E, C10 has been making its way onto ranges around the world since 2004. C10 originally only defined the logical data structure for recording. Live Data Streaming was later defined in the C10 standard utilizing UDP broadcasting to enable monitoring of data over a network connection. In addition, the C10 Standard later defined Ground Based Recording and streaming of C10 data for ground based network applications. This in turn expanded C10 streaming based data processing in the telemetry ground segment. The overall result of the C10 infiltration has been an extensive build up of software based applications to support both C10 recording and .PUBLISH network based real-time and post mission data monitoring

In the past, for post mission ground reproduction, the T&E community reconstructed PCM data into its native digital signal format for ground playback / replay into hardware based processing systems. C10 format standardization has opened the door for computer processing of data without having to reconstruct the PCM stream. To date, software based data reduction has not been the predominant method for performing Engineering Unit (EU) conversion of real time data for a number of reasons. This is primarily due to computer limitations for real time processing and the switching cost to move EU conversion from the traditional PCM front ends to software based solutions. A large majority of software applications started out handling only C10 file processing for post mission applications, but have been extended to handle C10 live streaming data. The number of highly capable software applications supporting EU conversion, display, and analysis has significantly increased over recent years. For the more capable commercial software applications, the ability to handle prevalent data types is expected and does not require special development.

Since there is extensive investment in handling real time and post mission C10 data for both the air and ground segments, a method has been defined to encapsulate the C10 packets into a fixed bit rate PCM stream for the purposes of down linking the C10 network data over a constant bit rate PCM Stream.

2. Objectives for C10 TM Down Link (C10 TMDL)

The main objective of the C10 down link is to multiplex all the existing legacy data types such as analogs and discretes in addition to the newer data types such as high speed asynchronous sources (fiber channel, Gigabit Ethernet, 1394b, etc) and High Definition (HD) Video into a single telemetry downlink steam. A secondary objective is to minimize switching cost to cutover to the C10 TMDL. To minimize switching cost, it is mandatory to utilize only legacy transmitters, encryptors, receivers, bit syncs, and TM front ends. In addition, the C10 TMDL has the potential to reduce test preparation time and verification testing. The following is a subset of objectives for the C10 TMDL downlink:

- Little or no changes to ground processing hardware and software
- Quick setup, not requiring tedious build up of PCM formats and no testing of PCM formats for proper placement of measurements in the PCM frame
- Commensurate bit error rate performance with PCM/FM or other Tier 1 or 2 RF modulation techniques
- Provide a convenient method to multiplex and downlink High Definition (HD) video
- Provide a good method to downlink network data
- Utilize asynchronous packets to transmit asynchronous data vs. periodic time sampling
- Eliminate redundant interfaces in the data recorder and encoder
- Merge C10 data and external PCM streams or Ethernet streams into one PCM Stream

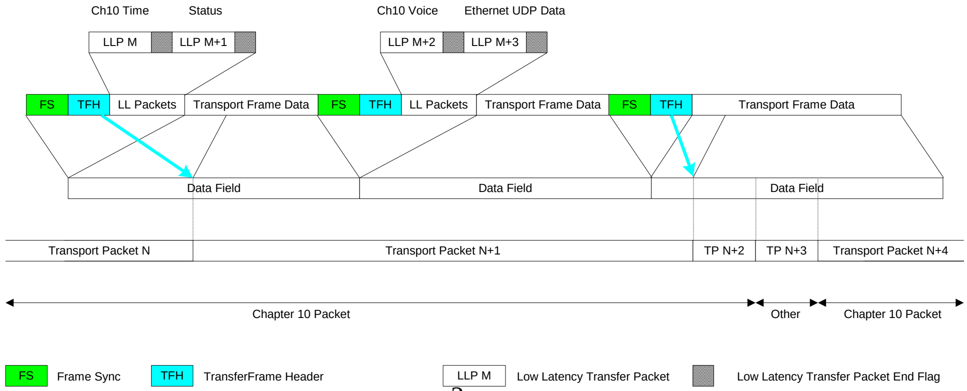

Figure 1 - Overview of the C10 TMDL PCM Transport

3. Fundamental: Description of C10 TMDL PCM Telemetry Encoding

The C10 TMDL transmits data in a Chapter 4, fixed bit rate, IRIG Standard, Class II, PCM stream. The data fits in the Class II PCM stream category because it utilizes an Asynchronous Embedded Format in the host PCM stream. The DAU, Encoder or Recorder serves as the TM gateway that inserts the C10 standard packets in the TM downlink stream. A field proven format for multiplexing the data into a PCM stream was chosen. The chosen format is very similar to the mechanism used in the Consultative Committee for Space Data Systems (CCSDS) Packet Telemetry and the now retired IRIG 107-98, Digital Data Acquisition and On Board Recording Standard. At the top layer, the packets will be inserted asynchronously into a PCM stream having a minor frame structure called the "Transport Frame". The source test platform device such as a recorder or encoder first encapsulates data in a C10 Data Packet. The C10 packet serves as the mechanism to transport all data types and is the logical data structure used to multiplex different data types in the TMDL PCM transport stream. The following is an overview of the Transport Frame mechanism and the insertion of C10 packets into the C10 TMDL PCM stream.

The stream consists of the following:

The **Transport Frame** is a PCM Minor Frame up to a maximum length of 8192 bits. The Transport Frame uses a 32-bit Frame Synch word and contains 5 x 223 bytes (8-bit date words).

FRAME SYNC
First Header Pointer, Golay (24,12,8) coded
(OPTIONAL) LOW LATENCY TRANSPORT PACKET 1
(OPTIONAL) LOW LATENCY TRANSPORT PACKET END BYTE 1
...
(OPTIONAL) LOW LATENCY TRANSPORT PACKET M
(OPTIONAL) LOW LATENCY TRANSPORT PACKET END BYTE M
TRANSPORT PACKET 1
...
TRANSORT PACKET N

Figure 2 - Transport Frame Structure

As mentioned earlier, the frame structure above is very similar to the IRIG 107-98 Digital Data Recording Format and CCSDS Packet Telemetry format. The only major extension to the CCSDS Packet Telemetry format is to add self-correcting coding to the structure-critical elements, such as the **Transfer Frame Header/First Header Pointer** and the beginning of each Transfer Packet.

For protection of the structure critical items an extended Golay code is used. This code expands a 12-bit word to 24 bits. It corrects up to 3-bit errors in the 24 bit word, and detects 4-bit errors in this 24-bit code sequence. The coding and decoding of this code is relatively inexpensive and can be realized with simple 4 kByte hardware or software lookup tables and a 12-bit logical exclusive OR operation as can be seen on Figure 3.

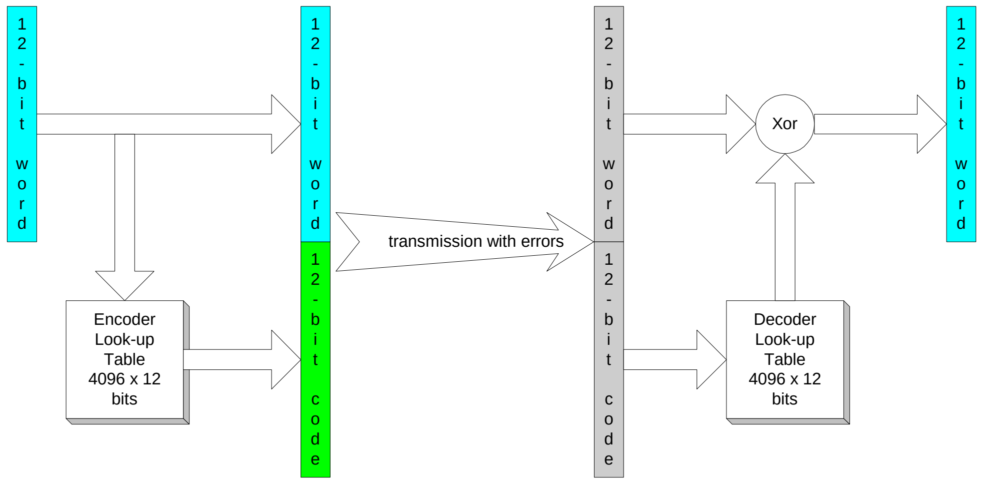

Figure 3 - Extended Golay Encoding and Decoding

To allow quick synchronization for the asynchronously inserted packets, the first data word of the frame is used as a pointer/offset to the first packet start location in the frame (if a packet exists in the frame).

The Transport Frame contains Transport Packets. The size of the Transport Packets will vary and can be very long (based on the C10 standard), spanning several Transport Frames. This is necessary to keep the overhead low, but on the other hand, the transmission of a long packet may cause too long a delay waiting for critical data that cannot wait until the end of the long packet is transmitted.

To counter the blocking of the low latency critical packets, a **Low Latency Transport Packet** Mechanism is introduced. These packets allow for momentary interruption of the transmission of a long packet, and insertion of one or more packets with low latency requirement. The long packet transmission is resumed after the low latency transport packet part of the frame is completed.

Transport Packets are normally used to transmit C10 packets; however other data types can be inserted into the stream, such as raw Ethernet data, or status information about the C10 TMDL. A Transport Packet containing C10 data can be an entire C10 Packet, the beginning, middle, or end of a packet. The Transport Packet consists of a Transmit Packet Header and Transmit Packet Data.

TRANSPORT PACKET HEADER, Golay (24,12,8) coded
PACKET DATA 1
…
PACKET DATA N

Figure 4 - Transport Packet Structure

The_size of the Transport Packet Header is 24 bits, and coded as 2 x 12 bit parts on a 2 x 24-bit Golay (24,12,8) code word. The Transport Packet Header consists of: Transport Packet Flags and the Transport Packet Content Identifier, an indicator as to which portion of a C10 packet is contained (whole, beginning, middle, or end).

In order to protect the C10 Headers from telemetry downlink errors, it is also necessary to protect the most structure sensitive parts of the C10 headers. The same Golay (24,12,8) coding is used. The first 12 bytes of the header are replaced with the structure critical

Channel ID, Data Length and Packet Length fields. The replacement structure before the Golay coding can be seen in Figure 5.

<table>
<tr><td>11 8</td><td>7 4</td><td>3 0</td></tr>
<tr><td colspan="2">Reserved (0)</td><td>Ch. Id (15..12)</td></tr>
<tr><td colspan="3">Channel Id (11..0)</td></tr>
<tr><td>Packet Trailer Size</td><td colspan="2">Data Length (18..12)</td></tr>
<tr><td colspan="3">Data Length (11..0)</td></tr>
</table>

Figure 5 - Protecting the Chapter 10 Header

Randomization and Error Correction are optional. The Forward Randomization defined by the IRIG 106 standard was evaluated versus the Additive Randomization technique defined in CCSDS. It was decided to choose the CCSDS additive randomization technique due to the fact that errors with additive randomization do not propagate and increase the bit error rate for isolated bit errors.

Three randomization and error correction methods are supported: no error correction, 223-to-255 byte, and splitting into 5 x 223 byte blocks, each block extended by 5 x 32 CRC bytes Reed Solomon error correction. 5 Reed-Solomon block structure has been chosen, and interleaving between blocks is also applied during the transmission.

BLOCK1	223 DATA BYTES
CRC1	32 BYTE CHECKSUM
BLOCK2	223 DATA BYTES
CRC2	32 BYTE CHECKSUM
BLOCK3	223 DATA BYTES
CRC3	32 BYTE CHECKSUM
BLOCK4	223 DATA BYTES
CRC4	32 BYTE CHECKSUM
BLOCK5	223 DATA BYTES
CRC5	32 BYTE CHECKSUM

Figure 6 - Reed-Solomon Error Correction

4. Performance Considerations

For legacy PCM data transmission, the transmitters, antennas, and receivers are chosen to at least achieve a maximum of 1 error in 10^6 bits. Under normal operations, the entire link will provide better performance than 10^{-6} BER except in conditions where antenna masking occurs or the test item is in a high multipath environment. The C10 TMDL has been tested against a number of dropout conditions such as multipath/fading, burst errors, and random bit errors characteristic of a low link margin. A starting point benchmark established was; how well does C10 TMDL operate versus PCM with the same modulation technique (FM). Data was compared for PCM FM transmission of a PRN code PCM stream versus the same PCM PRN stream being transmitted over a C10 TMDL link. Analysis indicated that C10 TMDL provided bit error rate performance commensurate with PCM FM data under the same RF conditions.

It was discovered that for bit error occurrence more often than 10^{-6} (such as 10^{-5} or 10^{-4}), data sources such as HD video degrade due to the propagation of the errors in the compressed video stream. Other packets affected at high bit error rates are large packets such as high speed Ethernet. Since mission conditions may limit ability to achieve 10^{-6} consistently during a mission; the option to utilize Reed Solomon error correction was added to maintain performance in high bit error rate conditions.

Latency may be a critical performance factor. C10 TMDL is not suitable for supporting every mission scenario. For tests such as missile, aircraft flutter, and aircraft loads, where microsecond latency is mandatory due to range personnel, or equipment safety concerns, immediate time sampling of a PCM encoder is suitable.

With that said, there are a large number of missions involving fixed and rotary wing aircraft and ground vehicle testing that do not require minimized reaction time from the mission controller or safety officers. For these mission types, C10 TMDL is ideally suited.

The latency of the C10 TMDL is determined by a number of factors. The first factor is how long a C10 packet is opened during data acquisition. C10 mandates that the packet be closed within 100 milliseconds. If the data is used for C10 TMDL, it is mandatory to close the packets out early in order to achieve a total airborne latency in the range of 30 to 100 milliseconds.

The longest latency data source is compressed video. Since compression takes an appreciable time period, the compression encoder dictates the overall latency of the output. For most other data types such as PCM, Ethernet, MIL-STD-1553, ARINC 429, discretes, and analog data, the DAU can be optimized to minimize latency.

In order to support the transmission of latency critical data and non-latency critical data sources, a latency critical bit is included in the architecture. Setup of the DAU recognizes that a specific C10 packet is latency critical and the DAU prioritizes that packet in a completely different way than if it was a non-latency critical channel. Latency critical packets are kept open for a short time only (approximately 10 to 20 milliseconds) and latency critical stuffing of the channel into the C10 TMDL stream is utilized.

With little or no optimization 10 to 50 millisecond latency is achievable from the time the data was received to the output of the data into C10 TMDL stream.

One critical low latency data type is hot microphone cockpit audio. Hot microphones are necessary to free up pilots hands and eliminate pilot keying of the radio for continuous air to ground radio transmissions. In the aircraft, the ground controller audio is broadcast to the cockpit. Since the ground controller voice, merged with other cockpit communications, is broadcast to the pilot, a byproduct of the hot microphone can be that the ground controller audio is retransmitted back to the ground control room. The ground controller can then hear a delayed replication of their own voice. If the round trip delay is greater than approximately 100 milliseconds, the delayed audio feedback can be very disruptive to the controller. Feedback in the range of 30 milliseconds or less is not discernible.

A further performance consideration is filtering of data to fit all data within the allocated bandwidth of the down link PCM stream. Typically, a recorder captures all data and writes all data to a C10 disk file. Frequently, the bandwidth of all data channels will exceed the available C10 TMDL bandwidth. Data management is necessary to filter data and measurements to be within the bounds of the allocated C10 TMDL bit rate. In order to achieve this, filtering of each data type is sometimes necessary. This task is analogous to determining the time sampling schema for a PCM stream. For the most prevalent data type, such as PCM, it is possible to perform minor frame word extraction from the externally received PCM stream to eliminate all PCM words not required for real-time ground viewing and to create a lower bit rate stream containing only data of interest. Using this method is ideal because the timing for the parameters is unmodified. Since they are Minor Frame Data Words, the word occurrence rate in the filtered PCM stream is effectively equal to the occurrence in the unfiltered PCM stream

Figure 7 - Filtered PCM Stream

For Data Types such as MIL-STD-1553, ARINC 429, and Ethernet, entire messages or words from the messages can be extracted. For video, compressed High Definition (HD) video can either be converted to standard definition (SD) or follow on sampling of the compressed video can be applied.

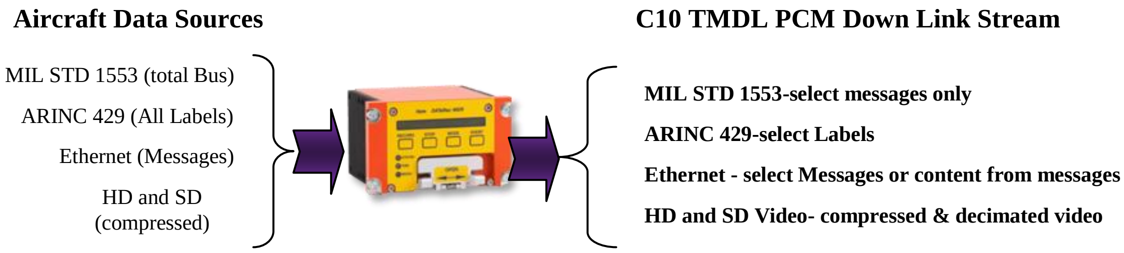

Figure 8 - Channel Filtering

5. Operational Aspects

As mentioned earlier stuffing of the more advanced data types such as HD video and Ethernet data into a fixed position in a PCM stream can be a tedious operation. Asynchronous data such as Ethernet, Asynchronous RS-232 and 422, MIL-STD-1553, and other high speed data channels such as 1394B and Fiber channel are better suited to transmit air to ground over an asynchronous data pipe since the data is an asynchronous source. A message is inserted into the C10 TMDL stream only when a message arrives at the airborne gateway (encoder, recorder, or DAU).

The building up of the C10 TMDL stream is simple compared to building a PCM format. Both processes require knowledge of the approximate rate and quantity of data for each channel. If the data rate is low such as ARINC 429, the entire channel can be sent without having to perform label filtering. The instrumentation engineer determines the available TM PCM stream maximum bandwidth, and then identifies which channels of data are required.

The final step is to determine what filtering should be applied to the data so the aggregate sum of all data is slightly less than the available C10 TMDL stream bandwidth. The gateway provides information to confirm the date rates are within the C10 TMDL aggregate stream rate and the status of each data source is provided to establish total confidence in the content of the individual channels.

One beauty of the C10 TMDL is the receiving side. There is no tedious testing required to verify specific measurements are in the correct PCM word locations and are being sampled at the correct rate. In an ideal situation, for each C10 TMDL measurement, the entire data for that measurement is transmitted. If not, verification of the integrity of the data after filtering, that analog data is scaled correctly and that C10 channel IDs are from the correct data sources is required.

Another feature of the C10 TMDL is that it is very simple to change the C10 TMDL output on the fly by enabling and disabling only the channels dedicated to the C10 TMDL. Another attractive feature of the C10 TMDL is the ability to receive an external PCM stream or Ethernet stream and transmit them to the ground merged with all other data sources in the gateway, for example, when the existing airborne pallet has a single PCM TM down link.

For a project that requires adding multiple HD videos, but the encoder does not handle them, C10 TMDL is an attractive solution. Instead of buying an HD video module card for both the recorder and encoder, only purchase one for the recorder and use the recorder C10 TMDL output to drive the transmitters.

Normally, the external PCM is already connected to a recorder input, thus with one change in the clock and data lines, HD video is merged with the existing IRIG chapter 4, PCM stream.

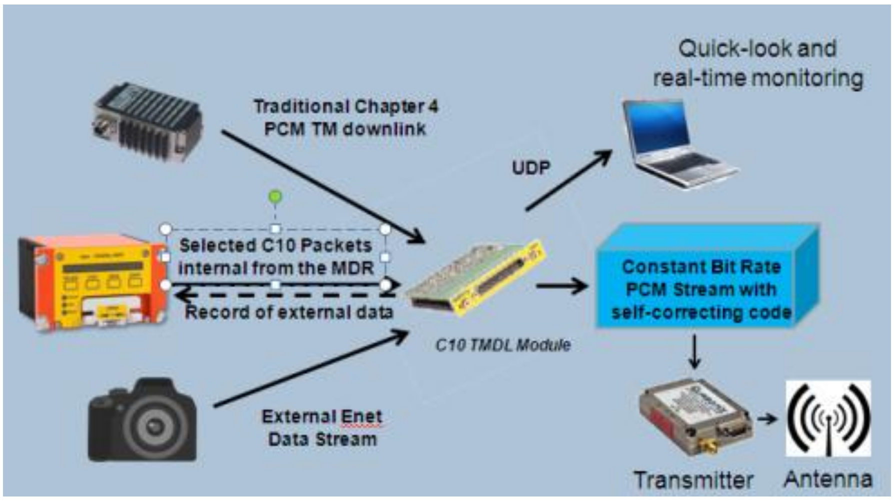

Figure 9 - Merging of External PCM and Ethernet into C10 TMDL Stream

6. Ground System

For now, a hardware box is utilized to recover the data from a C10 TMDL stream and to reproduce the signals back into native format such as externally received PCM, externally received Ethernet, Video, and analog/voice signals (HOT MIC).

A C10 .PUBLISH live data stream is produced for network based data distribution and software based processing. The network addresses are defined for the ground segment and applied to the C10 UDP live stream output. Thus, the network output can be compatible with all ground facility networks.

The following diagram illustrates the ground segment architecture.

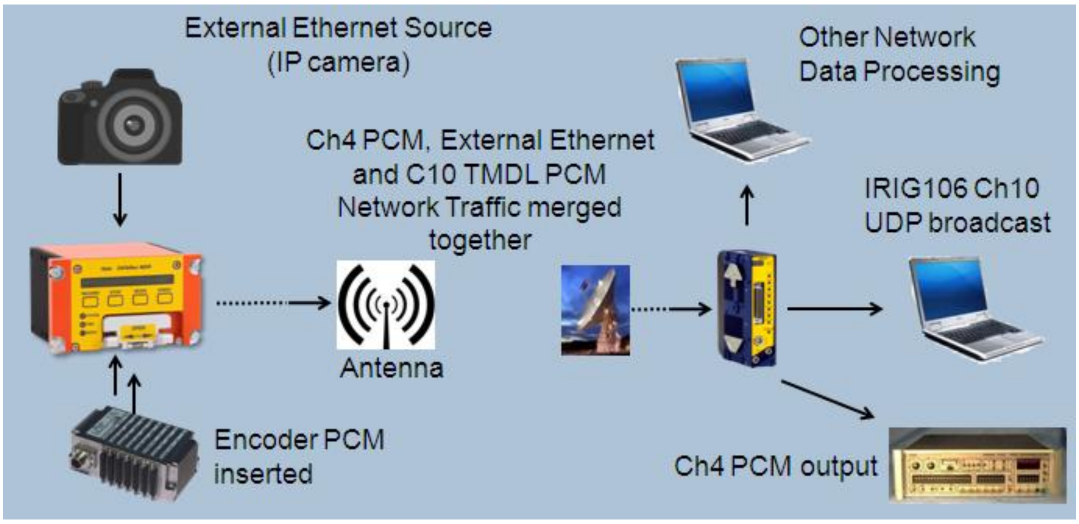

Figure 10 - Ground Reproducing

A very interesting application is for TM Decom vendors to incorporate the C10 TMDL into their system. This would enable data to be handled exactly like a typical PCM data source. The C10 TMDL stream would plug directly into the decom and it would process the PCM in its Front END and distribute C10 Packets to other entities monitoring or viewing the real-time data.

In addition, other applications such as MIL-STD-1553 Bus Analysis systems are incorporating C10 network streaming into their packages. This enables instrumentation engineers to look directly at the 1553 in real-time without actually connecting to the bus or the aircraft.

7. Conclusion

Investment and build up of applications around the IRIG Chapter 10 Standard for both the ground and air segment is extensive. The C10 live network data streaming is ideal for plane side quick look and real time mission monitoring. The ability to extend the C10 network data streaming using a PCM stream provides real-time connectivity to all of the C10 based software applications on the ground. It provides a great method to multiplex existing PCM streams with data sources such as high definition video. It also simplifies the airborne instrumentation task of setting up for a mission and virtually eliminates tedious testing on the ground mission monitoring side. It provides extensive flexibility to make on-the-fly changes of the data channels being down linked.

On the ground side the data sources can be reconstructed back to the native data type such as video. Due to the ease of mission setup, integrity of the data, compatibility with new high speed data types such as HD video and serial interfaces, C10 TMDL has the possibility to establish itself as a viable alternative method to downlink data.

The C10 TMDL system was introduced to the IRIG committee developing the telemetry standards at ITC 2012 and it was well received. It appears that some version of the C10 TMDL will be standardized in the near future. It is also anticipated that TM Decom providers as well as other test utility vendors will incorporate the reception of C10 TMDL as an interface. The possibilities for C10 TMDL are limitless.

8. References

[1]"Consultative Committee for Space Data Systems, Packet Telemetry", CCSDS 102.0-B-5, Blue Book November 2000.
[2]"Telemetry Standards, IRIG Standard 106-11 (Part 1)", Chapter 4, June 2011
[3]"Wikipedia, The Free Encyclopedia", from the Internet, Binary Golay Code