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Implementing Tmns Data on Demand

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Abstract

The Telemetry Network Standard (TmNS) was released as part of the 2017 version of the IRIG-106 standards. Traditionally, serial streaming telemetry data has been sent on a unidirectional link from the test article to the ground. The TmNS standard offers a new approach to acquiring flight test instrumentation (FTI) data that changes this paradigm by allowing the use of bi-directional data links. These bi-directional links allow for commands and requests to come from the ground back to the aircraft. This offers a new capability to the flight test community to request data on demand from the flight test recorder.

One of the longest-standing problems with traditional telemetry has been data dropouts. These gaps in the flight test data can occur at any point in a test flight, and they can prevent the ground controllers from knowing if a test was successfully completed. TmNS offers a solution to this problem by allowing the ground to request a PCM backfill to re-send the section of the data that was lost. This paper explores a fully functional demonstration system that Curtiss-Wright has created to show an end-to-end PCM backfill operation using a TmNS compliant recorder, two TmNS radios, and the IADS real-time visualization and analysis software.

Key words: TmNS, Data On Demand, PCM Backfill, Transceiver

Introduction

Pulse code modulation (PCM) telemetry has been the foundation of the flight test industry for over 50 years. PCM telemetry, however, has imperfect RF performance, resulting in flawed real-time data on the ground. This inadequate data still facilitates much-needed real-time data services, such as safety of flight, but limits the amount of data analysis tasks that can be performed in real-time.

Over the years, many technological methodologies have been used to either identify or limit the frequency of the data dropouts caused by PCM RF telemetry. Some key examples are:

1. Checksum/CRC checks
    a. Efficient at detecting bit errors, so bad data is not processed
    b. Provides no ability to correct for those errors
2. Forward error correction
    a. Variety of different algorithms, each with their advantages and tradeoffs
    b. Generally, incurs a high amount of overhead on a bitstream

In this paper, a system is presented showing how to achieve near-perfect data quality on the ground in a real-time operational scenario. This system uses approaches defined in the IRIG-106 Telemetry Network Standard (TmNS) set of standards, namely PCM backfill, using commercial off-the-shelf (COTS) hardware and software supplied by Curtiss-Wright, all of which are available today.

System Architecture

The demonstration system consists of several Curtiss-Wright products:

MnACQ-2600 – A data acquisition unit (DAU) that outputs a TmNS compliant Ethernet stream of data and a PCM output. The data contained in the TmNS Ethernet Stream and the IRIG-106 Chapter 4 PCM output is the same.

NSW-12GT-1 – A network switch capable of statically and dynamically routing data from multiple network elements.

nREC-4000S-3 – A TmNS compliant recorder that can respond to data on-demand requests from other hardware/software for actively recording TmNS data files.

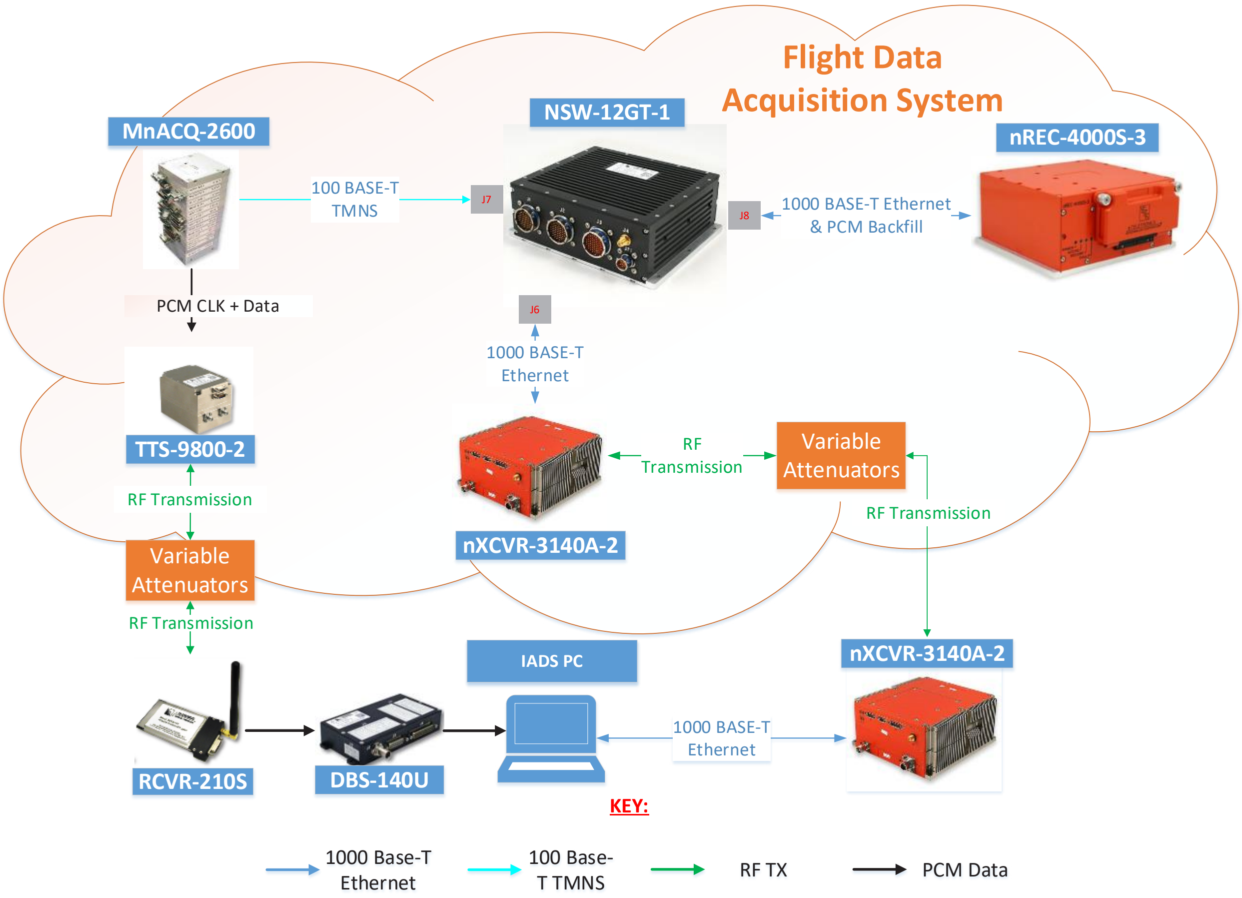


Fig. 1. System Architecture Diagram

nXCVR-3140A-2 – A TmNS compliant radio, allowing bi-directional communication between ground and air installations.

TTS-9800-2 – An IRIG-106 Chapter 2 compliant PCM transmitter with tri-band support for S, L, and C RF frequency bands.

RCVR-210S – A receiver/bit sync module that can demodulate RF transmitted PCM data and recover the bit clock.

DBS-140U – A 40 Mbps USB 2.0 Bit Sync/Decom that parses an IRIG-106 Chapter 4 PCM stream and passes the data to ground station software for display and analysis.

IADS – Industry-leading ground station software to process and display a variety of different flight test inputs.

Variable Attenuator – An RF attenuator that can vary the amount of RF attenuation.

System Theory of Operation
In this system, the data originates at the MnACQ-2600 and follows two paths: the Ethernet recording path and the IRIG-106 Chapter 4 PCM transmission path. The Ethernet recording path is where the MnACQ-2600 outputs IRIG-106 Chapter 24 TmNS packets, routed through the 12-port switch, to the nREC-4000S-3, which is actively recording the data, as if a flight test is occurring.

The IRIG-106 Chapter 4 PCM transmission path takes the same data payload in the IRIG-106 Chapter 24 TmNS packets and outputs that data as an IRIG-106 Chapter 4 PCM output. The IRIG-106 Chapter 4 PCM output is connected to the TTS-9800-2, which modulates the data in L-band, S-band, or C-band with an SOQPSK modulation. In a typical flight test application, the TTS-9800-2's RF output would be wired to an antenna for RF transmission over variable distances during the flight test to be received at a ground station.

To demonstrate the system at the ITC 2021 show, the TTS-9800-2 will transmit the IRIG-106 Chapter 4 PCM data. We will then use RF coaxial cabling and multiple attenuators to simulate the distance between the transmitting and receiving antennas. This will also lower the overall power level to an acceptable level for the RCVR-210S receiver. A variable attenuator is also included in the multiple attenuators to have the ability to degrade the RF power level from a functional power level to a marginal power level to a non-functional level.

The RCVR-210S receives the RF coaxial cable after the attenuation and de-modulates and bit-syncs the signal to recover the clock and data and input it to the DBS-140U decom.

The DBS-140U will receive the recovered clock and data signals and decom the IRIG-106 Chapter 4 PCM minor/major frames. This consists of checking for a Sync Pattern every X number of bits and, if applicable, a Sub-Frame ID (SFID) at a particular word location in the PCM minor frame. If, for some reason, the Sync Pattern is not found every X number of bits or an incorrect SFID is found, the frame will be discarded and the decom will enter a search mode, where it checks for the Sync Pattern anywhere in the data stream. Once a match is found, it will check the match by advancing X number of bits and verifying that the Sync Pattern is found in the expected location. Once this happens, the decom will enter a lock state and begin passing frames to the software once again.

IADS will then receive the PCM frames and extract parameter data for viewing in real-time displays, such as strip charts.

To facilitate a bi-directional connection from the ground PC to the airborne recorder, the system contains a pair of nXCVR-3140A-2 transceivers. These transceivers are capable of wirelessly transmitting and receiving Ethernet packets. One of the nXCVR-3140-2 transceivers, which we will refer to as the ground transceiver, is connected to an Ethernet port on the PC that is running IADS. In a real-world system, this transceiver would connect wirelessly to the airborne transceiver on board the test vehicle, but in the demonstration system, the ground nXCVR-3140A-2's RF connection is passed through attenuators to simulate transmission distances and attenuate the RF power. The other end of the RF connection connects to the airborne nXCVR-3140A-2. The airborne nXCVR-3140A-2 has an Ethernet connection to the NSW-12GT-1, allowing Ethernet packets to flow to and from the airborne network.

The nXCVR-3140A-2 transceivers differ from traditional PCM transmitters in the following key ways:

1. The nXCVR-3140A-2 transceivers transmit Ethernet packets, whereas the TTS-9800-2 transmitter transmits a PCM bitstream.
2. The nXCVR-3140A-2 transceivers can transmit data to and from the ground, creating a bi-directional link from the air to the ground. Traditional PCM transmitters can only telemeter data from air to the ground. The ground does not have a way to communicate back to the air.
3. Multiple nXCVR-3140A-2s can use the same RF spectrum to transmit data. This is done via a shared schedule between groups of nXCVR-3140A-2s, which allocate transmit and receive time for each transceiver.
4. The nXCVR-3140A-2s utilize burst mode SOQPSK modulation, which is a modulation scheme that is only present when data needs to be transmitted. Traditional PCM telemetry does not use burst mode modulation schemes, so conventional transmitters cannot transmit on the same RF spectrum.

It is important to note that there is no data flowing through the nXCVR-3140A-2 links for this demonstration. The bidirectional link will be utilized only when needed by the IADS software to fill in missing data.

We will use adjustable attenuation on the RF links in order to simulate data dropouts. At baseline, with little attenuation between the TTS-9800-2 transmitter and the RF receiver, IADS will be able to process and display parameters with no data loss. The processed parameters are displayed as normally done with traditional PCM telemetry. To simulate the RF dropouts from normal over the air PCM telemetry, we will raise the attenuation between the TTS-9800-2 transmitter and RF receiver. This will result in a state of marginal performance where good PCM frames will be passed to IADS along with a mixture of missing frames and/or frames with bit errors.

The IADS software has the responsibility of doing the following tasks in this scenario:

1. Detecting problematic PCM frames:
    a. Missing PCM frames.
    b. PCM frames with bit errors.

2. Sending low latency TmNS data requests to the nREC-4000S-3 when it detects erroneous or missing frames.
3. Receiving the requested frames from the nREC-4000S-3.
4. Replacing the missing or bad PCM frames in the PCM telemetry stream with the nREC-4000S-3 frames.
5. Processing the new PCM telemetry stream with the "PCM backfill" frames to make an error-free data presentation of all parameters in the PCM telemetry.

Detection and Retrieval of Problematic PCM Frames

There are several requirements that the PCM telemetry frame must meet to allow IADS to detect problematic PCM frames. For a major frame with multiple minor frames, a SFID is necessary. Combined with the Sync Pattern, a SFID allows IADS to uniquely identify each PCM minor frame. This also provides IADS with the ability to identify missing PCM minor frames by detecting cases where the SFID value skips one or more expected values. However, this will not allow IADS to detect larger chunks of missing data, such as multiple missing major frames.

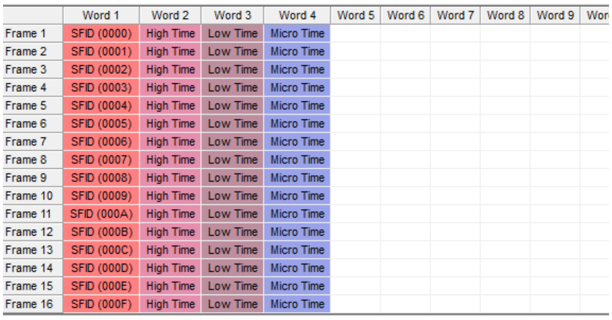
To detect larger chunks of missing data, the PCM frame must include an embedded 48-bit IRIG time stamp that resolves time since the beginning of the current year with microsecond resolution. Since PCM telemetry is a synchronous continuous bitstream, every minor frame represents a fixed amount of time. In the event where multiple major frames are missing, it is possible to calculate how many frames are missing from the following information:

1. By knowing the length of the PCM telemetry frame in bits and combining this with the stream's bit rate, we can calculate the time per minor frame.
2. The start time for the TmNS data request is set by storing the last good timestamp that was received before a series of bad/missing PCM frames. The end time for the TmNS data request is set by the most recently received PCM frame's time or, in the case where the programmable timeout period of bad/missing PCM frames is met, the current time in the decom. The subtraction of the end time from the beginning time gives us the amount of time without PCM telemetry.
3. By dividing the amount of time without PCM telemetry by the known PCM telemetry frame time, we can arrive at the number of minor frames missing from the time interval.

So far, we have only addressed how to detect missing PCM frames of varying sizes in a real-time PCM telemetry stream coming from a decom. We have not addressed how to detect bit errors in the individual PCM frames. Bit errors are a common scenario in PCM RF transmission. It should be noted that bit errors present in either the SFID or the Sync Pattern are expected to be dropped at the DBS-140U decom, as they will not pass the frame check sequence. This means that errors in the SFID or Sync Pattern will appear to IADS as a time gap rather than a bit error. Bit errors that occur within the PCM frame data, but otherwise have good SFID and Sync patterns, are not detectable via the DBS-140U decom.

To detect the case where bit errors are present in a PCM frame without errors in both SFID and Sync pattern, a 16-bit CRC is calculated by the MnACQ-2600 and inserted into the data in every minor frame. This CRC is calculated between each pair of CRC samples, and the resulting calculated CRC value is inserted into the PCM data. When IADS receives the PCM telemetry data, it will calculate the CRC value on the received PCM frame and compare it to the CRC value stored in the PCM frame. If the CRC values are the same, no bit errors have occurred in the PCM frame, and IADS can safely assume all bits are correct in the frame. If the CRC values are different, IADS knows that one or more bit errors have occurred in the minor frame and should be thrown away.

Please note that, in a 16 bit CRC, there is a 1 in 65536, or roughly 0.0015%, chance that a frame with a bit error in it will have the same calculated CRC value as the original calculated CRC value from the MnACQ-2600. This risk is deemed acceptable for this demonstration system. If this risk does not meet operational requirements, longer CRCs (such as 32-bit or 64-bit) could be implemented in the hardware and IADS to mitigate this risk.



	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6	Word 7	Word 8	Word 9	Wor
Frame 1	SFID (0000)	High Time	Low Time	Micro Time						
Frame 2	SFID (0001)	High Time	Low Time	Micro Time						
Frame 3	SFID (0002)	High Time	Low Time	Micro Time						
Frame 4	SFID (0003)	High Time	Low Time	Micro Time						
Frame 5	SFID (0004)	High Time	Low Time	Micro Time						
Frame 6	SFID (0005)	High Time	Low Time	Micro Time						
Frame 7	SFID (0006)	High Time	Low Time	Micro Time						
Frame 8	SFID (0007)	High Time	Low Time	Micro Time						
Frame 9	SFID (0008)	High Time	Low Time	Micro Time						
Frame 10	SFID (0009)	High Time	Low Time	Micro Time						
Frame 11	SFID (000A)	High Time	Low Time	Micro Time						
Frame 12	SFID (000B)	High Time	Low Time	Micro Time						
Frame 13	SFID (000C)	High Time	Low Time	Micro Time						
Frame 14	SFID (000D)	High Time	Low Time	Micro Time						
Frame 15	SFID (000E)	High Time	Low Time	Micro Time						
Frame 16	SFID (000F)	High Time	Low Time	Micro Time						

Fig. 2. Sample PCM Format With SFID, Time Words, and CRC

When IADS detects a missing or bad CRC frame, it is thrown away, and the time of the bad or missing frame is calculated from the last good frame's time and saved in memory. IADS will then wait until it receives an error-free frame or a timeout period has expired. At that point, IADS will determine the end time for the event.

In TmNS, each data channel is identified by a unique ID called the Measurement Definition ID, which is formed at the TmNS Data source, the MnACQ-2600 in this demonstration. IADS will create a TmNS data request, which requests a stream of TmNS data identified by the channel's MDID and the start and stop times for the missing PCM telemetry frames. The TmNS data request is then sent via Ethernet, through the ground nXCVR-3140A-2 to the airborne nXCVR-3140A-2, then through the NSW-12GT to the nREC-4000S-3.

The nREC-4000S-3 is anticipated to be in an active recording session, recording data from the MnACQ-2600 (and in a practical application, many other DAUs) when the TmNS data request is received. The nREC-4000S-3 parses the TmNS data request and searches all recordings, including the active recording, for the specific stream's MDID identifier as well as start and end times of interests.

Once the nREC-4000S-3 finds the data of interest from the TmNS data request, it streams a TmNS data response back to the IADS PC through the transceiver network. The IADS PC then receives and parses the TmNS data response from the nREC-4000S-3. IADS will then fill in the bad and missing frames with the error-free frames from the nREC-4000S-3. The now error-free data can then be updated in every real-time display in IADS, such as the strip chart.

The result of this system is an error-free data presentation of the PCM telemetry. This is made possible by utilizing the unique TmNS capabilities of the nXCVR-3140A-2 and nREC-4000S-3 hardware, integrated with the IADS real-time telemetry software.

As an example, Figure 3 shows two IADS strip chart displays of the same parameter from a PCM telemetry stream. The left strip chart is experiencing RF disturbances and has errors in the data, while the right strip chart has been corrected using the PCM backfill process, and it shows perfect sine wave data.

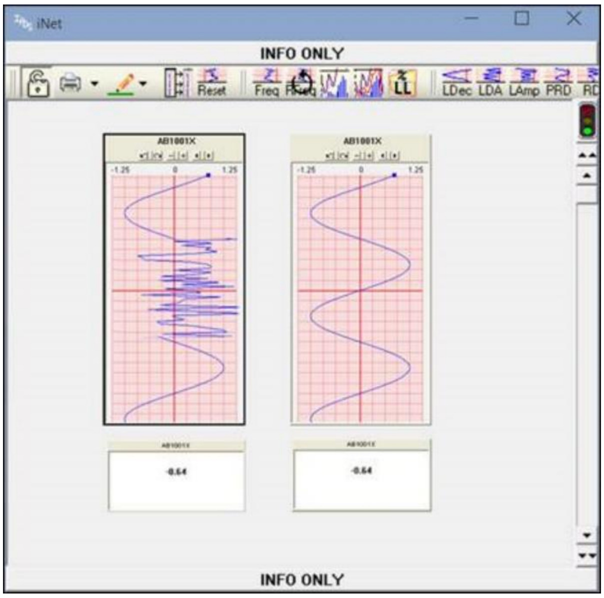


Fig. 3. PCM strip chart example of a parameter with and without the PCM backfill functionality

Additional System Considerations

A cost of this error-free data presentation using this PCM backfill process will be some amount of additional latency in all PCM telemetry data. IADS needs to reserve extra time to detect, formulate, send the TmNS data request, receive the TmNS data response from the aircraft with the missing/bad PCM telemetry frames, and fill them into the original PCM stream before IADS sends the PCM telemetry data to the screen for the analysts to view.

This latency will be variable, based on several different factors:

1. Size of the PCM telemetry minor frame.
    a. Larger minor frames will take longer to transmit to the ground if errors are found in them.

This document was reviewed on April 27, 2022 and does not contain technical data.

2. Length of IADS timeout period before requesting TmNS frames.
    a. If several PCM frames are erroneous in a row, IADS will keep track of a maximum wait time or number of frames before sending the TmNS data request.
    b. This maximum wait time will also add to latency. The latency that is added is a tradeoff between the transceiver bandwidth utilization and the available processor power on the nREC-4000S-3.
3. The overall schedule of the nXCVR-3140A-2 network.
    a. The schedule of the nXCVR-3140A-2 network defines how often each nXCVR-3140A-2 in the entire RF network has an available time slice to transmit data.
    b. A "worst-case" latency can be calculated based on the transmit and receive schedules of the overall nXCVR-3140A-2 network.
4. The time between receiving the TmNS data request and transmitting the TmNS data response from the nREC-4000S-3.
    a. This is a processer dependent operation and could be variable based on several factors of the nREC-4000S-3, including:
        i. How many files are on the nREC-4000S-3
        ii. How much data is stored on the media
        iii. How large or small the TmNS data request for data is
        iv. How large or small the TmNS data response is (this will be related to the size of the TmNS data request)

This variable latency will drive a configurable latency model in IADS. The user can select how long to delay the PCM telemetry data before sending the data to a display. For this demonstration, the latency will be determined empirically. It is predicted not to exceed 150 milliseconds.

It is also possible that the nXCVR-3140A-2 will have an RF transmission issue, similar to those found in the original PCM telemetry. Some factors which mitigate this potential issue are:

1. The nXCVR-3140A-2 link is only utilized when there is a problem receiving RF PCM telemetry, leaving its predicted utilization far less than that of the RF PCM telemetry.
    a. Less utilization leaves fewer opportunities for issues in the transmission and receiving of this data to occur.
2. Robust RF performance with 20 Watts of RF power and a -86 dBm typical receiver sensitivity.
3. The nXCVR-3140A-2 transmits RF MAC frames, which consist of LDPC code blocks, which the receiving nXCVR-3140A-2 can automatically correct.
4. IADS can build a similar detection and re-request process if there are issues with receiving the TmNS data response frames from the nREC-4000S-3 through the nXCVR-3140A-2 radio links at the expense of additional latency.

Overall Benefits of Pcm Backfill Model

Once a well-understood and acceptable end-to-end latency model is in place between IADS and the rest of the ground/airborne network, data anomalies from traditional RF PCM telemetry can be significantly reduced or eliminated entirely. This enhancement is envisioned to provide significant value to control rooms viewing the real-time PCM RF telemetry and, thus, to flight test programs.

By utilizing a "request and backfill data only when needed" model of PCM backfill and the nXCVR-3140A-2's burst mode SOQPSK modulation, enhanced data quality can be achieved with a spectrum efficient approach using a primary PCM RF link along with limited utilization of the nXCVR-3140A-2's bi-directional RF network.

Because of the nXCVR-3140A-2's burst mode SOQPSK modulation, many nXCVR-3140A-2s can utilize the same spectrum and "take turns" when to transmit/receive data via their schedules. Also, because this service is envisioned to be used only in the infrequent cases when needed, multiple flight test programs and multiple control rooms can utilize a single ground network to communicate with a network of airborne nXCVR-3140A-2s on multiple aircraft. This saves bandwidth and cost compared to each flight test program having its own airborne and ground hardware. Since all the nXCVR-3140A-2 in the RF network need to be programmed with the same schedule, this will drive the need for enhanced inter-program communication and management. However, with this cost comes a benefit for all flight test programs: enhanced data quality with a shared ground service model, reducing cost and improving data quality with minimal additional spectrum consumed.

This better data quality can allow more analysis tasks that need high data quality to happen in real-time in the control rooms. Previously, these tasks could only be done via the flight recordings. An example of this would be a power spectral density (PSD) analysis, which relies on a Fast Fourier Transform (FFT) as a primary mathematical computation of the analysis. When an FFT computation has incorrect or missing samples in its data set, the data result becomes skewed/incorrect. However, with the added confidence of perfect data and the combination of IADS real-time archival and retrieval capabilities, it is possible to produce near real-time PSD plots that can be trusted to make decisions. Decisions like whether a given test point is passed or potentially if it needs to be re-flown while the aircraft is still in-flight.

This also can drive flight test programs to use their PCM bandwidth differently than they do today. Generally, the telemetered PCM format contains a subset of the data that is collected by the onboard instrumentation system due to RF spectrum bandwidth limitations. Thanks to the PCM backfill feature, it is possible to guarantee excellent data quality over the telemetry link. This means that the flight test engineers can skew the data included in the PCM format towards analysis-based tasks and reduce the amount of purely informational data.

The ultimate result of this feature will hopefully be the ability to accomplish more test points per flight while simultaneously shrinking the amount of time required for data processing of flight test data. It allows the end-users to have a trusted set of data available to start data analysis while the aircraft is still in the air.

Conclusion

Increased performance in flight test programs is best achieved by finding ways to move the industry forward through technological innovation, enhanced system integration, and feature-rich functionality exceeding ordinary operational requirements.

Curtiss-Wright believes that the PCM backfill capability that is made possible by our implementation of the TmNS standard across our product line will help to further this goal by moving the industry forward. It will empower engineers to walk away with “clean” data without having to re-fly “noisy” test points or wait for post-flight data processing. Most important, PCM data backfill is the gateway to many other future innovations thanks to the unique abilities that the TmNS transceivers provide for low latency, spectrum efficient, Ethernet-based communication with airborne instrumentation networks while in flight.

In partnership with the IRIG-106 TmNS standards, Curtiss-Wright believes that this will lead to an increase in the number of test points that are successfully accomplished in a single mission. This will reduce flight test schedules and enable the flight test industry to do more in less time than ever before. All stakeholders in a flight test program will benefit from this. PCM backfill is only the beginning of the added value created from the integration activity of making the ground and air systems operate as one.

References

[1] Telemetry Standard, Range Commanders Council Document IRIG-106-19, Chapters 4, 21, 22, 23, 24, 25, 26, 27, and 28, July 2019.