iPCM TELEMETRY SYSTEM

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ABSTRACT

The execution of experimental Flight Test Campaign (FTC) provides all information required for the aircraft development, operation and certification. Typically the execution of a FTC encompasses three major systems as follows: Flight Test Instrumentation System (FTI) that is basically a measurement system; Real-Time Telemetry Link (RTL); and Ground Telemetry System (GTS). At the early days, for the development of small aircrafts (i.e. Fighter), the primary source for FTI data was provided by the RTL due to inherent limitations of the open reel airborne data recorders (i.e. media and size), operating under high-dynamics condition. Nowadays with the introduction of solid-state data recording devices, data integrity and reliability is no longer an issue. At the ITC 2010 Blue Ribbon Panel, Mr. Thomas Beard, the executive Director of the Air Force Flight Test Center in Edwards Air Force Base emphasized the need to reduce refly and to improve FTC efficiency. Such statement imposes a new paradigm in Telemetry, which is to improve RTL integrity and reliability level equivalent to the solid-state data recording devices. Therefore the Telemetry community will be able to execute test point validation for refly reduction and quasi real-time data reduction analysis for efficiency improvement. The major solutions that address such issue are Spatial Diversity (SD) architectures and the iNet. The SD solution requires multiple antenna system (which is very expensive) that could still produce ineffective results at high-dynamics test points (e.g. Spin). At the beginning the iNet consortium proposed the usage of TCP protocol for data transmission. Problems associated with TCP limitations such as data latency and overhead lead to the usage of UDP protocol that does not guarantee the packet delivery. To properly address these issues the IPEV R&D group proposes the iPCM Telemetry architecture to be used as RTL. The iPCM uses hybrid architecture for data transmission taking the advantage of legacy digital transmitters combined with iNet-based transceivers to retrieve missing data. The development and the evaluation of iPCM architecture will be executed as a PhD Thesis in ITA University. The expected performance and benefits of iPCM are presented and discussed.

KEY WORDS

Flight Tests, Telemetry, Data Link, iNET.

1. INTRODUCTION

Based on two major principles: flight safety and data analysis efficiency, the real time telemetry link is one of the most important tools for the achievement of a successful Flight Test Campaign (FTC).

Nevertheless, over the years the deficiencies of the used protocol for wireless data transmission in the flight test environment become well known. High efficiency versus noise and losses, data reliability versus low efficiency, latency and wideband demands, as well as the signal-to-noise ratio (SNR) degradation on behalf of increased of bandwidth use are some of the trade-offs that should be surpassed with the introduction of innovative technologies (i.e. New paradigms in Telemetry).

In summary the usage of a Real Time Link (RTL) in an experimental FTC, fulfill three basic needs (Figure 1):

1. In the occurrence of a critical failure where the aircraft is lost, the Ground Telemetry System (GTS) is a safe box where all airborne data will be stored. Therefore with this information the engineering staff could investigate the problem and to implement all required corrections to continue the development program;
2. Real-time data converted into Engineering Units (EU) could be continuously monitored in the GTS by the ground crew. Such option is used to avoid the violation of the cleared flight envelope which could eventually result in a critical flight condition (Case 1); and
3. Real time data could be used to validate the test point and to avoid the repetition of expensive flights. Considering that some flights are risky this feature also improves flight safety.

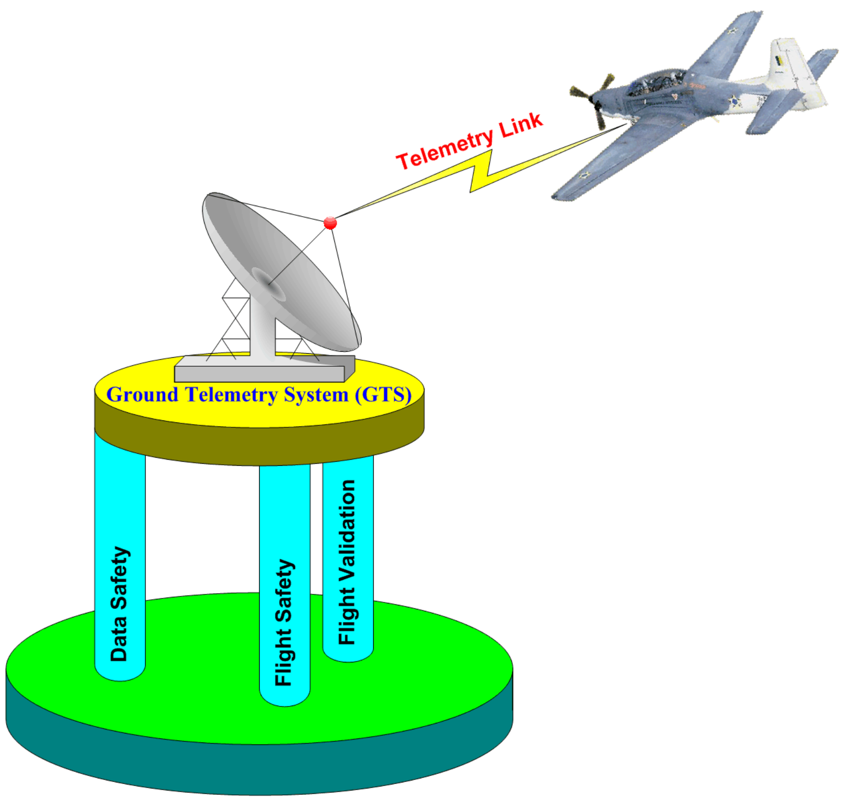

Figure 01 – Telemetry Link Primary Role

Therefore the primary role for the GTS is closely linked to the flight safety. In addition this system could improve the test program efficiency and reduce its costs.

By other hand if we could improve the RTL reliability, it is possible to introduce a new operational scenario where the data reduction analysis could be implemented in a quasi real-time environment and therefore to provide the optimum efficiency solution for a FTC.

These inherent link issues can be surpassed when performing tests on large aircraft, where it is possible to have a full flight test crew on board to perform the flight test coordination, data validation and data reduction analysis. In this case, the RTL could have a secondary role.

However, when the test platform is an Unmanned Aerial Vehicle (UAV), guided weapons or fighters, the real time telemetry link is an essential tool to match test safety requirements and to increase its efficiency. Precisely for the mentioned test platforms, the signal quality degradation as well as the abrupt losses of signal is much more evident due to the high dynamics associated with the tests profiles required for the compliance demonstration of the associated certification requirements that are inherent to these prototypes category.

The legacy telemetry based on the IRIG-106 Standard Chapter 4 [1], has lasted for five decades almost with no changes, due to the high efficiency features and low complex architecture of the PCM protocol. Nevertheless, with the advent of the quasi real time tools implementation for data reduction analysis and test point validation, in conjunction with the high costs of the flight test campaign, the PCM was placed in a check. This happened because the traditional PCM has no methods to recovery lost data after signal quality degradation or signal losses.

Taking into account this boundary conditions novel solutions are proposed. The most discussed architecture is the Integrated Network-Enhanced Telemetry (iNET) [2], based on the Ethernet protocols, aiming the implementation of telemetry networks with wideband wireless capability, high reliability and covering vast areas, similarly to a large computers network. However, the use of Ethernet protocols such as Transport Control Protocol (TCP) [3] and the User Datagram Protocol (UDP) [4] alone is unsatisfactory for achieving the transmission requirements in the flight test environment, as addressed in references [5] and [6].

In view of the facts, the telemetry link in real time also brings big challenges, keeping open the discussion to the study of new technologies that will meet the new flight test community requirements based on the real needs to improve the reliability and the data analysis efficiency.

Focused on these needs, this paper presents an alternative solution that combines the benefits of traditional telemetry using IRIG-106 PCM and a new protocol for data recovery in accordance with the iNET program philosophy concepts. This novel architecture takes the benefits of both solutions and introduces new paradigms for the test community.

2. INTEGRATED NETWORK-ENHANCED TELEMETRY (iNET)

The Integrated Network-Enhanced Telemetry (iNET) was designed with a purpose that goes beyond just solving the problems of reliability in the data transmission and data reception via real time telemetry channel for applications in flight tests. The purpose of The U.S. Defense Department had been to find a feasible way to improve the basic architecture of the real time telemetry link that would be able to increase the capacity of data transmission by controlling dynamically the spectrum required for test and ensuring the full recovery of data by ground station. To aggravate this situation the flight test community is currently loosing the spectrum war all over the world and being limited for narrower bandwidths. In fact the allocation of the new C-Band link for flight tests that could provide lager bandwidths is not really guaranteed. Therefore the benefits of this protocol would not be limited only to applications in flight test campaigns, but also extend to training centers and data acquisition.

The great complexity of the iNET project may have overshadowed the leading need of the T&E (test and evaluation) community which would be to improve the telemetry protocol to ensure data recovery by the ground station and to ensure higher efficiency and safety levels for the execution of flight test, as highlighted by Mr. Thomas Beard, the executive director of the Air Force Flight Test Center in Edwards Air Force Base during ITC 2010 Blue Ribbon Panel. However many studies have been conducted in order to implement the iNET with Ethernet protocols, using a similar philosophy applied in a large computer network.

The main data transmission protocols used in the iNET architecture are TCP and UDP. The TCP provides reliable data-transfer service by defining acknowledgement, congestion control, lost packet retransmission and it have capability to optimize the usage of the available bandwidth. The UDP is simpler than TCP and it does not offer any guarantee or notification of the packet delivery.

At first sight TCP seems to be the most appropriate solution for this issue, but when evaluating the channel considering heterogeneities, congestion, delays, losses in the airborne telemetry environment the conclusion is quite different. By analyzing the TCP protocol some performance issues can be found. Each new TCP session requires a 3-way handshake signalling before any real data is transmitted. In addition and every packet loss is considered by TCP as a result of congestion in the network, for this reason, TCP reduces the congestion window decreasing the transmission rate. According to Nikki Cranley and Diarmuid Corry [7] is possible to prove by simulations of different network topologies that TCP / IP is not the most appropriate method for transmitting data in real time. TCP/IP can be overcome by the UDP in some cases, but the assurance of service (QoS) is still an issue.

In addition to the TCP and UDP, other protocols have been researched but a great number of issues remain to be solved. As well the requirement of the enhanced airborne telemetry capability remains without a final solution.

3. INTEGRATED PULSE CODE MODULATION (iPCM)

There are several paradigms to be recognized in the world of telemetry and one of them is the fact that it is not necessary to use only established network protocols to solve the problems of reliability of the data gathered from the real time telemetry link used in the flight test environment. It is true that protocols such as TCP and UDP are very useful when used in networks, such as on board in a large aircraft. However these protocols, as shown previously, have serious drawbacks when dealing with the transmission of data from a test platform to a ground station via radio spectrum.

One option would still be using the spectral density as a way to increase reliability in data reception. However, during dynamic maneuvers, such as wind up turns and spins, the problem of data losses still persist unanswered. Another very important issue it is the cost`s reduction employing new technologies. Consequently the iPCM comes up as a way to rupture the paradigms of the need to use network protocols to ensure reliability in data transmission and to demonstrate that high investments are not needed to achieve the desired quality standards for the data received from a telemetry channel.

This technology employs standard IRIG-106 PCM and algorithms for data quality and data losses identification, associated at two telemetry channels. The first channel of communication is unilateral. It uses standard IRIG-106 PCM being always active and will be treated as a real time channel (RT). The RT receives data from the platform and it is susceptible to losses and noises inherent of the telemetry channel. The importance of the RT channel is associated with the flight safety, since the delay between transmission and reception is negligible, reducing the time response of the ground crew to alert the pilot with regard to hazardous situations. Therefore this channel is used to supporting the taking of decisions related to flight test.

The second channel, with bilateral communication, also uses PCM as the transport protocol, but this channel is enabled only by the demand generated by the detection of low signal quality or abrupt losses in the RT channel. It establishes the communication with the test platform requesting the data lost return, which are stored in a buffer implemented in the platform. When these data are recovered in the ground station, another algorithm is used to manage them. Thus, the data processed and free of noise received by the RT channel being integrated with the data gathered from the second channel in an orderly manner.

Consequently it is possible to recover the full flight test data and use them in the second channel, which will be treated as a Quasi Real Time channel (QRT). The QRT is used for the validation of the test points and data reduction during the execution of the flight. The possibility of accomplishing these tasks comes aligned with the current trend of to reduce refly through validation in near real time and increase the efficiency of test campaigns through the use of tools for data reduction in near real time, as demonstrated in ITC 2009 for an Air Data System (ADS) calibration flight test campaign [8].

One of the motivations of this work can be described using the test of EMBRAER AMX A-1 during a spin as an example. During the maneuver the performing telemetry can usually lose some pieces of information. At this condition the engineering staff located at GTS is unable to validate the test point without verifying the data collected during the maneuver. Usually in these cases the adopted procedure is to repeat the test point, which adds additional delays to the test campaign and increasing its cost.

Thus the iPCM channel can retrieve such data and make them available, for the test team in the ground station. The additional delay of iPCM including the total data recovering and processing time should be not an issue when taken into consideration the time spent by the pilot to recover the aircraft after the maneuver, reposition in the test area and check the settings for the next test point.

The basic architecture of the iPCM system is composed of (Figure 2):

1. A receiving system (RT CHANNEL) that processes data from the aircraft by RT channel in real time.
2. A workstation that receives these data and processes it using an application called QUALITY of SIGN. This software should detect imperfections in the received data and identify the lost frames, sending this information to other system called QRT CHANNEL and storage the good data in a recorder (RT RECORDER). The application QUALITY of SIGN uses statistical data and prior knowledge of the dynamics of certain groups of parameters to identify noise, spikes and other imperfections of the channel as a whole.
3. The QRT CHANNEL system receives the Frame Lost identification (FliD) and sends a coded message via the PCM to the platform, containing the FLiD values required for the information retrieval. Once the message has received, the iPCM BUFFER system identifies the requested frames and sends it to the ground station via the PCM in the QRT channel.

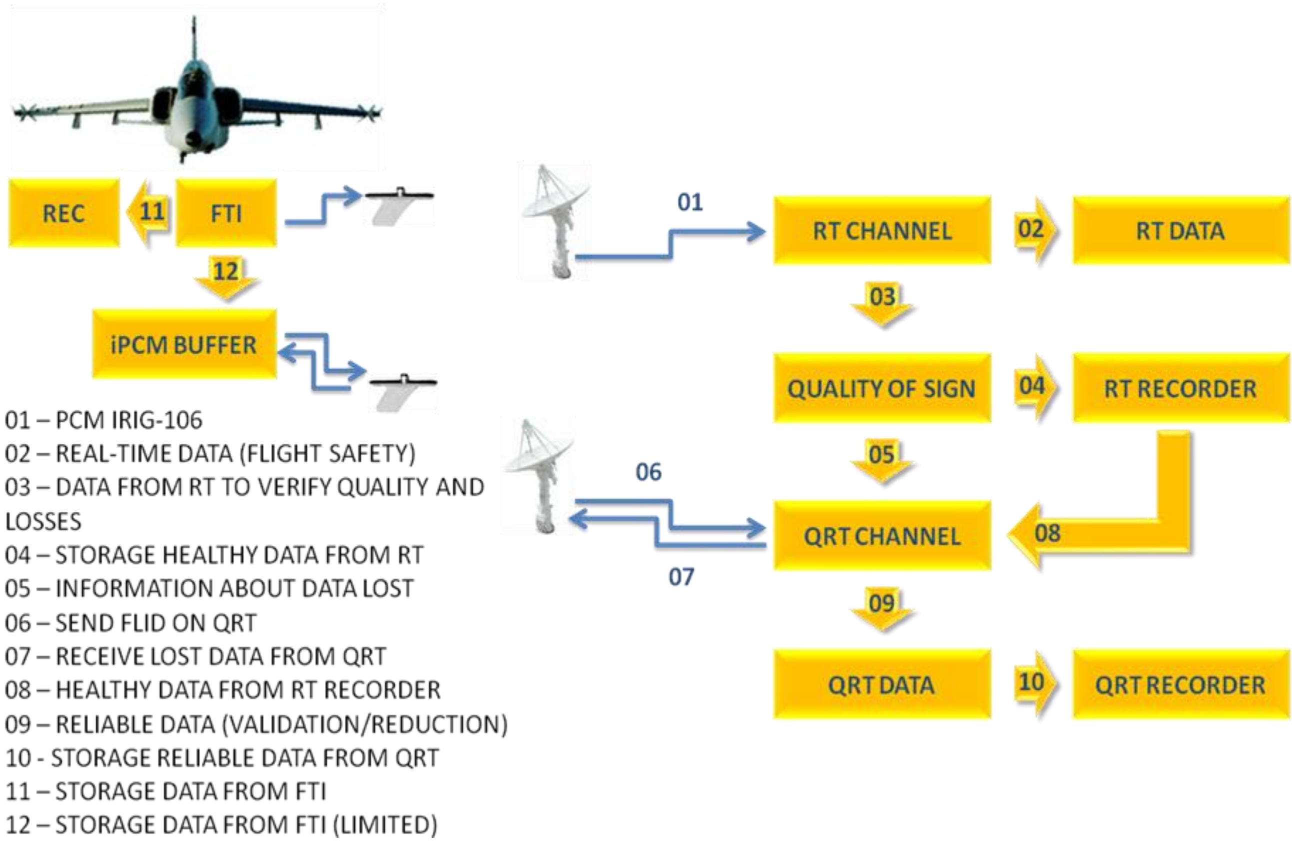

Figure 2. iPCM Architecture

After receiving the sequence of lost frames, the QRT CHANNEL system recovery full information uniting the data recovered from second channel with the data stored in the RT RECORDER. The QRT CHANNEL system interrogates the iPCM BUFFER system until the request frame is sent, when it is received on ground the next lost frame is requested and so on until complete recovery of information. Thus there is no an acknowledgment message to the iPCM BUFFER, its function is only send what is requested, staying in a charge of the QRT CHANNEL the identification of the information received and the continuing of the process. The result is a complete recovery of the information, available on the QRT DATA system for validation and data reduction by the ground crew. These data are also stored in QRT RECORDER system.

To identify the lost frames, and repackage of the recovered information in a logical order, control words called Lost Frame identification (FliD) were created. These words are placed before the parameters are referenced to it and right after of the Minor Frame Sync Pattern or subframe ID, when applicable, and it receives the information of the frame counter programmed in the Flight Test Instrumentation (FTI). Consequently each frame is identified by a sequential number, which allows the QUALITY of SIGN system to transmit the information about which frame needs to be recovered from iPCM BUFFER.

In order to transmit the FLiD information, 32 bits are used in two words of 16 bits. This result was reached in accordance with the limits defined by the IRIG-106 standard for the PCM Class I:

The maximum length of the minor frame shall exceed neither 8192 nor 1024-bit words. The minimum bit rate shall be 10 bps and the maximum bit rate shall not be greater than 10 Mbps.

Using as example the major frame as depicted in Figure 2, and considering this minor frames with 8 words of 16 bits in the maximum bit rate allowed by IRG-106 for the PCM Class I. We can compute that the number of frames per hour which is 281,250,000. Thus the usage of 32 bits FLiD can count up to 15 test hours in the maximum bit rate even employing a very short minor frame.

	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6
Minor Frame Sync Pattern	SFID =1	FLID1 =0	FLID2 =1	Param A1	Param B1	Param C1
	SFID =2			Param A2		
	⋮			⋮		
Minor Frame Sync Pattern	SFID =Z	FLID1 =0	FLID2 =Z	Param AZ	Param BZ	Param CZ

Figure 3. Minor Frame with FLiD

Now it will be compared the efficiency of iPCM on QRT channel against a typical UDP using the Ethernet packing for the UDP protocol as described in the reference [9]. In accordance with the Table 45-1 of reference [9] UDP has packet encapsulation overhead of 82 bytes whereas iPCM on QRT has only 5 words of 16 bits (10 bytes) of overhead. Thus the efficiency calculated for a packing of 500 bytes of information is nearly 98% for the iPCM and nearly 86% for the UDP, as shown below:

- iPCM efficiency: 98% ≈ 500 bytes / (10 bytes + 500 bytes)
- UDP efficiency: 86% ≈ 500 bytes / (82 bytes + 500 bytes)

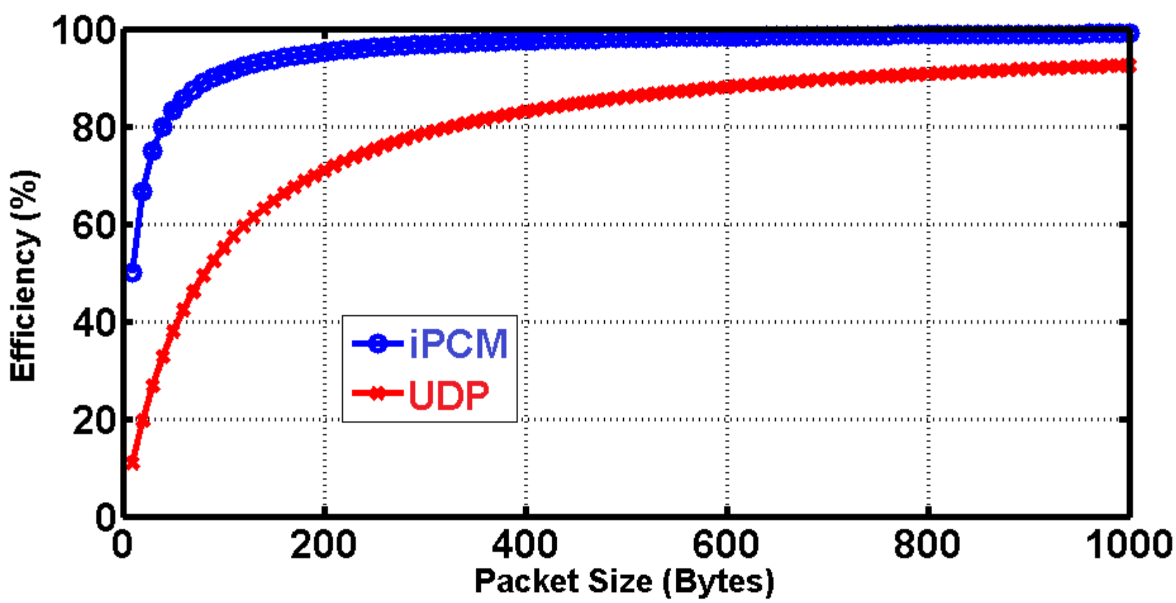

Figure 4. Packing efficiency UDP versus iPCM

Real time simulations of iPCM architecture had been performed using the Matlab® [10] software as platform. A matrix of flight data gathered from flight test performed with the EMB-312 T-27 "Tucano" was used to reproduce the data gathered from FTI. In order to simplify the simulation the lines of matrix was considered as frame of information and added one column with the simulated FLiD.

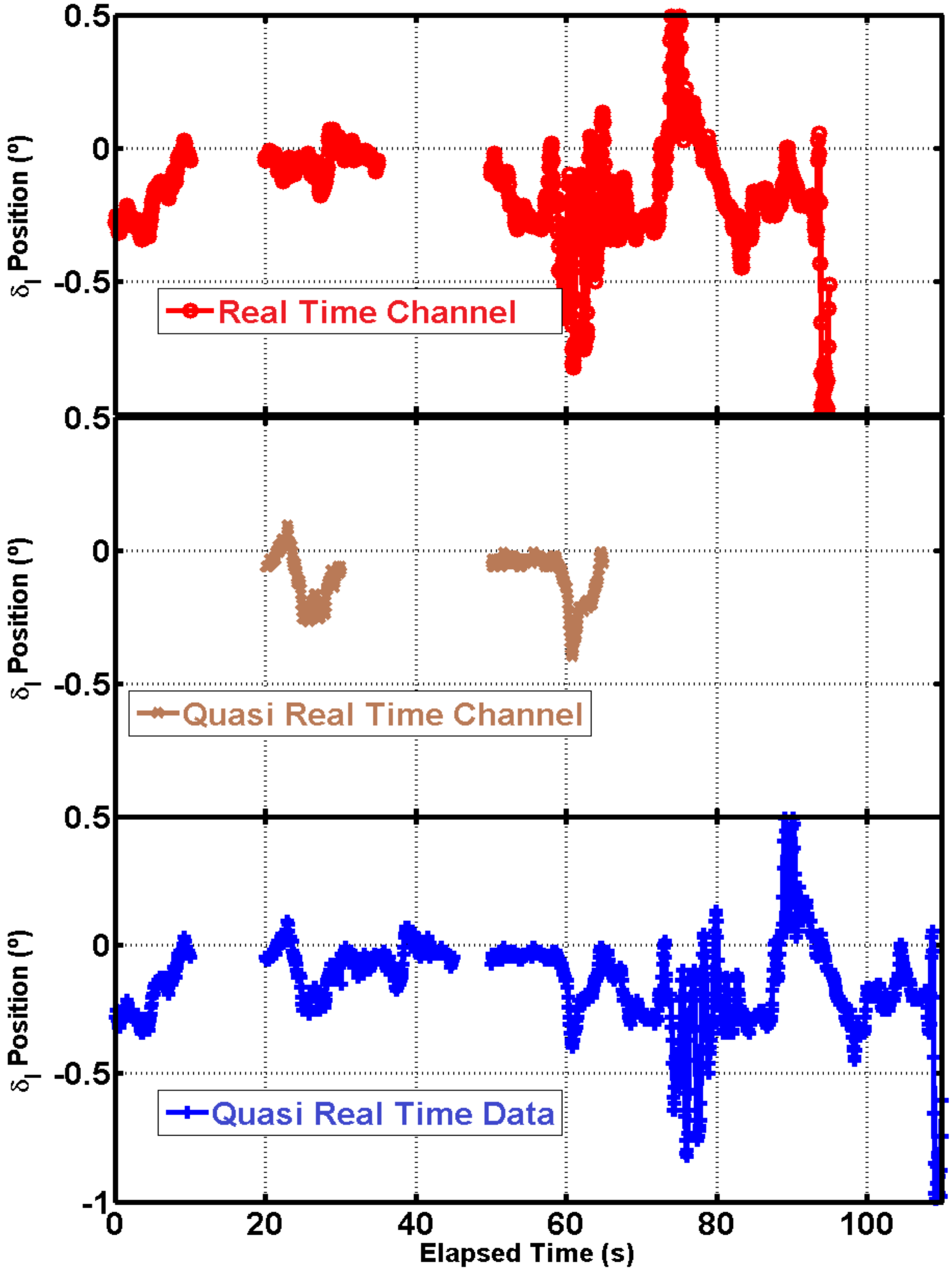

Figure 5. iPCM Simulation – T-27 Elevator Position [δ_l (º)]

Then it was created a link between the matrix and the Matlab Simulink with the purpose to simulate the RT channel and other function was implemented to simulate some losses and noise in the RT. The data received from the link is stored in other matrix playing a role of RT RECORDER. The occurrence of data loss is represented by the inclusion a not-a-number (NaN) character in all parameter position of the lost lines/frames excepting the associated FLiD and stored into the RT RECORDER.

The data from RT CHANNEL had been gathered by the QUALITY OF SING and after the FLiD was identified it was sent to QRT CHANNEL. The iPCM BUFFER was implanted using a matrix in the workspace of Matlab. The storage capacity of this matrix was set to be 20% of the full flight data.

Using the FLiD, the QUALITY OF SIGN function implemented had accessed the matrix iPCM BUFFER in the workspace and recovered the simulated lost data. These data had incorporated in the RT RECORDER matrix, in the correctly order defined by the FLiD, and saved in QRT RECORDER matrix. Finally the data was presented in a strip charts representing the QRT DATA.

Analyzing the strip charts from the figure 4, it is possible to verify the simulated losses in the RT channel in the intervals between 10 and 20 seconds and 35 and 50 seconds. As proposed, the QRT channel is activated when the telemetry link was re-established in order to recover the lost data from iPCM BUFFER using the FLiD to identify it. In the third strip chart the data recovered from QRT channel is plotted with data gathered from the RT channel, respecting the original FTI acquisition order and forming the QRT DATA. In this way it becomes possible to perform the data reduction during the flight test.

In this simulation, for didactics reasons, the data used from RT RECORDER to recompose the flight test data had been taken in the same rate of FTI. However to reduce the delay in information retrieval, the data from RT RECORDER can be attached to the QRT data at a higher rate.

From this simplified simulation, it is possible to confirm the real benefits of the iPCM algorithm. That could lead us to an a possible solution for increasing the data reliability of the real time telemetry link.

4. CONCLUSIONS AND FUTURE WORK

This paper presented the iPCM as new proposal of a telemetry protocol to improve the data reliability aiming two major goals:

- Improvement of the flight safety levels; and
- Data reliability increase to improve flight test campaign efficiency.

Given the T&E community needs, this new protocol combines the benefits of traditional telemetry using IRIG-106 PCM and a new method for data recovery in accordance with the iNET program philosophy concepts, focused in flight test.

The efficiency of the iPCM is higher than the traditional Ethernet protocols even its overhead increased by 32 bits to carry the frame lost identification (FLiD).

To address the iPCM capacity, a simulation was performed. The results proved that the protocol allows recovering the lost data and perform the complete data reduction during the flight test, unless a delay proportional to the time and frequency of the losses.

Now the next challenge is to implement this technology using the Brazilian Researches and Flight Tests Institute facilities and to validate this protocol for IRIG-106 limits and data reliability requirements.

Future works should include:

- Study of the buffer capacity for the iPCM BUFFER and specify a particular reliable quick access memory to meet the protocol requirements;
- Improve a capacity of QUALITY of SIGN algorithm to detect and identify imperfections in the data received from the RT channel; and
- Measurement and evaluation of elapsed time of QRT CHANNEL system to recover the data from iPCM BUFFER and verify the worst cases.

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