REAL-TIME IMPROVEMENT ON FLIGHT TEST TELEMETRY RECEPTION USING A BEST SOURCE SELECTOR

Florian SANDOZ(1), Philippe KLAEYLE(2), Pierre BASTIE(3)
(1) Space and Communication BU, Safran Data Systems, Les Ulis, France
(2) Space and Communication BU, Safran Data Systems, Colombelles, France
(3) Telemetry solutions, Safran Data Systems Inc., Norcross, US
florian.sandoz@safrangroup.com, philippe.klaeyle@safrangroup.com,
pm.bastie@SafranDataSystemsUS.com

ABSTRACT

This paper highlights the benefits of using a Best Source Selector in a flight test range, and explores the difficulties encountered by the practical implementation of such a device. Different options are then discussed to ease life of the users. An innovative solution is presented able to provide a solution to the limitations of existing setups. We will also discuss a method of validation of such Best Source Selector device.

KEYWORDS

Telemetry, Flight test, Best Source Selector, IRIG 106, IRIG 218-20

INTRODUCTION

The basis of real-time telemetry downlink as commonly practiced in flight test ranges is to have an airframe under test, being equipped with an RF transmitter transmitting in real-time a telemetry signal modulated by a PCM stream containing information related to various physical values measured on-board as well as buses, video captures…, and then on the ground to receive in real time this signal to process the transmitted data through different means.

In practice, it is often interesting to receive the signal from different locations on the ground, as this gives visibilities of the airframe from different angles, providing a better opportunity to avoid masking effects due to airframe maneuvers and effects from the terrain. In addition to these different angles of visibility, having multiple tracking antennas at different locations on the ground also allows to extend the geographical area where such flight tests can be done, without the need to have larger antennas or high transmission power.

Having multiple locations receiving the TM signal means that the several PCM streams produced on the ground need to be routed to a main station and properly combined to each other, in real time, which is the function of the Best Source Selector.

CHALLENGES IN THE BEST SOURCE SELECTOR

A. Alignment in time

The basis of a Best Source Selector is to select one stream out of many based on best quality. When switching from one stream to another, we need to make sure that we do not introduce discontinuities in the flow of information, as such discontinuities would introduce errors in the retrieved data.

Usually, flight testing an aircraft or a missile is done on large areas, as these airframes are moving at high speed. As we want to track the airframe from different antennas, and that we then need to bring the received information back to a single place, we cannot underestimate the time needed for the information to cross the distance.

First reason for having a misalignment in time between the different streams reaching a Best Source Selector is related to the distance separating the airframe from the different antennas. We are talking about a propagation of RF waves in the atmosphere that we can consider at a constant speed, close to the speed of light. During the flight, it could be that at a certain moment the airframe is rather close to one antenna and far from another antenna. The distance difference between the airframe and the different antennas will introduce a delay. Furthermore, as the airframe is in movement, the delay will evolve over time.

In Figure 1 we can see that the airframe being closer to the antenna 1 than to the antenna 2, the propagation time T2 is longer than the propagation time T1.

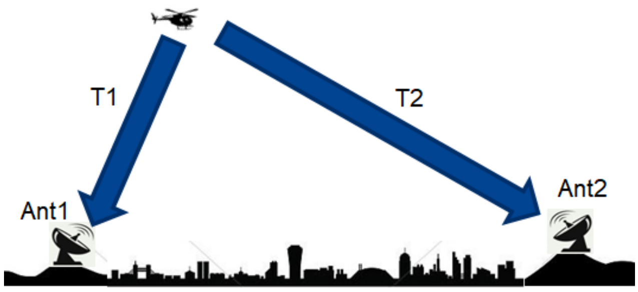

Fig. 1. Example of different propagation time depending on the location of the airframe

Second reason for having a misalignment is the time needed for the information to travel from the antenna to the best Source Selector itself. To benefit from different look angles of the airframe or to extend the flight test range coverage, the antennas are located far from each other, possibly with distances above 100 km. To bring the signals from the different antennas to the Best Source Selector will introduce a delay that is proportional to the distance to be traveled.

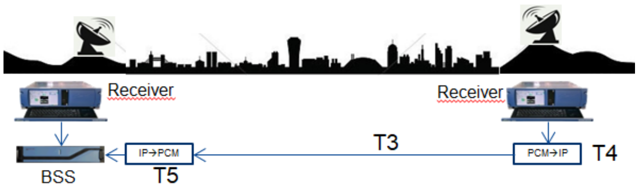

Fig. 2. Example of additional propagation time related to the distance between the antennas and the latency in the converters

In figure 2, T3 represent the time needed for the data to reach the Best Source Selector from the remote antenna location.
A third reason for having a misalignment is when the stream is routed through some infrastructure that will introduce certain latency. One could think of routing these streams through an Ethernet network using off-the-shelf interface boxes available on the market. Another way is to route these streams through point-to-point radio links that also introduce latency on handling the signals.

Figure 2 highlights the latency introduced by the converters from PCM signal to Ethernet (T4) as well as from Ethernet to PCM (T5)

The Best Source Selector will have to process different streams from different antennas, each suffering a certain delay, and be able to realign the streams in time by comparing the sequences of data carried by the different lines.

B. Retrieving the signal quality

The Best Source Selector will select the best stream between all the incoming ones. To make a proper choice, the device needs to estimate the quality of each stream.

Much impairment can deteriorate the signal that is transmitted. Noise contribution in the RF link is probably the first to be considered, but other effects can contribute like echoes, interferences, Multipaths…

The Best Source Selector is using baseband signals, therefore after RF conversion and signal demodulation.

A meaningful quality indicator of a digital PCM stream transmitted is the eye diagram. A good eye opening, as depicted in figure 3, will mean very little noise or interferences in the transmission.

On the opposite, a closed or poorly opened eye, as for example the one in figure 4, will mean a lot of noise and interferences with a high probability of errors when going from the analog to the digital domain in the bit synchronizer.

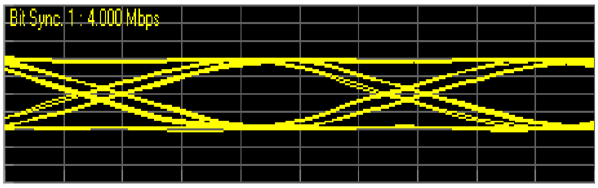

Fig. 3. Example of a good quality reception highlighted by a large opening

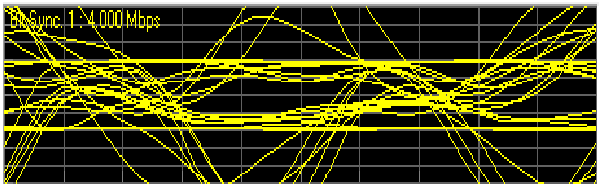

Fig. 4. Example of poor quality reception providing a limited eye opening, resulting in the occurrence of many errors

Extrapolating the signal quality from the eye opening is possible while working on the analog signal and having the bit synchronizer inside the Best Source Selector. However in a range implementation it is quite unpractical to transport analog signals over long distance, as the transport itself can impair the signal that is transmitted. Usually, the signal that is transported over a long distance is a digital signal, either a PCM stream, or this PCM stream converted into IP packet and carried over an Ethernet network infrastructure. Figure 5 shows that the signal quality information is lost when going from analog to digital signal.

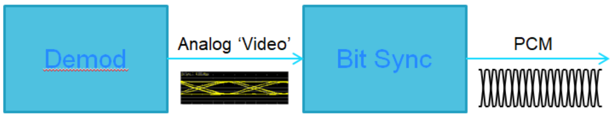

Fig. 5. Signal path in a receiver, showing that the signal quality available on the Analog "video" is lost in the PCM signal

The major limitation related to receiving only digital PCM streams in a Best Source Selector is that there is no more quality information, and we cannot estimate whether the bit level 0 or 1 received is sure at 99% or only at 51%.

Therefore, when receiving a digital PCM stream in a Best Source Selector, the only way to retrieve a quality information is to use a frame synchronizer to determine the frame sync lock status assuming the PCM stream is not encrypted. Another way is to use majority vote between the different incoming streams but this only works when there are at least three streams continuously.

The above illustrates the reasons behind the introduction a new capability to assign a quality metric to any PCM stream produced by a TM receiver.

NEW CAPABILITIES

A. Time alignment

In order to time align the various incoming streams, the Best Source Selector compares the sequences of the incoming data to determine the delay of one stream to another one. If the time difference is important, the number of bits to be compared can be huge, especially if we are operating at high bit rate.

As an example, assuming that the time difference can be up to +/-200 ms with a bit stream of 15 Mbps, the window of comparison needs to be wide of 6 millions of bits. One will easily understand that to reach an alignment with such a large window and to assure that the alignment is done and maintained in real time can easily become impossible with affordable solutions.

In the time difference between incoming streams, we can differentiate the constant time difference introduced by the transport of the data over the infrastructure (T3, T4 and T5 in figure 2), from the dynamic time difference related to the movement of the airframe (T1 and T2 in figure 1).

Introducing a fixed value for the latency related to the infrastructure and identifying it in the Best Source Selector allow the BSS device to cope only with the dynamic time difference which is far less important, and that can more easily be considered.

B. Information on the quality of the signal

In order to improve the retrieval of the quality of the signal, a new feature has been introduced to the IRIG 106 standard, under the name DQM/DQE, standing for Data Quality Metric / Data Quality Encapsulation. The idea behind this scheme is to add at a predefined regular interval few additional data (48 bits) in the PCM stream coming out of a receiver including a specific frame identifier followed by some bits of standardized information representing the quality of the received signal (16-bit Data Quality Metric).

Figure 6 shows the usual PCM stream with a Frame Word (FW) inserted at a regular data interval.

Figure 7 shows the same PCM stream with added DQM/DQE scheme. An additional packet (DQ), inserted at a pre-defined regular interval, has his own synchronization word followed by the quality information DQM.

Fig. 6. Example of an usual PCM stream with Frame Word (FW) output by a receiver

Fig. 7. Example of the implementation of DQM/DQE in a receiver

While the DQM information is added on the PCM output following the bit synchronizer (see fig. 8), its value is derived from various processing results inside the receiver. A typical one is the eye opening from the demodulator & bit synchronizer in case of noise affecting a PCM-FM or SOQPSK modulated TM link. In case of coded waveform (STC, LDPC), the error correction result is also used while it uses other processing results from demodulator and equalizer in case of Multipaths or adjacent channel interference. One will refer to the IRIG 106 standard that has defined few DQM calibration tests depending on the channel impairment. The consequence of adding DQM information to the PCM stream is the slight increase of the bit rate of the actual link between the receiver and the Best Source Selector (increase from 1 to ~ 4% max)

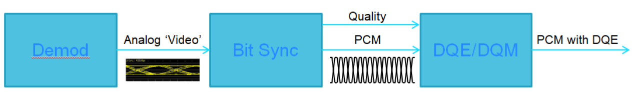

Fig. 8. Illustration showing add-on of DQM into the PCM stream in a receiver

In the Best Source Selector, thanks to the specific frame identifier, the data quality information can be retrieved and used for the best stream selection. The Best Source Selector will typically strip out those additional DQE/DQM information for its output as legacy decommutators will not be able to process it and will therefore not lock.

SIMPLIFYING THE IMPLEMENTATION

Implementing a Best Source Selector in a range often results in difficult choices and optimizations.

A. Taking care of the different formats

We have seen that when an antenna is located far from the place the Best Source Selector needs to be used, we need to carry the signal through some infrastructures. Often this infrastructure is based on public or shared Ethernet networks and then there is a need to implement conversions from PCM to Ethernet and then back to PCM with dedicated equipment that makes the implementation even more complicated.

On the other hand, the signal coming from the receiver that is co-located with the Best Source Selector can easily be connected to it, possibly even in analog, taking then advantage of extracting the data quality in the embedded bit synchronizer.

Until recently the existing Best Source Selectors were taking either physical signals in analog or digital PCM (Data & Clock) format, or Ethernet based signals (telemetry over IP), but mixing them was not possible, creating significant constraints in the layout of a range.

Either all the telemetry streams had to be put in Ethernet format, which means additional equipment and burden when the Best Source Selector was located in the same rack as some of the receivers. Or the remote stream transported over Ethernet had to be converted back to PCM stream to be processed by the Best Source Selector.

The implementation presented in this paper is based on the Safran “Hybrid” Best Source Selector, capable of accommodating both the legacy analog and PCM and telemetry over IP streams. In addition, the stream selection criteria can be easily mixed.

B. Latest Telemetry over IP protocols

Until recently, when it was required to send Telemetry data over Ethernet IP, external converter boxes were used to convert PCM into Ethernet and then reconstruct PCM from Ethernet. While working fine for pseudo PCM transport application, this solution did not time tag the data at the PCM conversion. With timing of the signal reception lost, it could not be used by the Best Source Selector to estimate the fixed delay due to the infrastructure.

As for the telemetry over IP formats, the IRIG 106 chapter 10 UDP throughput has been widely used as it is also used as the recording format for digital recorders. Nevertheless, for real-time transport, it is not the most efficient as the overhead quite large is not optimized (in particular due to the TMATS packet). Therefore, the RCC has introduced the IRIG-218 telemetry data over Ethernet format, optimized for real-time transport with a smaller overhead reducing therefore latency.

This paper presents a Best Source Selector with native Telemetry over IP capability in either ch10 or IRIG-218 formats. The advantage is that it is not required to use additional standalone conversion boxes in front of the Best Source Selector to reconstruct the digital PCM stream (Data / Clock) as the Best Source Selector can directly retrieve the PCM stream over Ethernet in either format, streamlining the ground station infrastructure and removing single point of failure equipment.

Furthermore, when the Telemetry over IP conversion is directly performed by the receiver (Ch10 or IRIG-218), time tagging is added by the receiver and can be used by the Best source Selector to automatically determine the fixed latency related to the infrastructure.

VALIDATION OF THE PERFORMANCES

The validation of a Best Source Selector in the lab is not easy. For example, to reproduce the actual physical implementation of a range as well as to simulate the maneuvers of the airframe, it requires to duplicate the same signal with different delays and varying amplitude.

Using Matlab, we have constructed a simulation routine introducing different type of delay and fading to a telemetry signal, creating an IRIG 106 chapter 10 file, as depicted in figure 9.

To simulate a worst-case scenario, we introduce a complete cancellation of the signal, situation that can be seen for example on a missile or a launch vehicle that is spinning, and where visibility from different angles brings additional information. See figure 10.

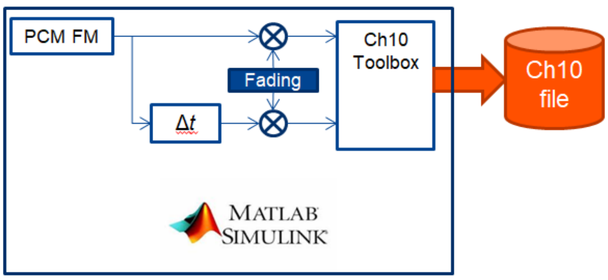

Fig. 9. Creation of an IRIG Ch10 file to validate the BSS, introducing delay and fading

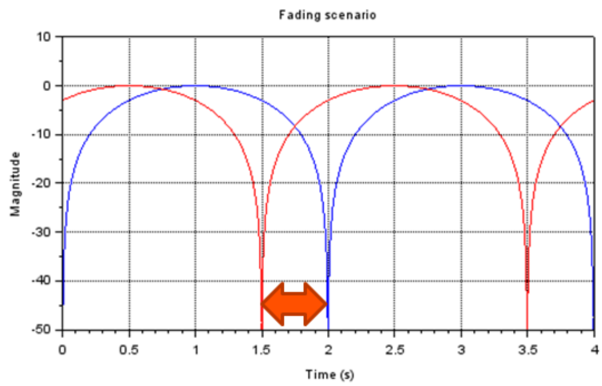

Fig. 10. Fading profile used for the simulation

The content of these PCM chapter 10 files was used to FM modulate IF carriers at 70MHz in a Safran Data Systems RSR recorder and reproducer. Those last were then fed to a receiver, providing analog baseband outputs that were recorded to create the test signals to the best source selector.

We made this approach twice to get 4 baseband signals.

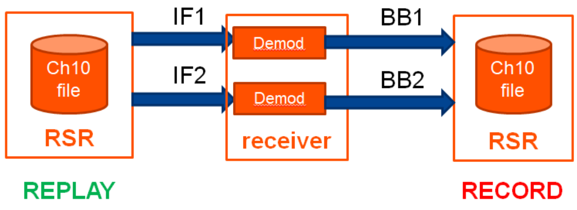

Fig. 11. Creation of the test signal

Fig. 12. Replay of the test signal into the Best Source Selector

When replaying the four analog basebands, we end up with the same reference signal with different delays and having their amplitude varying in time with each signal reaching zero level at a different moment.

This method is performed using analog inputs of the Best Source Selector, however the same behavior will occur if the data reaching the device were in PCM format or Ethernet format. Indeed, in this last case, the device will simply use the data quality information (DQM) already contained inside the PCM stream. However the process of time alignment and best source selection will be the same.

During replay, we see that none of the individual signals received on its own provides a good Bit Error Rate. This result is not surprising as each signal has a null (zero level) every few seconds leading to a loss of synchronization and the need to reacquire the signal.

However, we see that the Best Source Selector provides a very good performance as its output remains continuously locked with an error free BER.

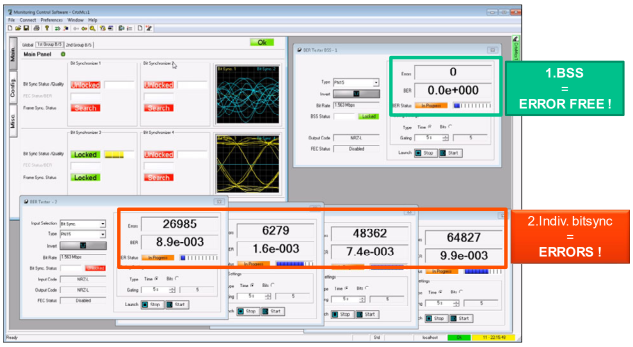

Fig. 13. Result of the validation of the Best Source Selector

CONCLUSION

We have seen in this paper the benefits brought by a Best Source Selector into a Flight Test range: increase availability of the telemetry link when the airframe is going through complex maneuvers, extend the range coverage, while having continuously real-time uninterrupted telemetry data.

We have discussed the difficulties associated with the implementation of such best source selector like the need to compensate for various data latencies, and the need to support different types of data transport (i.e. analog baseband, PCM streams, telemetry over Ethernet with various formats…)

We have seen that the Best Source Selector implementation proposed by Safran mitigates those difficulties while it can now accommodate any types of incoming signals and mix them in various ways to take the best of them in order to get the real-time associated data.

We have also seen how the use of native TMoIP formats (ch10 or IRIG-218) directly from the receivers into the Best Source Selector can facilitate the compensation of the fixed latency introduced by the actual implementation in a range.

Finally, we have described a robust test method to validate the Best Source capability in a lab environment.

REFERENCES

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