Development of Ethernet-based Flight Test Instrumentation

Customer

National Aerospace Laboratory NLR

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EXECUTIVE SUMMARY

Development of Ethernet-based Flight Test Instrumentation

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Description of work

This paper describes the development of Ethernet-based Flight Test Instrumentation at NLR. It presents the concept of the system to be developed and the current status.

Applicability

Parts of this development already found its application in major flight test projects, of which two examples are highlighted:

- The Generic Instrumentation System for helicopter/ship qualification trials, introducing a telemetry datalink and real-time quick-look data processing based on Ethernet.
- The update of the F-16BM “Orange Jumper” flight test instrumentation by installation of new data acquisition equipment using an Ethernet communication protocol.

This report is based on a presentation held at the 26th SFTE-EC Symposium, Seville, Spain, October 6-8, 2015.

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Abstract

In the application of Flight Test Instrumentation (FTI) there is a development in the use of Ethernet network based data communication instead of the conventional IRIG-PCM point-to-point data connections. The reason for this development is obvious: the data communication uses Commercial Off-The-Shelf interfaces, both hardware and software, and therefore savings are made on the system's complexity and costs.

Also at the National Aerospace Laboratory NLR this change has taken place and Ethernet-based data acquisition and recording components have been used in some recent major flight test projects. For two of these projects the Ethernet developments are highlighted.

Firstly, the FTI system in the F-16BM "Orange Jumper" test aircraft of the Royal Netherlands Air Force has been updated to an Ethernet-based master-slave data acquisition system. With the application of this system significant savings could be achieved on costs for dedicated flight test wiring in the aircraft.

Secondly, the Generic Instrumentation System for the Defence Helicopter Command with the main purpose of ship/helicopter qualification trials is also based on Ethernet components, especially for real-time quick-look facilities on board of both the ship and the helicopter and the telemetry data link between both platforms.

These examples show that already important progress has been made in the past years introducing Ethernet-based components in FTI systems. However, the transition from legacy IRIG-PCM based FTI systems to Ethernet-based systems does require hardware and software changes throughout the entire flight test instrumentation system. To perform these changes in a more integrated system approach new knowledge is required. At present a research program is performed to obtain this knowledge.

Content

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Abbreviations

Acronym	Description
10-WIF	German-Dutch Wind tunnels
AC	National Aerospace Laboratory NLR
CF	Research and Development
COFDM	Coded Orthogonal Frequency Division Multiplexing
COTS	Commercial Off-The-Shelf
CTEIP	Central Test and Evaluation Investment Program
CWC-AE	Curtiss-Wright Controls Avionics and Electronics
DAU	Data Acquisition Unit
DC	Direct Current
DDLS	Digital Data Link System
DHC	Defence Helicopter Command
DHCP	Dynamic Host Configuration Control
EMC	Electro-Magnetic Control
EMI	Electro-Magnetic Interference
FEC	Forward Error Correction
FTI	Flight Test Instrumentation
GIS	Generic Instrumentation System
HEDAS	Helicopter Data Acquisition System
IEEE	Institute of Electrical and Electronic Engineers
IENA	Test Installation for New Aircraft (French acronym)
iNET	Integrated Network Enhanced Telemetry
iNET-X	iNET Extended
IP	Internet Protocol
IRIG	Inter-Range Instrumentation Group
LAN	Local Area Network
LNA	Low Noise Amplifier
MLU	Mid-Life Update
MMSC	Micro Miniature Signal Conditioner
MST	Master (location)
NATO	North Atlantic Treaty Organization
NFH	NATO Frigate Helicopter
NLR	National Aerospace Laboratory (Dutch acronym)
PCM	Pulse Code Modulation
PCU	Programmable Conditioner Unit
PMU	Programmable Master Unit
PTP	Precision Time Protocol
QAM	Quadrature Amplitude Modulation

RF	Radio Frequency
RFPA	Radio Frequency Power Amplifier
RNLAF	Royal Netherlands Air Force
RT/QL	Real-Time/Quick-Look
Rx	Receive
SCA	Ship Controlled Approach
SHOL	Ship/Helicopter Operational Limits
TCP	Transmission Control Protocol
Tx	Transmit
UDP	User Datagram Protocol
US DoD	United States Department of Defense
WAN	Wide Area Network

1 Introduction

In the application of Flight Test Instrumentation (FTI) systems there is a development towards systems based on Ethernet instead of the conventional IRIG-PCM data communication between system components. Using mature Commercial Off-The-Shelf (COTS) techniques reduces system complexity: fewer special interfaces have to be developed. The integration between airborne and ground-based facilities, such as data processing stations, which are already based on standard computer techniques, will be easier.

At the National Aerospace Laboratory NLR this change is also taking place and Ethernet- based data acquisition and recording components have already been used in some recent major flight test projects, of which two example projects will be presented in this paper:

- The development of a flight test instrumentation system for performing ship/helicopter qualification trials for the Defence Helicopter Command (DHC). This system will introduce an Ethernet data link between helicopter and ship, allowing real-time data processing facilities with Ethernet interfaces.
- The upgrade of the FTI of the F-16BM “Orange Jumper” test aircraft with an Ethernet-based data acquisition system.

2 System concept

The transition from legacy IRIG-PCM based FTI systems to Ethernet-based systems does require hardware and software changes throughout the entire system. This is mainly due to the different nature of the packetized Ethernet data compared to the fixed frame IRIG-PCM data, which requires new solutions for data de-commutation and time synchronization.
The generic concept of an FTI system with its main functions is shown in Figure 1.

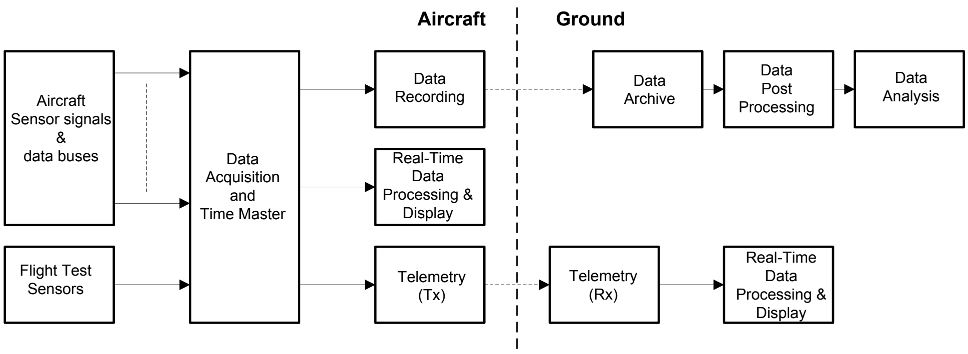

Figure 1: Generic concept of a Flight Test Instrumentation system.

The inputs of the FTI system origin from the aircraft sensors and data buses and additionally installed flight test sensors, including video (high-speed) cameras. The main functions of the airborne part of the FTI system are:

- data acquisition, including a time master to correlate all acquired data to one source,
- airborne data recording,
- airborne real-time data processing and display,
- telemetry transmission.

The main functions of the ground-based part of the FTI system are:

- (raw) data archiving of recorded data,
- data post processing,
- data analysis,
- telemetry reception,
- ground station real-time data processing and display.

In legacy FTI systems the data flow between the different components in a system is mainly based on IRIG-PCM data (as described in IRIG-106 [Ref. 1], Chapter 4). The change to an Ethernet-based data communication between the different components requires study with regard to the functionality and abilities of existing equipment. This will result in the procurement of new hardware and software to obtain the capabilities required for a fully functional Ethernet-based FTI system as depicted in Figure 2.

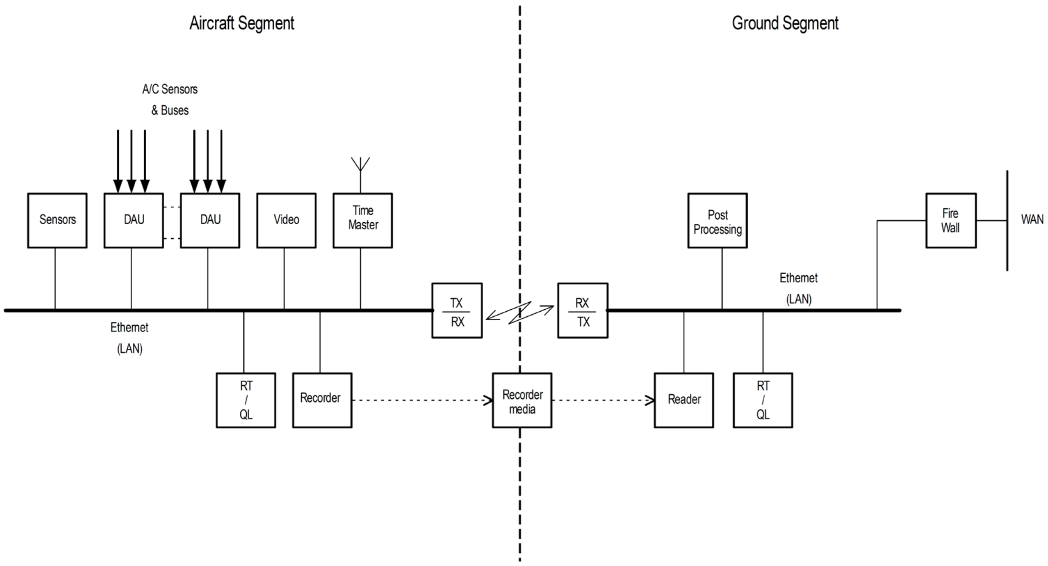

Figure 2: Ethernet-based Flight Test Instrumentation system.

In the Ethernet-based FTI system every component from the generic concept interfaces with an Ethernet Local Area Network (LAN), both in the aircraft segment and in the ground segment. If required both networks can be transparently connected by a wireless data link. Optionally, the dedicated network with flight test data can be connected via a firewall to a Wide Area Network, allowing for remote access of flight test data.

3 Research program

Outside the NLR similar developments of the above concept are going on and are monitored with interest for applicability in NLR projects. An example is the Integrated Network Enhanced Telemetry (iNET) programme initiated by the US DoD Central Test and Evaluation Investment Program (CTEIP). Based on the core recommendations and technologies outlined by the iNET programme, Curtiss-Wright defined the iNET-X standard [Ref. 3] as an extension for their flight test equipment, which is also in use in NLR FTI.

The iNET programme is a large scale and long term activity and therefore the results are not always directly applicable for NLR's projects. For that reason NLR defined and funded research to further develop the Ethernet-based FTI concept in an evolutionary approach as presented in Reference 6. The plan for this research defines a minimal FTI configuration as depicted in Figure 3, consisting of the core functions: on-board data recording and ground-based data processing of the recording media. After establishing the core functionality the system will be extended stepwise to the functions presented earlier in Figure 2.

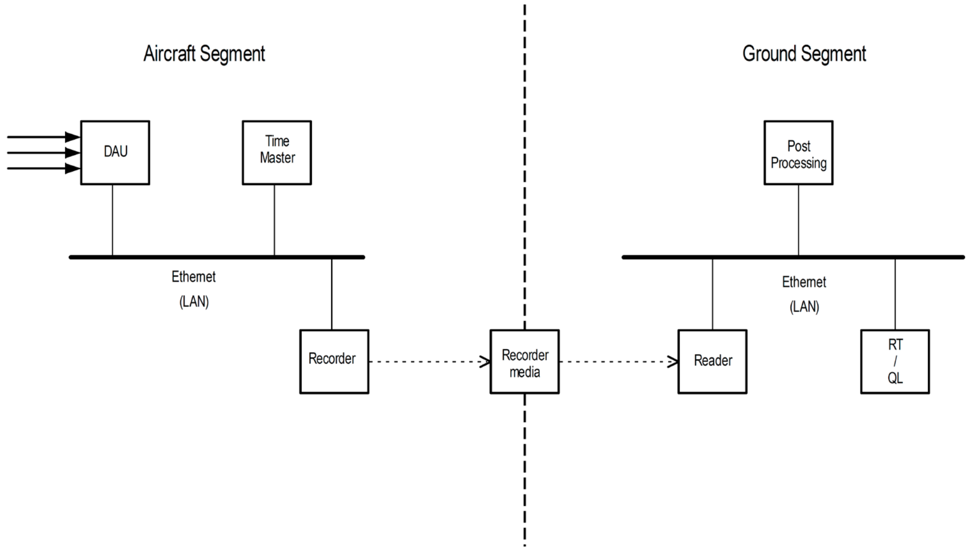

Figure 3: Minimal Ethernet-based FTI configuration with core functions.

The major fields of development for the core functions, for which appropriate standards have to be established and further explored, are as follows:

- Data acquisition communication: in recent projects the iNET-X protocol [Ref. 3] has been used.

- Recording: developments are based on the standards of IRIG-106 [Ref. 1, Chapter 10]. NLR is using airborne recorders based on this standard since the year 2005.
- Time protocol: in recent projects the Precision Time Protocol (PTP) according to the IEEE 1588 standard [Ref. 2] has been applied.
- Data processing: both real-time data processing and post processing facilities will require development of new software to handle the new data standards.

The application of new hardware components demands a new effort in qualification and certification for specific airborne applications.

The time frame for developing the core functionality will be the end of year 2016. To realize the fully functional concept the major areas of development will be:

- standardisation of data communication protocols and system configuration data,
- (real-time) data processing,
- telemetry data links,
- Ethernet-based video,
- real-time/quick-look (airborne) hardware,
- smart sensor application.

The next chapters will highlight the development already started in major flight test projects at NLR.

4 Generic Instrumentation System

For several decades NLR has been involved in the execution of Helicopter/Ship Operational Limit (SHOL) qualification. A flight test instrumentation system HEDAS, was developed by NLR for the Westland Lynx SH-14D. This helicopter was in service at the Royal Netherlands Navy for 36 years. The arrival in the year 2010 of a new navy helicopter, the NH Industries NH90 NFH (Figure 4), and the development of several new navy vessels has triggered the development of a new FTI system.

Figure 4: Ship/helicopter trials with the NH90 NFH.

The closer cooperation between air force and navy required the new FTI to be more generic, for use in all defence helicopters presently in service. The Generic Instrumentation System (GIS) was developed by NLR for the Defence Helicopter Command (DHC).
The primary requirements for the system were aimed at measurements to determine the Ship/Helicopter Operational Limits (SHOL) [Ref. 5]. The system had to be certified in all defence helicopter types.

In the NLR approach to the SHOL trials the helicopter and ship data were combined and presented in real-time. These combined data are used to monitor the safety and progress of the

trial, i.e. approve or discard test points flown. With the HEDAS the helicopter data was sent to the ship by means of a legacy telemetry downlink, where the test team monitored and directed the flight trials. For the GIS-DHC to be developed it was required to have the capability to direct the flight test trials from either the helicopter or the navy vessel, thus requiring a bi-directional data link.
With legacy telemetry links this would require two individual datalinks: one for the uplink to the helicopter and one for the downlink to the ship. For this development a choice was made for a single bi-directional wireless Ethernet link.

The data format over the link was chosen based on earlier decisions for IRIG-106 Chapter 10 data recording format and the introduction of true Chapter 10 recorders in other FTI systems for the RNLAF. Chapter 10 UDP data packets were the obvious choice for the data format. Furthermore, due to a tight time-schedule, the choice for the real-time quick-look software was limited to the VuSoft solution of JDA, which at the time was the only readily available software package meeting the requirements, especially processing two UDP data streams simultaneously.

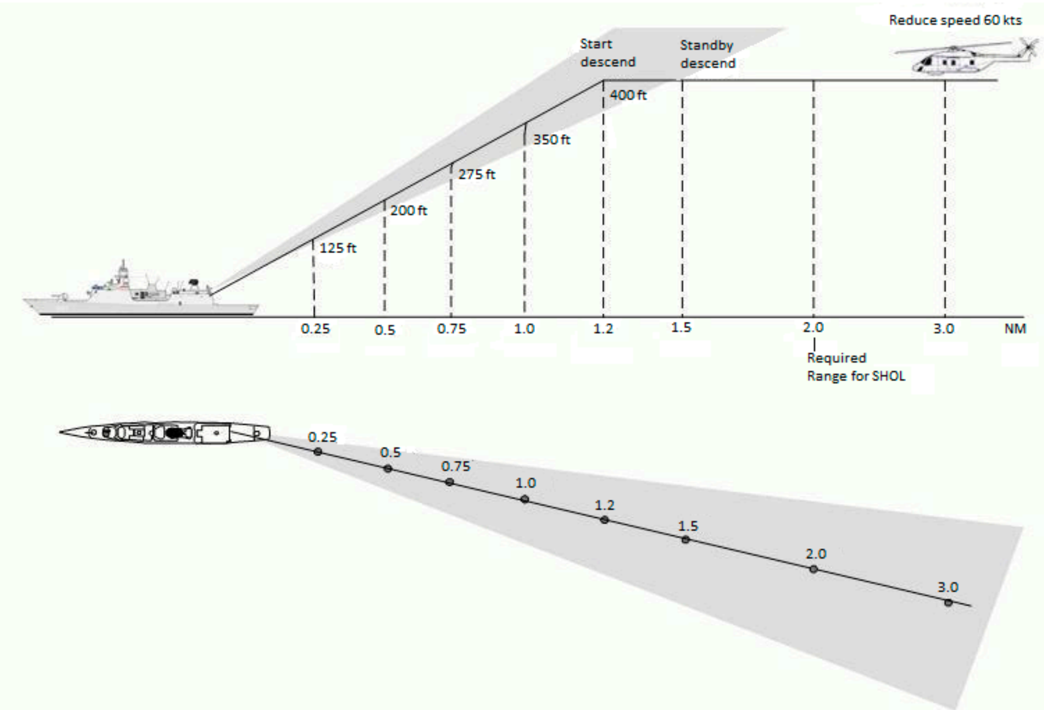

Figure 5: Typical Ship Controlled Approach.

The required coverage of the telemetry link is obtained from the operational procedures as defined in the Directives for Operating Helicopters on board of Navy Units (only available in Dutch) from which Figure 5 is derived, showing a typical Ship Controlled Approach (SCA). As indicated in the figure, the required coverage is limited to 2.0 NM from astern of the navy vessel. For departure, coverage is only required until the helicopter is clear of the vessel. The estimate for the required data link capacity was less than 1 Mb/s.

A functional block diagram of the developed GIS is supplied in Figure 6. For the Wireless Datalink a system was purchased from NSM Surveillance, utilizing IP-based COFDM (Coded Orthogonal Frequency Division Multiplexing) transceivers that use independent transmit and receive carriers between the ship and the helicopter. Each link can be independently configured for operation in either the 4400-4625 MHz low-frequency NATO band or the 4775-5000 MHz high-frequency NATO band. A gap of at least 150 MHz between receive and transmit frequencies is required for proper RF isolation within the diplexers. The modulation and the Forward Error Correction (FEC) are configurable and operate independent in each direction, allowing for asymmetrical links if desired.

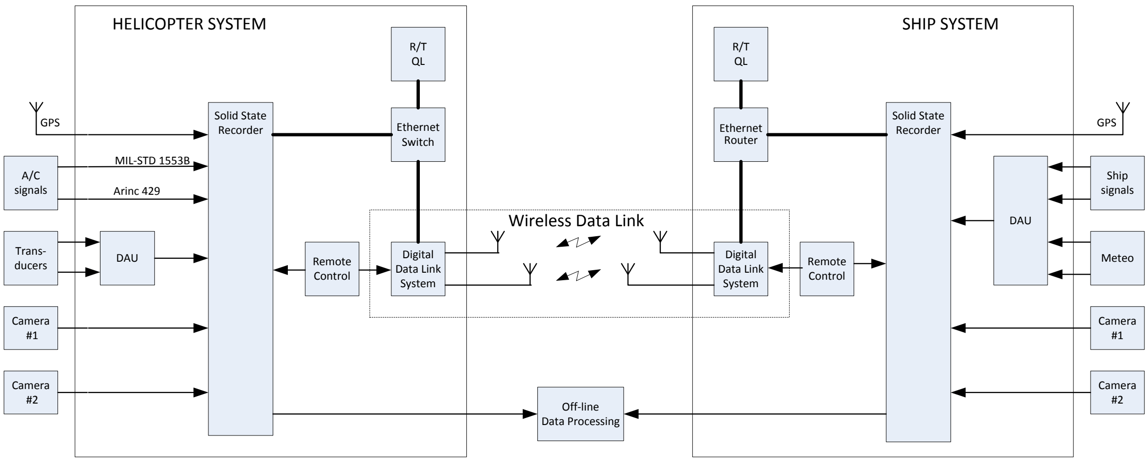

Figure 6: Block diagram of the Generic Instrumentation System.

Both the helicopter and the ship are equipped with a Digital Data Link System (DDLS) consisting of two Antenna Assemblies and an Electronics Unit as shown in the block diagram of Figure 7. The Antenna Assemblies use omni-directional antennas for the previously mentioned frequency ranges and are equipped with diplexers and Low Noise Amplifiers (LNA) for the receive channels. The two antennas ensure that there will be link coverage by means of space diversity combining. The transceiver is housed in an Electronics Unit, together with a DC/DC power supply, a 5 watt Radio Frequency Power Amplifier (RFPA) and a power splitter to feed the two transmit outputs.

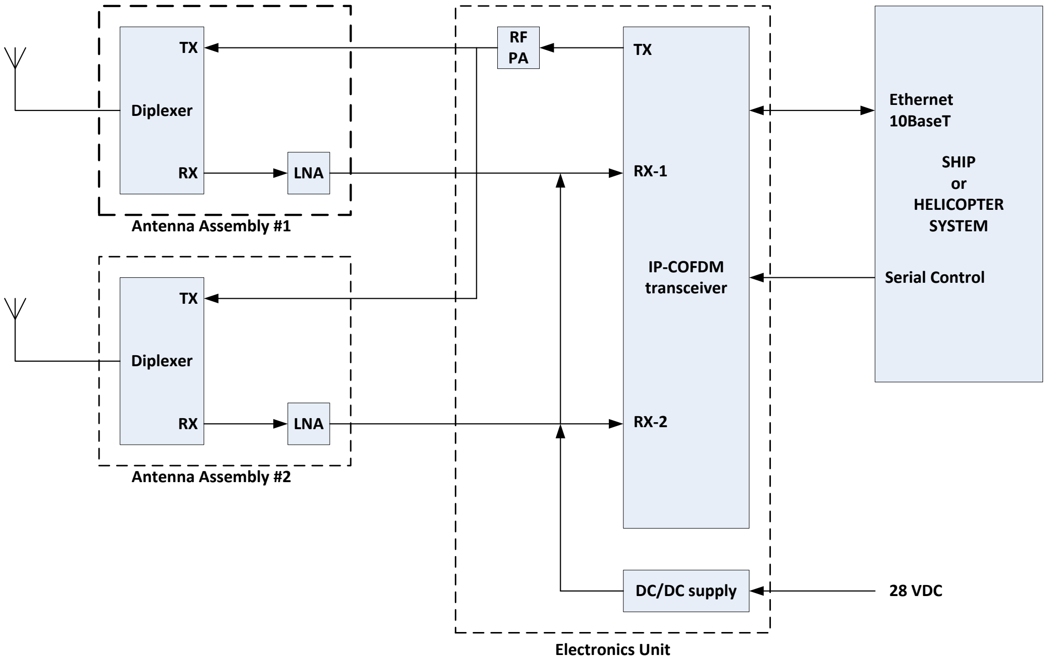

Figure 7: Block diagram of the Digital Data Link System.

The Electronics Units as originally delivered did not comply with the EMI/EMC requirements for airborne helicopter use. NLR designed a custom build housing which was EMI/EMC tested and met the requirements (Figure 8). An example of the helicopter antenna assembly, containing the LNA and diplexer can be seen in Figure 9.

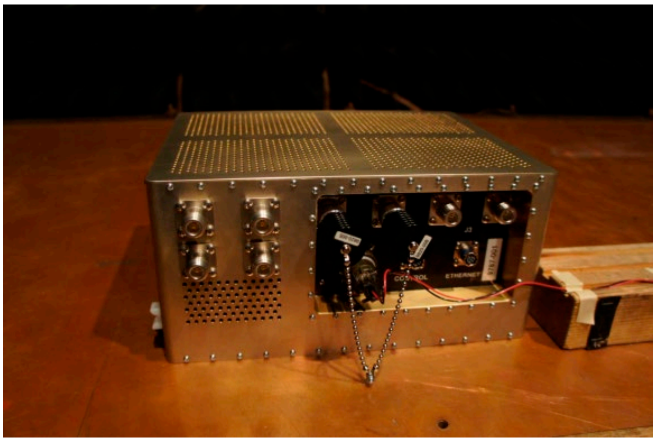

Figure 8: Electronics Unit of the DDLS during EMI/EMC tests.

Figure 9: Antenna Assembly.

The data link acts like a wireless bridge between two Ethernet networks. The DDLS does not have its own IP-address and simply just passes Ethernet traffic from one end of the link to the other end. It is transparent to IP protocols and passes DHCP requests, routing protocols, TCP/IP, UDP, etc. The results of link tests performed by NSM are summarized in Table 1, showing that the required ranges for SHOL trials can be obtained. A sea/flight trial was successfully conducted by NLR and DHC to verify the link performance.

Table 1: Digital Data Link System test results.

Mode	Modulation/FEC	Data Capacity	Distance	Margin
8	64 QAM, FEC 2/3	5.0 Mbps	1.3 NM	5 dB
7	64 QAM, FEC 1/2	4.2 Mbps	2.7 NM	3 dB
6	16 QAM, FEC 2/3	3.4 Mbps	2.7 NM	5 dB
5	16 QAM, FEC 1/2	2.6 Mbps	2.7 NM	7 dB

5 Instrumentation for F-16BM "Orange Jumper"

Since the year 1999 the FTI in the F-16BM "Orange Jumper" J-066 (Figure 10), as presented during the SFTE in 2000 [Ref. 4**]**, has been successfully operational during the flight tests for the Royal Netherlands Air Force (RNLAF). The prolonged lifespan of the F-16 MLU aircraft by the Dutch Ministry of Defence required a renewal of the installed legacy FTI system to allow flight tests up to the estimated end of life of the aircraft in the year 2023. Since the original data acquisition equipment had become obsolete, a completely new system was required.

Figure 10: F-16BM J-066 "Orange Jumper" test aircraft.

The legacy FTI system was installed at different remote locations throughout the aircraft. A high level system diagram is depicted in Figure 11, showing the major system components. The parts of the system affected by the renewal are shaded in blue. Besides the data acquisition system these are the system setup and off-line data processing facilities which had to be adapted to accommodate the new type of data.

Furthermore, during the certification process it was found that the new FTI could not meet the requirements for the power conditions according to MIL-STD-704A, which has higher limits for surge voltages than the current revisions MIL-STD-704E and -F. Since it could not be excluded that these surge voltages occur on the F-16BM power bus, additional transient suppression had to be added in the AC/DC power panel which supplies the power to the FTI.

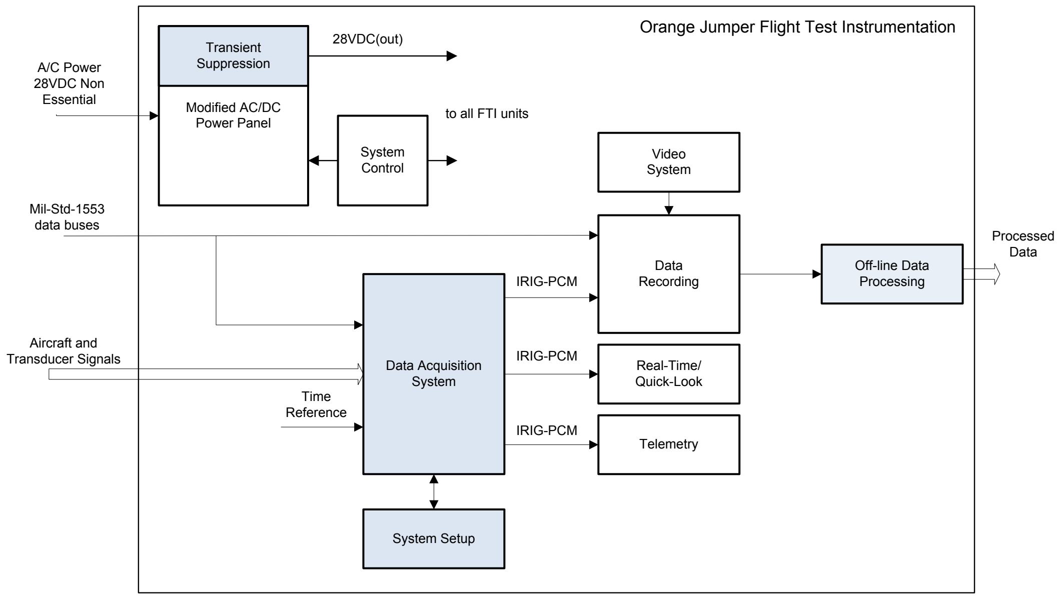

Figure 11: High level diagram of the "Orange Jumper" FTI indicating the modified parts.

The legacy data acquisition system was based on components of the formerly company Aydin Vector and configured in a master-slave configuration with dedicated wiring for the proprietary 10-Wire Interface (10-WIF) between the Programmable Master Unit (PMU) and the remote data acquisition units. Figure 12 represents an overview of the locations of the components. There are five branches routed throughout the aircraft, connecting the PMU master location (MST) with each remote data acquisition unit location. These remote units consisted of the Programmable Conditioner Unit (PCU) and the Micro Miniature Signal Conditioner (MMSC) for locations with less available space.

Replacement of the existing dedicated wiring between master and slave units would have been too costly, so it was a strong requirement that the new FTI had to re-use the existing 10-WIF wiring. After exploratory tests it was concluded that it had to be feasible to use this wiring for Ethernet data communication. After an evaluation of available data acquisition systems from different vendors, the KAM-500 equipment of Curtiss-Wright Controls Avionics & Electronics (CWC-AE) was selected to implement an Ethernet-based data acquisition system. In cooperation with CWC it was demonstrated that the Ethernet system concept was feasible using the existing wiring. Additional tests were performed to verify that EMI requirements could be met.

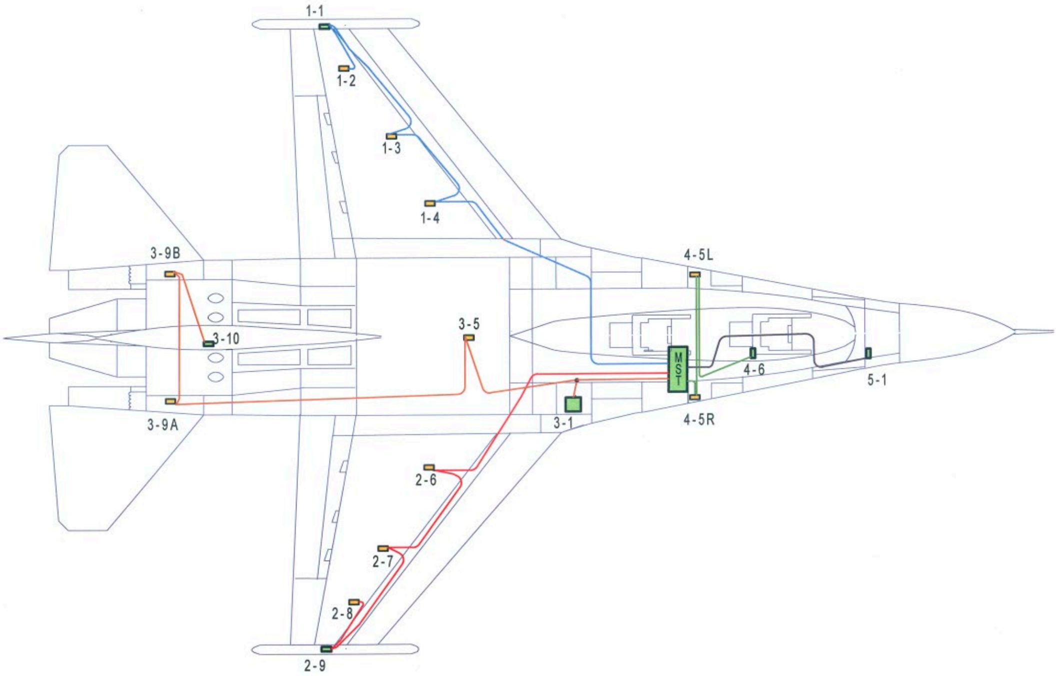

Figure 12: Installation overview of the data acquisition system.

The interfaces of the data acquisition system with the recorder, the real-time quick look system and the provisions for telemetry are still based on IRIG-PCM. Therefore an Ethernet to IRIG-PCM bridge had to be implemented. Figure 13 represents the applied concept. A separate data acquisition unit is equipped with an Ethernet bus monitor module connected with the aggregated data output of the master switch unit. The additional PCM encoder module is taking data from the bus monitor and outputs the PCM data in the same format as used in the old system, preventing modifications to other parts of the FTI.

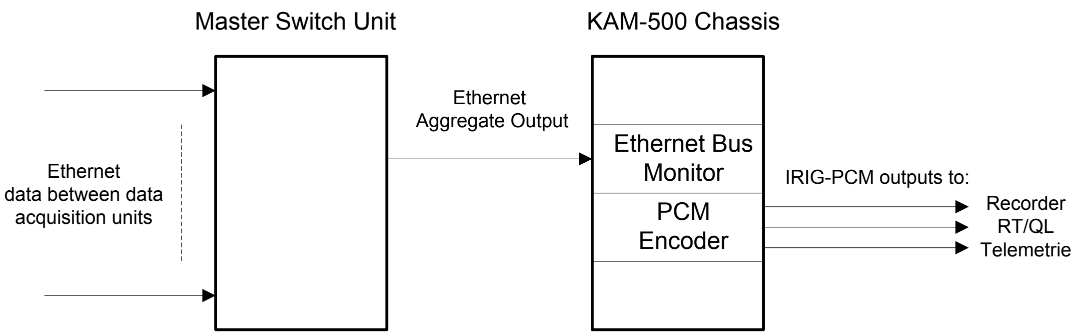

Figure 13: Ethernet-based KAM-500 FTI system with Ethernet to IRIG-PCM bridge.

The KAM system supports both iNET-X and IENA data protocol. The iNET-X protocol was selected in favour of the proprietary IENA UDP protocol for reasons of availability of documentation and processing facilities and standardization.

Time synchronisation between all units throughout the aircraft was established by means of the Precision Time Protocol (PTP) according IEEE 1588-2002 v1.0 [Ref. 2]. Normally an external GPS antenna connected to the Master Switch Unit (MSU) will synchronise the unit. Installing an extra antenna on the aircraft was too much effort and therefore too expensive. Another method for time synchronisation had to be found. The FTI data recorder is the only unit equipped with a battery required to keep the time after “on ground” synchronization. The time output signal of the recorder is however not compatible with the MSU time input. To solve this, the KAM-500 chassis of the bridge from Figure 13 was also equipped with a Time Code Module for signal conversion between recorder and MSU. Without an external GPS antenna, it is normal operation to synchronize the FTI to GPS before every flight. The total time synchronization principle is shown in Figure 14.

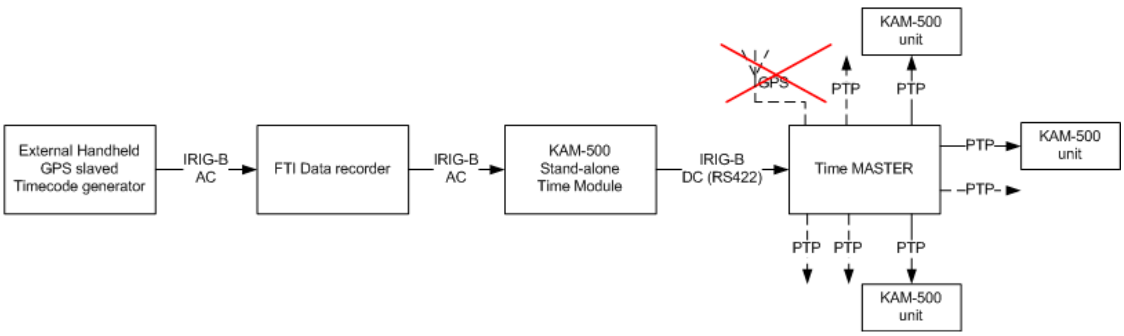

Figure 14: FTI time synchronisation principle.

For each location throughout the aircraft it was inevitable to replace electrical and mechanical connections to existing wiring and airframe. Since the “Orange Jumper” had to stay a fully operational aircraft, space on all locations is very limited. In most cases this resulted in complex bracket designs (Figure 15) and completely filled mounting locations (Figure 16).

Figure 15: Complex bracket in the tail section.

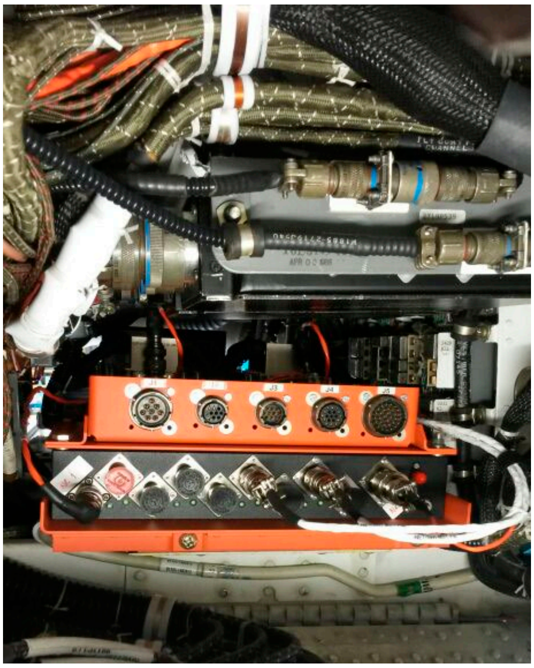

Figure 16: Installation of the master switch unit.

The renewed Ethernet-based FTI system allows the RNLAF to perform flight tests with the “Orange Jumper” until end of life of the F-16 MLU aircraft, without being confronted with excessive FTI maintenance end repair costs. Future improvements of the “Orange Jumper” FTI system will include an extension to a complete Ethernet FTI system concept, providing data recording, real-time quick-look and telemetry facilities with direct Ethernet interfaces. This will eliminate the need of an Ethernet to IRIG-PCM bridge, which will reduce the costs for system maintenance and configuration.

6 Conclusion

In this paper the development of Ethernet-based Flight Test Instrumentation at NLR has been outlined. Based on a general concept the main areas of work were indicated. Two examples of recent projects making use of parts of the developments demonstrate the advantages and motivate to continue working towards a fully functional Ethernet-based FTI system.

The use of COTS equipment sometimes requires adaptations to meet the specific flight test requirements. Both examples show that NLR is very well capable to realise these adaptations, in close cooperation with his customer (i.e. the RNLAF) and equipment vendors.

7 References

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Appendix A Authors' biographies

Johan Klijn holds a BSc degree in Electrical Engineering from the Institute of Technology of Amsterdam where he graduated in 1981. Since that time he works at the National Aerospace Laboratory at the Aircraft Systems (formerly Flight Test Systems) department of the Aerospace Systems Division, recently as Principal Project Engineer. He was involved in the design and installation of flight test instrumentation systems in both military (F-16, several helicopter types like Apache, Chinook, NH-90) and civil (Fokker prototype) aircraft. He was project leader for the design and installation of flight test instrumentation in an F-16 MLU aircraft of the RNLAF and project leader of the Advanced Flight Test Facilities project, which aims at general modernisation of flight test equipment within the NLR. At present he has tasks in instrumentation projects with regard to qualification and certification, system safety analysis and configuration management. In the past he presented papers about flight test instrumentation at symposia of the SFTE (1991, 2000, 2006) and AGARD (1996).

Rian Striegel holds a BSc degree in Electrical Engineering from the Institute of Technology of Amsterdam where he graduated in 1980. He then started working at NLR, the Netherlands Aerospace Centre, where now he is a Principal Project Engineer at the Aerospace Systems Division in the Aircraft Systems department. He was involved as a Flight Test Instrumentation Engineer in numerous civil and military flight test programmes all over the world. He has been instrumentation project manager for several NLR and European test programmes. Nowadays he is involved in the modernisation of flight test equipment and especially data processing at NLR. He has presented papers about flight test instrumentation at Dutch symposia and at the SFTE 2006.

Frank van Rijn holds a BSc degree in Electrical Engineering from the University of Rotterdam where he graduated in 2006. Since that time he works at the National Aerospace Laboratory at the department Aircraft Systems of the Aerospace Systems Division, recently as senior Project Engineer. He was involved in the design and installation of flight test instrumentation systems in military aircraft (F-16, several helicopter types; Apache, Chinook, Cougar, NH-90) plus instrumentation systems on board of several Navy vessels. He was project leader for the upgrade of the design and installation of flight test instrumentation in the F-16 MLU aircraft of the Royal Netherlands Air Force Test Aircraft J 066 the "Orange Jumper". At present he is extending the flight test instrumentation system for the F-16 MLU "Orange Jumper" with extra sensors for measurements during aerial refueling and store separation flight tests. In 2011 he participated in the SFTE engineer exchange program.

Yuri Oterdoom holds a BSc degree in Aeronautical Engineering from the University of Amsterdam in Professional Education where he graduated in 2001. Since that time he has been employed as an engineer at Fokker Technical Services, where he worked on F-16 Flight Controls Systems. Since 2003 he works as a Senior Maintenance Engineer F-16 Avionics and Armament at Directorate of Weapon Systems and Establishments Air Systems Branch Fighter and Trainer Aircraft Division Section Maintenance Engineering F 16. He was involved in the engineering and installation of flight test instrumentation systems in the F-16 MLU J-066 test aircraft “Orange Jumper” of the RNLAF. At present he is the “Orange Jumper” project manager and is involved with the development, testing and implementation of Satellite Communication (SATCOM) capability for the RNLAF’s F 16 fleet.

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WHAT IS NLR?

The NLR is a Dutch organisation that identifies, develops and applies high-tech knowledge in the aerospace sector. The NLR's activities are socially relevant, market-orientated, and conducted not-for-profit. In this, the NLR serves to bolster the government's innovative capabilities, while also promoting the innovative and competitive capacities of its partner companies.

The NLR, renowned for its leading expertise, professional approach and independent consultancy, is staffed by client-orientated personnel who are not only highly skilled and educated, but also continuously strive to develop and improve their competencies. The NLR moreover possesses an impressive array of high quality research facilities.

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