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Tornado FTI Refurbishment: Bridging Legacy and Modernity in Aerospace Engineering

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Abstract

The Tornado FTI Refurbishment Project aims to extend the aircraft's service life from its first flight in 1974 until 2030. This holistic modernization involves significant upgrades to the Flight Test Instrumentation (FTI) and Ground Stations (FTGS). Onboard communications are being transitioned from PCM (Pulse Code Modulation) to Ethernet, from S-Band to C-Band and data transmission is evolving from analog (/Ch4) to digital telemetry (SOQPSK/Ch7). Addressing electromagnetic compatibility (EMC) issues was crucial, with a specialized shielding concept ensuring the integration of new hardware with legacy systems. Infrastructure modernization, including upgrading a 30-year-old measurement system, was essential. Performed during the COVID-19 pandemic, the project demonstrated exceptional adaptability and innovation. This presentation explores strategies for managing obsolescence, enhancing EMI resistance, and integrating advanced technologies, offering valuable lessons for future aerospace modernization endeavors.

Key words: Tornado, FTI Refurbishment, EMC, Shielding Concept, Digital Telemetry, Ethernet

1. Introduction

The Tornado aircraft, first flown in 1974, has long been a critical asset for the German Air Force due to its versatile capabilities. Facing the need to delay the replacement of its Tornado fleet, the German Air Force decided to extend the aircraft's operational lifespan to 2030, increasing its flying hours from 6000 to 8000. This extension postpones the immediate need for new aircraft amidst debates between the Eurofighter Typhoon (EFA) and F-18. Consequently, the FTI refurbishment became essential to support this extended service life.

This FTI refurbishment project was driven by the necessity to maintain Germany's capability to carry out NATO's nuclear strike missions. However, it faced significant technical challenges: the 70's Tornado was developed with analog telemetry, non-encrypted FTI, no onboard Ethernet, a weak EMI protection... Additionally, the last major update to the Manching FTGS was over 20 years ago. The project involved a holistic modernization of these outdated systems while ensuring continuous operational readiness, requiring parallel maintenance of both legacy and refurbished environments.

The global context of COVID-19 and the war in Ukraine further complicated the project, provoking supplier difficulties and necessitating new ways of working. The simultaneous refurbishment of 3 Tornado versions adds another layer of complexity. Modernizing this obsolete infrastructure required meticulous planning and resource management to ensure that both infrastructures remain operational during the transition.

Managing these aspects has required robust project management strategies, effective collaboration across multiple departments (FTI, FTGS, EMC, Design Office, electric cables design), and innovative solutions to logistical challenges.

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2. Overview of FTI Architecture and Time Synchronization

2.1 General FTI Architecture

The FTI architecture is designed to handle the complex requirements of modern flight testing, integrating advanced data acquisition, processing, and transmission technologies. The architecture aims to improve data reliability, synchronization, and transmission efficiency.

3.1.1 Key components

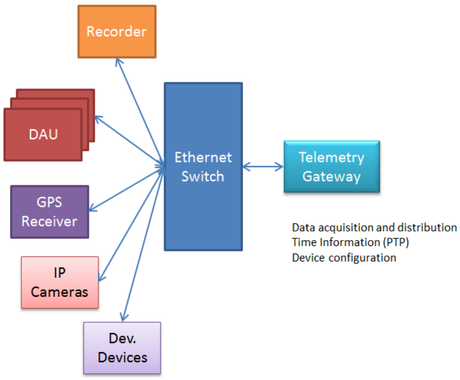

Fig. 1. Ethernet-based FTI architecture.

- Data Acquisition Units (DAUs) collect data from various sensors and systems throughout the A/C. These units are critical for capturing accurate and high-resolution data. Each DAU is equipped with multiple input channels that can interface with different types of sensors (temperature, pressure, acceleration, strain gauges...) and converts analog signals from sensors into digital data that can be processed and transmitted over the network.
- GPS Receiver: Provides precise time and positional data. The GPS receiver is critical for synchronizing the system clock with global time standards and providing positional data for flight analysis.
- HD Cameras: Capture visual data which can be integrated into the FTI system. Used to monitor various parts of the aircraft and provide video data that can be synchronized with other sensor data.
- Dev. Devices: Custom HW devices for specific data acquisition tasks. These devices can include specialized sensors, signal conditioners, and custom data processing units.
- Recorder: Captures and stores data from various sources for later analysis. Recorders are equipped with high-capacity storage devices and interfaces to receive data from multiple DAUs and other sources.
- Network Switches are central elements in the architecture that route data between different components using Ethernet-based communication. They handle data traffic management and ensure that data packets reach their intended destinations. These switches support advanced features such as VLANs, Quality of Service (QoS), and multicast traffic management to optimize network performance and ensure the reliable delivery of critical data streams.
- Telemetry Systems are responsible for transmitting the collected data to ground stations for analysis. These systems must handle high data rates and ensure reliable communication over long distances. Telemetry systems typically include RF transmitters, antennas, and receivers. The transmitted data is often encoded and compressed to optimize bandwidth usage and ensure data integrity during transmission.
- Synchronization Systems maintain precise timing across all components to ensure data integrity and accurate correlation. These systems are essential for coordinating data collection and ensuring that all recorded data is properly time-stamped. Synchronization is achieved using protocols such as PTPv2 (Precision Time Protocol) and IRIG-B. These systems also compensate for network delays and jitter to maintain high-precision synchronization across all devices.
- Ethernet Switch: Central hub for data routing and distribution. The switch connects all networked devices and manages data traffic to ensure efficient and reliable communication.
- Telemetry Gateway: Transmits data to ground stations and provides time synchronization and device configuration information. The telemetry gateway encodes and transmits data over RF links to ground-based telemetry stations.

3.1.2 Ethernet-Based Communication

The transition from traditional PCM to Ethernet-based on-board communication provides several advantages:

- Higher Data Rates: Ethernet supports much higher data transmission rates compared to PCM, enabling the transmission of large volumes of data efficiently. Ethernet networks in FTI systems can support gigabit and even 10-gigabit speeds, allowing for the simultaneous transmission of multiple high-bandwidth data streams.

- Flexibility: Ethernet allows for multipoint communication, enabling one-to-many and many-to-many data exchanges. This flexibility is crucial for modern FTI systems that need to handle diverse data sources and destinations. Ethernet switches can dynamically manage connections between devices, facilitating flexible and scalable network architectures.

- Standardization: Utilizing standard IP-based protocols simplifies the integration of new equipment and technologies, making it easier to upgrade and expand the system. Standard protocols such as TCP/IP, UDP, and PTP ensure interoperability between different vendors' equipment and future-proof the system against evolving technologies.

3.1.3 Data flow and routing

Network switches manage data flow within the FTI system. Data packets are routed based on IP addresses and port numbers, ensuring that they reach the correct destinations. Switches can also prioritize traffic, ensuring that critical data is transmitted with minimal delay. The data flow is designed to minimize latency and maximize throughput, which is essential for real-time data acquisition and telemetry.

2.2 Time-Synchronization in FTI systems

Accurate time synchronization is critical in FTI systems to ensure data integrity and proper correlation of events. The FTI system uses Precision Time Protocol version 2 (PTPv2) for this purpose.

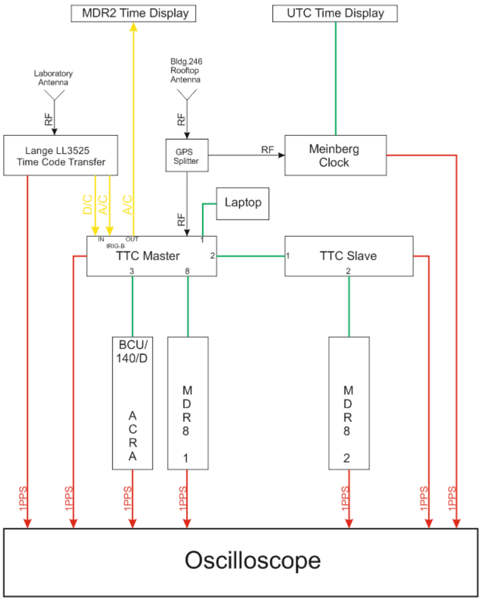

Fig. 2. Test architecture

3.2.1 Time-Synchronization methods

Primary Time Source: GNSS: The primary time source for the FTI system is the Global Navigation Satellite System (GNSS). The TTC master switch acts as the PTP grandmaster clock, continuously synchronized with GNSS. This provides highly accurate timing information to all network components.

PTPv2 Protocol: PTPv2 distributes timing information across the network. The protocol operates based on International Atomic Time (TAI) and compensates for network delays to ensure precise time synchronization. PTPv2 messages include synchronization, delay request, delay response, and follow-up messages to accurately measure and adjust for network delays.

3.2.2 Backup Time Sources

1) IRIG-B (DC and AC Codes): IRIG-B signals serve as secondary time sources when GNSS is unavailable. IRIG-B signals provide a reliable means of maintaining synchronization and are widely used in aerospace applications. IRIG-B transmits time information as a serial digital signal, which can be either DC-coded or AC-modulated.

2) Internal RTC (Real-Time Clock): The internal RTC of the TTC master switch is used as a last resort when external time sources are unavailable. The internal clock maintains time with a known drift rate, ensuring continuity of operation until external sources are restored. The RTC is periodically calibrated to minimize drift and maintain accuracy over extended periods.

3.2.3 Time Distribution in the Network

1) Grandmaster Clock: The TTC master switch, synchronized to GNSS, serves as the grandmaster clock. It provides the reference time for all other devices in the network. The grandmaster clock sends periodic synchronization messages to maintain consistent timing across the network.

2) Slave Clocks: Other network components, such as the TTC slave switch, ACRA DAUs, and Heim data recorders, synchronize to the grandmaster clock using PTPv2. This ensures that all components share the same time base. Slave clocks adjust their local time based on the received PTPv2 messages to stay synchronized with the grandmaster.

3.2.4 IRIG-B synchronization

IRIG-B signals are used to synchronize components in environments where GNSS signals are weak or unavailable. The system can switch between DC and AC codes based on availability.

3.2.5 Priority Order for Time Sources

a. IRIG-B (DC Code): Preferred source for manual synchronization before flight or test. This code provides high precision and is less susceptible to noise.

b. GNSS: Primary source for in-flight synchronization, providing the most accurate and stable time reference.

c. IRIG-B (AC Code): Used if GNSS is unavailable. This code is typically used in noisy environments where DC coding might be impractical.

d. RTC: Used if no external time sources are available. The RTC provides a fallback timing mechanism with known drift characteristics.

3.2.6 Testing and Validation of Time Synchronization

Various tests were conducted to validate the time synchronization capabilities of the FTI system. The following key results were obtained:

1) Timing Difference between Lange Time Code Transfer Unit and Meinberg Laboratory Time Reference:
   - Supplied by different antennas: ~110ns
   - Supplied by the same antenna: ~20ns
2) Time Synchronization of TTC Master Switch with GNSS:
   - Offset: ~96ns
   - Jitter: ~37ns
3) Time Synchronization with IRIG-B:
   - DC Code: Offset ~240ns, Jitter ~24ns
   - AC Code: Offset ~1.6us, Jitter ~2.1us
4) Synchronization of Slave Components:
   - TTC Slave Switch: Offset ~140ns, Jitter ~50ns
   - BCU/140/D: Offset ~62ns, Jitter ~99ns
   - MDR8 Units: Offset ~155ns, Jitter ~34ns

These results demonstrate the system's capability to maintain precise time synchronization across various components and conditions. The tests confirm that the FTI system can achieve nanosecond-level synchronization accuracy, which is essential for high-precision data collection and analysis.

3.2.7 Drift and Resynchronization

The drift rate of the RTC in the TTC master switch was evaluated under two scenarios:

- <u>Power-on drift</u> (without external time sources): 30μs/hour
- <u>Power-off drift</u> (after reconnection and synchronization with GNSS): 1.5ms/h

These measurements indicate that while powered, the internal RTC maintains a low drift but a higher drift rate is observed when powered off.

3.2.8 System Restart & Resynchronization

Several power resets were performed to evaluate the resynchronization behavior:

- <u>Master Switch</u>: 45s to resynchronize.
- <u>BCU/140</u>: 70s.
- <u>Slave Switch</u>: 100s
- <u>MDR8 units</u>: 120s
- <u>Whole system</u>: 140s

The timings indicate the time required for each component to achieve full synchronization post-reset.

3.2.9 Configuration adjustments

The MDR8 unit offers an "OFM-Shift" setting for clock offset adjustments:

- <u>Default setting</u>: 0 ns.
- <u>Adjustments tested</u>: Shifts to 170 ns and -100 ns to optimize synchronization

3.2.10 Recommendations

To ensure the highest level of precision and stability in time synchronization across the FTI system, the following recommendations are made:

- <u>Stabilization Period</u>: Allow at least 3 minutes post power-on before beginning operations to ensure all components are fully synchronized.
- <u>Synchronization Code</u>: Utilize IRIG-B DC code for manual time synchronization to achieve the best stability.
- <u>OFM-Shift: Employ</u> the MDR8 OFM-Shift setting for fine-tuning synchronization, adjusting as necessary based on detailed test results.
- <u>Operational Time Base</u>: Maintain UTC as the operational time base within the FTI system to avoid frequent reconfigurations and ensure consistency

By integrating robust synchronization methods and structured IP/UDP address allocation, the FTI system provides a scalable and high-performance solution for modern flight test requirements, ensuring accurate and timely data for analysis.

3.3 IP Address and Port Allocation for FTI Systems

3.3.1 General principles

Structured IP Address Allocation: The IP address allocation strategy is designed to ensure efficient routing and prevent conflicts within the network. By utilizing a designated IP address range, each subsystem and device can be uniquely identified, which is crucial for seamless communication and integration.

Segmentation by Subsystem and Device Type: To manage network performance and isolate traffic, each subsystem within the FTI architecture is assigned a unique range of addresses. Specific IP address ranges are allocated based on the type of device and its serial number, ensuring clear identification and preventing conflicts between different types of equipment.

Database Integration: When devices are received, they are logged into a component database where IP addresses are assigned according to the established schema. These IP addresses are then configured into the devices to ensure seamless integration into the network.

3.3.2 Destination IP Address Allocation

UDP-Based Communication: The FTI system utilizes UDP extensively due to its low latency and minimal overhead, which are essential for real-time data transmission. Multicast IP addressing is employed to efficiently distribute data to multiple destinations, ensuring that all necessary devices receive the required data streams simultaneously.

Multicast Addressing: A designated range is reserved for multicast traffic, segmented to avoid conflicts and ensure organized data flow. Addresses within this range are allocated by project and data stream, allowing for clear and manageable data distribution.

IGMP Management: The Internet Group Management Protocol (IGMP) is implemented to manage multicast group memberships. Devices use IGMP to join and leave multicast groups as needed, ensuring they receive the relevant data streams and optimizing network traffic.

3.3.3 Routing and Data Management

Switch-Based Routing: Network switches route data based on destination addresses, managing traffic efficiently to ensure prompt transmission. Prioritizing critical data is essential to minimize latency and maintain the high performance required for real-time data acquisition and telemetry.

Multicast Management: Devices use IGMP to signal switches to forward specific multicast streams. This approach minimizes unnecessary traffic, ensuring efficient communication and reliable data delivery across the network.

3.3.4 Destination Port Allocation

Structured Port Allocation: Ports are allocated systematically to ensure clear identification and prevent conflicts. This allocation is based on the function of the service or application and data format, promoting organized and predictable communication patterns.

Protocol Identification: Each subsystem and protocol are assigned specific port ranges to differentiate data streams effectively. Different subsystems and devices use specific port ranges to avoid conflicts and streamline network traffic management, facilitating easier troubleshooting and monitoring.

4 EMI & new shielding concept

4.1 Background and Initial Findings

Our investigation aimed to understand the root causes of EMC/EMI issues in the Tornado aircraft's FTI system. During the initial EMC System Interaction Testing, significant interference was detected on the UHF "Guard Channel" (=emergency channel). The sample measurement shown in Figure 3 illustrates these significant EMI peaks. These issues were particularly concerning as they could compromise the safety of the aircraft.

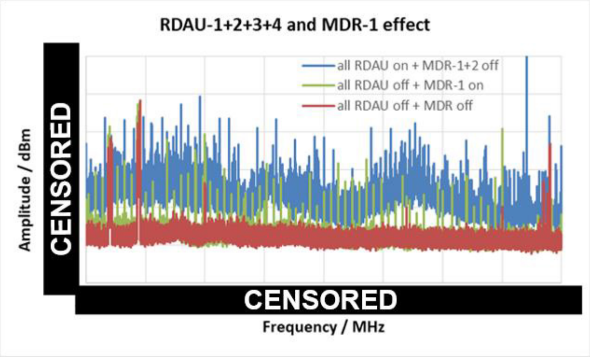

Fig. 3. EMI measures with the legacy shield

High levels of broadband EMI (peaks & higher floor level) were found in the ventral avionics bay containing the RDAU units, covering VHF and UHF bands, and a repetitive "raster" signal near the MDR (Modular Data Recorder) unit in the left-hand bay.

4.2 Problem identification

4.2.1 Shield terminations and grounding

Our assessment of the FTI installation revealed several core issues. Cable shield terminations were often bonded only at one end, and shields were grounded through connector pins, leading to poor EMI containment.

4.2.2 Use of pigtails

Some cable shields were connected to ground using long pigtails (over 30 cm), significantly increasing susceptibility to EMI. EMC engineers commonly identify poor cable shielding and terminations as primary issues associated with system-level emissions. Often, these poor terminations occur when a cable’s shield is twisted into a single wire, known as a “pigtail,” and connected to ground. While pigtails were a practical, inexpensive, and easy-to-use solution suitable for the infrastructures of the 1970s, they are now completely inadequate in a modern architecture with much stronger EMI.

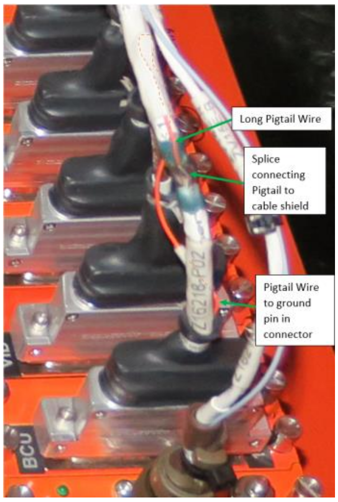

Fig. 4. Example of a bad pigtail: 17cm long, connected via a pin in the connector to the chassis inside the housing

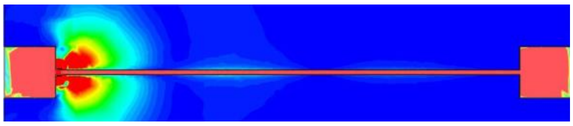

Fig. 5. Illustrative EMI measures of an installation with a pigtail on the left (http://rfemcdevelopment.eu/)

4.2.3 Connector Bonding Issues

Connector inspections revealed that paint on the shells prevented proper bonding to the mounting plates and many shields were not correctly bonded to their shells. Figure6 shows on its upper part a shield not bonded to the connector shell with the pigtail fed through a pin while its lower part illustrates a correctly bonded shield.

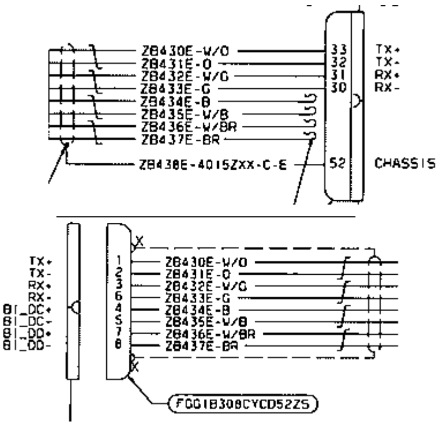

Fig. 6. Old (up) vs new shield (below): from not bonded to connector shell to correctly bonded to connector shell

Further examination indicated that improper shield terminations and liberal use of pigtails were significant contributors to the high EMI levels observed. Moreover, the presence of paint on the connector shells further impeded effective grounding leading to increased electromagnetic interference.

4.3 Problem resolution

4.3.1 Revised electrical drawings

To address these issues, we revised the electrical drawings (see Figure6) to ensure proper shield terminations.

4.3.2 Corrective Measures

We corrected the bonding at connector backshells, removed the pigtails (preferring a more expensive but more efficient 360° coverage at the connectors), and ensured all shields were grounded directly to the connector shells or chassis. Additionally, we adjusted the FTI datalink transmission rate to shift the raster signal off the guard channel frequency. The implementation steps included updating the electrical drawings, reinstalling the corrected cables, installing High-Pass filters in the TXs (telemetry transmitters), and verifying the effectiveness of these adjustments as illustrated in Figure5. These corrective measures were developed in consultation with the EMC department to ensure comprehensive resolution of the underlying issues.

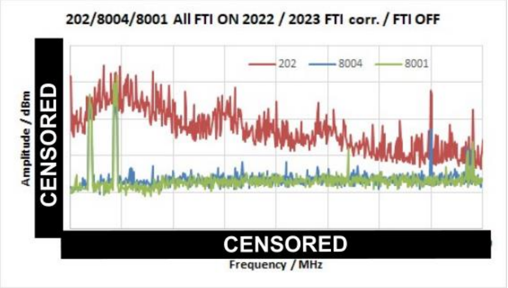

Fig. 7. Old shield (red) vs new shield (blue)

4.4 Verification and assessment

4.4.1 Post-Implementation Measurements

Following the implementation of the corrective measures, we conducted post-implementation measurements to verify their effectiveness. The comparison of EMI levels shows a significant reduction after the corrections, confirming the success of our solutions. The red line (202) represents the EMI levels before corrections, the green line (8001) shows the ambient environment, and the blue line (8004) indicates the levels after implementing the corrective measures.

4.4.2 Antenna Pickup Measurements

Additionally, antenna pickup measurements confirmed the absence of interference (no peak, no floor augmentation) on the guard channel frequency. These results demonstrate the effectiveness of the implemented solutions in mitigating EMI issues and improving overall system performance.

4.5 Specific action for GS-062 and GS-117

4.5.1 Compliance with PAN 6850

Based on EMC recommendations, we ensured all FTI cabling installations complied with PAN 6850. We replaced existing Ethernet cables with higher category cables where necessary and removed the pigtails.

4.5.2 Cable Replacement and Bonding

Proper bonding of all connectors to the chassis or shell was also ensured. The execution plan involved sequencing the refurbishment and testing of GS-062, GS-177 and GS-217, prioritizing immediate testing and verification for GS-062, focusing on electrical drawings creation for GS-217, and final implementation for GS-177.

4.6 Summary of the new shielding concept

4.6.1 Overall shielding approach

Our new shield concept involves utilizing an overall shield for cable bundles, connected with 360° coverage at the connectors, providing superior shielding compared to previous methods. This approach enhances EMI performance, improves signal integrity, and ensures compliance with PAN 6850 standards.

4.6.2 Implementation & cooperation

Moving forward, we will continue to work with manufacturers to improve the EMC characteristics of the MDR telemetry card and monitor and verify EMI levels post-refurbishment to ensure long-term compliance. This comprehensive shielding approach is designed to prevent any electromagnetic interference from affecting the sensitive instrumentation systems, ensuring reliable data transmission and system performance.

4.6.3 Impact of the new Shield Concept

The implementation of this new shield concept is a significant step towards maintaining the integrity and reliability of our flight test data. Ongoing collaboration with manufacturers will be critical in refining these shielding techniques and adapting them to future technological advancements.

5 FTI & telemetry upgrades

5.1 Context

The refurbishment of the Tornado aircraft's telemetry systems marked a significant technological transition from analog S-Band/FM/Ch4 telemetry to a more advanced digital C-Band/SOQPSK/Ch7 system, incorporating a new Modular Data Recorder (MDR). This shift aimed to enhance the capabilities and efficiency of data acquisition and analysis but introduced complex synchronization challenges.

5.2 First implementation: synchronization issues

The initial setup in the upgraded telemetry system, referred to as the 'red solution', involved randomizing data at the transmitter outputs (TX). This configuration did not include randomization between the MDR and the TXs, which necessitated a clock signal due to the absence of randomization in this segment.

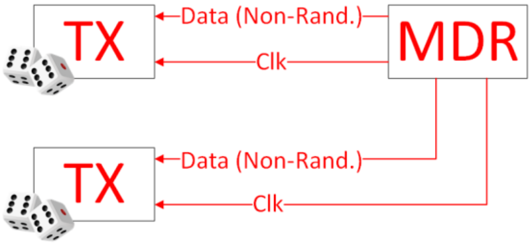

Fig. 8. First implementation: NRZL between MDR and TX. Randomization at TXs level

This initial setup in the upgraded telemetry system, involved randomizing data at the transmitter outputs (TX) level.

Nevertheless, with this setup, synchronization issues were noticed on the received signal at the FTGS.

- <u>FTGS point of view</u>: The FTGS team observed no issues within their receiver (RX), decryptor, or Ground Modular Data Recorder (GMDR) chain, suggesting that the challenge might originate from the FTI configuration itself.

- FTI point of view: The FTI team noted that this setup worked without issue both when used with the Dimona test aircraft and within the FTI labor, the problem may then come from the data processing at the FTGS.

It has been finally discovered that the synchronization problem was occurring on the FTI side, more specifically from the decentralized randomization taking place at the level of the 2 TXs which led to timing discrepancies between outputs. Even small (some ms), they were enough to provoke the signals desynchronization.

Since the Dimona has only a single TX, this problem was not detected when testing this setup with this test A/C in an earlier phase. Similarly, in the FTI labor with 2 TXs, power levels were much different from real cases, and not provoking this symptom.

5.3 New implementation

Recognizing the need to address the transmitter synchronization issue, a new setup was developed, with a centralized randomization at the MDR level, ensuring synchronized outputs and eliminating the discrepancies observed with the first setup.

Fig. 9. New implementation: R-NRZL between MDR and TX. Randomization at MDR level

5.4 Temporary mitigation

While identifying the issue developing a fixes setup, a temporary configuration was implemented to maintain system functionality without interruptions: we temporarily used a C-Band/Analogical FM/Ch4 configuration, combining the new standard C-Band frequency with the legacy analog modulation. This setup provided a middle ground by utilizing the new frequency band while maintaining the more synchronization-tolerant FM modulation until the new FTI setup was fully operational.

6 Lessons learnt

- Project Management Complexity: Managing simultaneous refurbishments of multiple Tornado models required meticulous planning and execution. Balancing the integration of new measurement systems, regular maintenance, and synchronization of updates without disrupting the project timeline underscored the importance of effective project management.
- Strategic Financial and Technical Resource Allocation: Effective financial management was critical for integrating advanced systems and new telemetry infrastructure. Addressing obsolescence in test installations and measurement systems required significant investments in new HW and SW, highlighting the need for strategic resource allocation. A poorly managed refurbishment could cost more than the purchase of a new fleet on the long term.
- Stakeholder relationships: External factors such as COVID-19 and geopolitical tensions complicated supplier management and logistic. This underscored the value of maintaining robust relationships with stakeholders like WTD61 and various suppliers to ensure consistent supply and integration of components.
- Specificities in working with old systems: Working with ancient systems brings specific challenges, including poor documentation and outdated concepts from an era of a.o. low EMI levels and non-encrypted flight transmissions. Some original suppliers no longer exist or have been acquired, complicating spare parts sourcing and upgrades. Adapting to new regulations required detailed engineering assessments and documentation updates, especially for EMC PAN 6850 compliance. Overcoming certification hurdles for older components highlighted the need for reevaluating standards. Be prepared to retest and recertify ancient systems and develop hybrid solutions that integrate legacy technologies with modern standards to ensure compatibility and functionality. These challenges highlighted the importance of a good documentation and extensive personnel trainings.
- Managing Parallel Infrastructures: The FTI refurbishment required the parallel maintenance of two dedicated infrastructures for the Tornado (Legacy & Refurbished): two complete SW chains (FTI to FTGS) and two SW ecosystems on the FTGS side (Pre-Flight/In-Flight/Post-Flight). This added complexity to an already intricate environment, as other programs like the EFA are managed simultaneously. Developing a refurbished version did not eliminate the need to support the legacy version, which continues to operate concurrently.

- Testing under real conditions is irreplaceable: The difference between controlled test scenarios and real operational environments highlighted the need for more robust and realistic testing protocols. Unexpected system behaviors in actual conditions emphasized the importance of thorough real-world testing.
- Value of Cross-Departmental Collaboration: Successful refurbishment relied heavily on collaboration across multiple departments, including FTI, FTGS, EMC, DO, and electrical drawing. This cooperation was vital for solving complex issues and integrating various system components effectively.

7 References

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9 Glossary

ADS	Airbus Defence and Space
a.o.	Amongst Others
BCU	Bus Control Unit
clk	Clock
Dimona	Dimona H-36 D-KARG A/C
DO	Design Office
EFA	Eurofighter
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FM	Frequency Modulation
FTGS	Flight Test Ground Station
FTI	Flight Test Instrumentation
(G)MDR	(Ground Based) Modular Data Recorder
GNSS	Global Navigation Satellite System
GS	German Strike
GT	German Tactical
IGMP	Internet Group Management Protocol
IP	Internet Protocol
IRIG	Inter-Range Instrumentation Group
NRZL	Non-Return-to-Zero-Level
PAN	Panavia
PCM	Pulse Code Modulation
PTP	Precision Time Protocol
QoS	Quality of Service
RNRZL	Rand. Non-Return to Zero Level
RTC	Real-Time Clock
SOQPSK	Shaped Offset Quadrature Phase-Shift Keying
TOR	Tornado
TTC	Trigger, Timing, and Control
UDP	User Datagram Protocol
UHF	Ultra-High Frequency
VHF	Very High Frequency
WTD	Wehrtechnische Dienststelle