DOI 10.5162/ettc2018/6.1

MIL-STD-1553B and it's potential for the future

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Abstract:

MIL-STD-1553B (MILBUS) as a network standard for military systems – with a data rate of 1 Mbps – comes across as (and is) a little out-dated, but is still well-known for its reliability, safety and the strong determinism of a real time bus protocol. The strong electromagnetic immunity of MILBUS has given rise to a number of new applications for military and civil programmes, as well as some lightweight applications with unshielded cables.

But the future will lead to higher speeds and we have made several efforts to implement the excellent MILBUS command/response protocol in modern and faster physical networks. The data rate capability for EFABUS / STANAG 3910 was raised by means of a parallel network. The result was the optical EFABUS Express. MIL-STD-1760E for stores defines a switched electrical Fibre Channel interface for mapping MIL-STD-1553 messages and for 1 Gbps mass data transfers. A fibre optic interface will follow. Another concept is the implementation of a collision- and delay-free protocol at Ethernet level.

Another option, especially for upgrade programmes, is E1553 / STANAG 7221, whereby available MILBUS cables are retained for a Broadband Real-Time Data Bus (B-RTDB) with Multi-Carrier Waveform (MCW) protocol for higher data rates.

Key words: Data Bus, MIL-STD-1553B, MIL-STD-1760, Fibre Channel, Fibre Optical

MIL-STD-1553B (MILBUS) introduction

Conceptual studies for the MIL-STD-1553 started in the 70s for the F-16 weapon bus. The idea was a robust and electromagnetic immune command/response data bus that can work in harsh environments to replace dedicated analogue or discrete connections between multiple avionics equipment within a military aircraft (A/C).

MIL-STD-1553B is now an international networking standard for the integration on military platforms and also for some applications on civil programmes. The revision of MIL-STD-1553B + Notice 2 [1] has been adopted by NATO as STANAG 3838.

The key element is a Bus Controller (BC) and various subsystems that function as Remote Terminals (RT). A Bus Monitor (BM) function is optional. Information data transfers are initiated by commands on a command/response protocol that can address up to 31 different RTs individually. Each RT (0…30) retains up to 30 Sub-Addresses (SA 1…30) for transmitting and 30 for receiving messages. Each message has maximum 64 bytes in 16 bit of data word format. (Fig 1, 2, 3). A status word indicates possible failure states. Command and status words differ from normal data words through a dedicated sync. Each word ends with a parity bit.

Broadcast transfers (RT 31) are also provided. Special mode commands (SA 0, 31) and programme-specific protocols for mass data transfer complement the protocol. The data code is Manchester II bi-phase. MILBUS has a very limited data rate of 1 Mbps.

The network is a shielded twisted pair wire with optional isolation couplers, the terminals are connected via bus-stubs (Fig 1).

Some parameters of the MILBUS network are:

- Zo: 70 – 85Ω (cable impedance)
- R_A: Zo ± 2% (bus termination)
- R_I: 0.75 Zo (fault isolation resistor)
- Cable (bus, stub): max 1.5dB/100ft (1 MHz)
  max 30 pF/ft

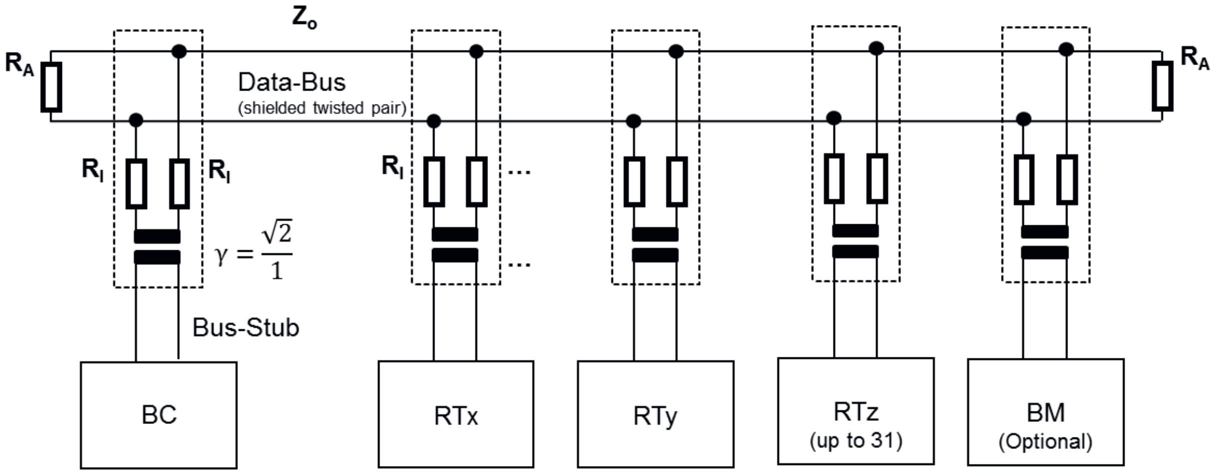

Fig 1: MIL-1553-B Data-Bus with isolation couplers for transformer coupled Bus-Stubs

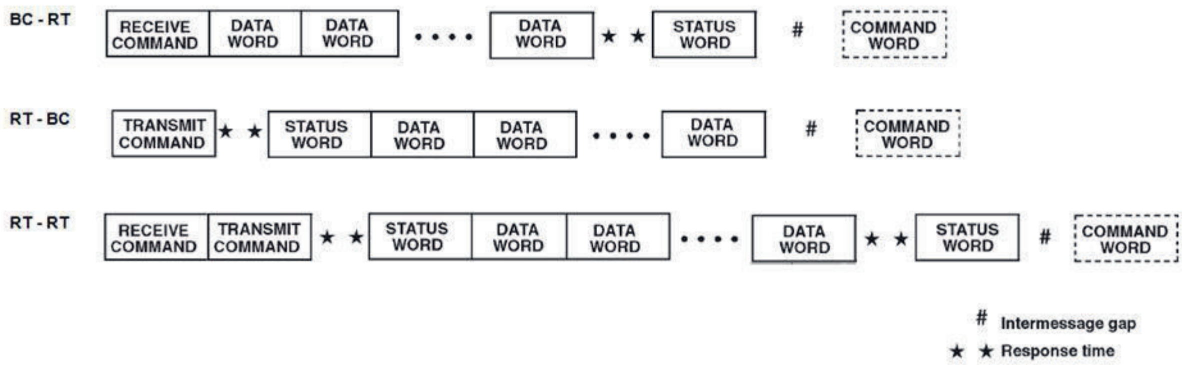

Fig 2: Typically information data transfer types [1].

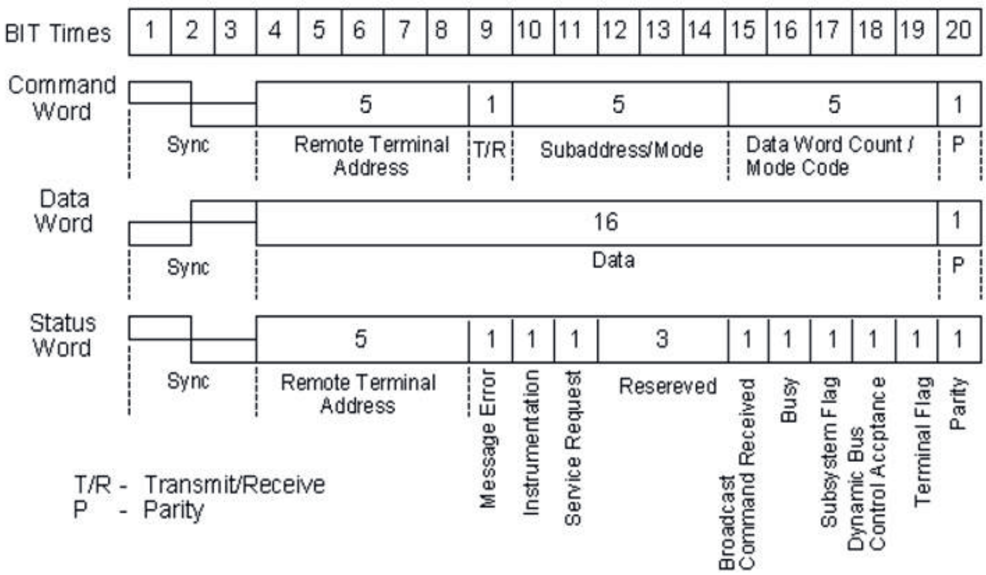

Fig 3: Command-, Data- and Status Word format [1].

Fig 4: A typical MILBUS-Message (Teledyne LeCroy WaveRunner with 1553 TD Trigger and Decode package)

Fig 5: Eurofighter A/C [2]

Special characteristics of MILBUS are:

- A physical layer with high electromagnetic immunity and therefore a very low error rate. Robust, for harsh environments. Technically mature by more than 40 years of service history.
- A deterministic strong synchronous operation for cyclic messages with very low timing jitters. The terminals synchronise themselves on the bus protocol. This results in high stability of the control circuit in an A/C. Acyclic messages are also possible.
- Immediate reaction to changes in operational situations, critical events or failures is possible by a fast command overwrite function.
- The direct and passive bus structure provides very easy access directly to the physical data transmission of the flight control and avionic subsystems. This structure enables rapid diagnostics and facilitates qualification- and certification activities.
- For safety reasons, a different redundancy concept was considered – in most applications the network is dual redundant and there is also redundancy of the BC

function. Quadruplex bus concepts are also known; for example for the safety-critical Eurofighter Flight Control System (FCS).

- The electrical bus network concept (impedance, termination resistors, isolation couplers and fault isolation resistors) determines a minimum system attenuation of 12dB. The bus length (Fig 1, Data bus) is not specified in MIL-STD-1553B. Our experience is 100m or even longer, if necessary.

Known problems with some new MILBUS applications:

In new applications, customers often do not consider the large variation in specified cable impedance for the MIL-STD-1553B standard, which is defined between 70 – 85Ω. This often leads to a negative effect of an undefined cable und a mixture of different bus terminations and isolation resistors. The consequence is often a very diverse impedance matching and a data bus with very limited performance. For this reason, the impedance of the bus system and all its components should be clearly defined. For the Eurofighter and many other programmes, for example, impedance was strictly defined at 77Ω ±2%.

Than, the standard retains the option for directly coupling a bus stub without the use of bus couplers. That sounds cheap, but in this case, the protection is lost in the event of a shortcut on a terminal. (Fig 6.). All terminals of the entire data bus are then affected by an invalid Manchester code. In addition, practical experience in electromagnetic compatibility (EMC) shows that a symmetric (twisted pair) and transformer coupled electrical bus connection has significantly better EMC interference immunity (noise-, common mode rejection and electrical DC isolation) than a bus without couplers for isolation.

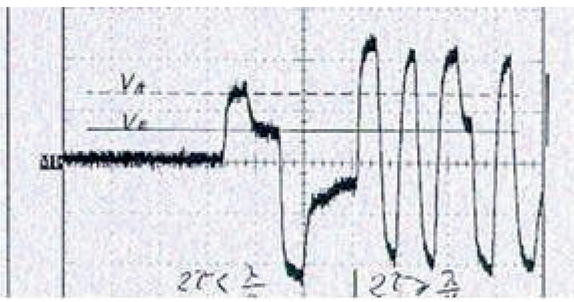

Fig 6: Signal distortion by a distant shortcut

These are the reasons why in MIL-STD-1553A the maximum permitted stub length for directly coupled stubs has been limited to 1ft (0.3m). In addition, MIL-STD-1553B + Notice 2 only permit transformer-coupled stubs for US Army and Air Force applications. In most A/C programmes, including the Eurofighter, direct coupling is prohibited in any case.

However, the fault isolation resistors of correct transformer-coupled stubs (Fig 1) protect the data bus from the effect of a single shortcut on a terminal. Only the directly affected terminal will fail in this case – other terminals are not affected.

But there is also a frequent problem with transformer-coupled stubs: Very often applicants try to 'save bus length' by exceeding the stub length (Fig 1, Bus stub). If a data bus is terminated correctly, the bus length is not a very critical factor; while the back reflection and the capacitive load of a long stub cable will degrade the whole bus signal.

For example, a transformer-coupled bus terminal on a bus stub of up to a maximum of 10ft (3m) causes an electrical load of >800Ω on the data bus, while the electrical load of a bus stub of more than 20ft (6m) is often 500Ω or less (see [2], figure I-1.7).

For this reason, the MILBUS standard recomends transformer-coupled stubs should not exceed 20ft [1]. However, in many A/C programmes, including the Eurofighter, stub length for transformer-coupled stubs is strictly limited by definition to a maximum of 10ft, except for longer test ports that are not connected during flight operations.

There is also a complex situation with upgrade programmes:

- Do we really need an upgrade from MIL-STD-1553B – or is it an earlier version like MIL-STD-1553A, which is quite different. (see [2], table II-2 and II-4.5.1.5.3)
- Then we have the known problem with the variation of cable impedance. An upgrade or extension should be performed with cables and components of the same impedance (Zo) as the original system.

As MILBUS is very reliable and failure tolerant, there is often a sloppy design approach with many small failures and over-tolerances – one argument for this is, why? It works!...

With upgrade programmes, there is often a small change and suddenly a limit is overdue. In this case very often a bus length over 10m is critical and the entire bus design has to be revised.

Based on this experience at Airbus Defence and Space, we found good practice by comparing the bus attenuation with an

DOI 10.5162/ettc2018/6.1

arithmetic bus model. The attenuation of critical bus components is additionally analysed during the design phase at a frequency of 0.2 to 5 MHz.

The assessment of signal quality (Fig 4, 6, 7) with an oscilloscope is also a relevant step in maintaining or reconstructing the physical signal quality. In case of reasonable doubt, we use a Time Domain Reflectometer (TDR) for additional fault analysis and determination of the existing cabling (Fig 8).

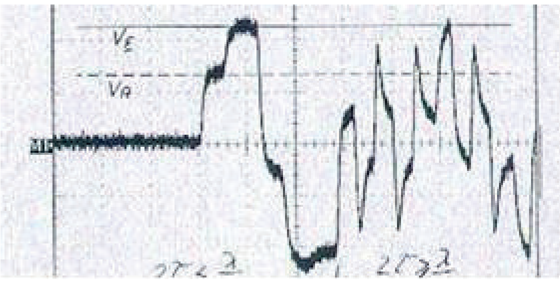

Fig 7: Signal distortion by a missing bus termination or a disruption of the cable (invalid Manchester code)

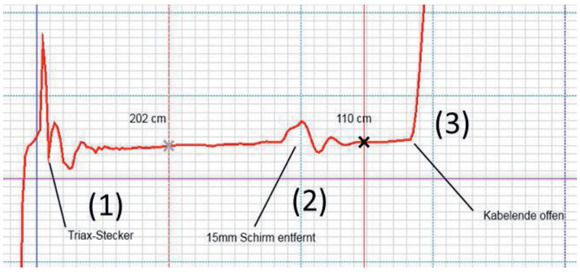

Fig 8: TDR for fault analysis: See wrong impedance of test adaption (1), fault on screen continuity (2) and missing bus termination (3)

In addition to wiring tests, our laboratory is one of only a few labs worldwide capable of performing the complete MILBUS RT Validation Test Plan to verificate the design of remote terminals. This includes protocol tests and physical tests such as signal level, waveform, zero crossing and noise immunity test.

We offer automatic or manual MILBUS configurations and patches for test rigs and benches.

Then our AIDASS® (Advanced Integrated Data Acquisition and Stimulation Systems) test support system family is suitable for subsystem and system tests.

These services and products are also for the German 'System Support Centre' (SUZ). The SUZ in Manching provides support for the entire range of Tornado and Eurofighter needs in cooperation between the German Air Force on the national customer side and Airbus Defence and Space on the engineering and industry side [10].

Lightweight applications with unshielded cables

Lightweight applications with unshielded cables were sometimes in demand.

It is not possible to replace the shielded twisted pair directly with a simple twisted pair cable without shielding, as this has a cable impedance of about 110Ω in most cases.

A simple way to use unshielded lightweight cable is to replace the termination and isolation resistors with correctly calculated resistors for the actual cable impedance (Zo).

Concepts for enhanced speeds for the future

MILBUS with 1 Mbps data rate is out-dated in many cases and we need significantly higher speeds, and there have been several efforts to implement the excellent MILBUS protocol in modern and faster physical networks. However, most commercial data bus products do not fulfil the reliability and determinism of MILBUS without modifications.

STANAG 3910 / EFABUS / EFEx

An early attempt to increase data rate was STANAG 3910. The idea was to improve the MILBUS command/response protocol and wiring by adding an additional high-speed data transfer network.

In this way, the data rate capability for the Eurofighter avionic and attack bus was raised to 20 Mbps by an additional optical network with a star coupler. The first issue was EFABUS. This was followed by EFEx (EFABUS Express), now with the command/response protocol and the data transfers on the fibre optic, without necessarily using an electric network. The number of potential messages and the data block length has also been increased to 8 kbytes.

Fibre Channel (copper/electrical)

Fibre Channel is a deterministic protocol that guarantees the provision of information. Fibre channel enables copper and optical connection.

Fibre Channel is in the meantime the primary avionics bus for the latest A/C fighter programmes in the US arsenal, including the F-35 Joint Strike Fighter, F-18E/F and F-16 Block 50+ [5].

MIL-STD-1760E Class I for weapons and storages defined a switched electrical Fibre Channel interface for mapping MIL-STD-1553 messages and for mass data transfers at 1 Gbps for the high-speed weapon bus in SAE-AS5653B on the high bandwidth lines (HB) with PINs 2 and W [5], [6].

SAE-AS5653B [7] also describes the command and control protocol FC-AE-1553 on Fibre Channel.

FC-AE-1553 sub-addresses 1 to 30 are reserved for legacy MIL-1553 data transfers with a payload of up to 64 bytes. Known broadcast transfers, mode commands and error handling protocols are also available.

Another transfer type is for MILBUS with an extended payload of up to 2 kbytes. Extensions for large file are about 4 Gbytes.

The switch is non-blocking to ensure minimal transport delays. The cable is a copper 75Ω coaxial.

SAE-AS5725B for miniature mission store interface (MMSI), which will be relevant for military UAVs in the future, is also considering a Fibre Channel interface.

Ethernet

Ethernet has great potential in commercial applications, but Ethernet and IP-based networking is not deterministic enough to replace MIL-STD-1553B.

However, commercial off-the-shelf (COTS) systems and thus Ethernet-based communication systems are increasingly being introduced for non-real-time and non-safety-critical mission systems, image processing and sensor fusion. The same applies for example to cabin entertainment systems on commercial A/C.

MILBUS is not very common in commercial aviation and Avionics Full DupleX Switched Ethernet (AFDX® / ARINC 664, part 7) as a protocol who guaranties a calculable maximum latency has been established mainly as replacement for ARINC 429 serial data links [8].

In Airbus Defence and Space technology programmes, additional an Ethernet-based collision- and delay-free and therefore deterministic command/response protocol, internally called MILBUS via Ethernet, was examined and patented. The principle is comparable with the FC-AE-1553 protocol on Fibre Channel or EFEx. MILBUS via Ethernet protocol is also planned for legacy MIL-1553 data transfers and for additional messages with increased address space and block lengths.

FireWire / IEEE1394

FireWire is mainly used as a COTS mission data communication system on some A/C designs, including the F-35. SAE-AS5643B has established FireWire as a military and aeronautic standard. The standard does not consider a real-time protocol for legacy MILBUS data transfers.

Fibre optic interfaces

Fibre optic has excellent electromagnetic immunity and allows data rates of significantly more than 1 Gbps with a potential of up to 1 Tbps.

Therefore some current activities are in the field of fibre optic interfaces.

EFABUS and EFEx was a very early fibre optic application. This was also a time in which we had our first experiences with operating an A/C with fibre optic cables, connectors and interfaces. An additional OM 3 fibre connection with an Ethernet protocol is planned for the next generation Eurofighter.

In commercial aviation (Airbus A380 / Boeing 787) and in military transport A/C A400M, an interconnection system based on an OM 1 62.5/125 graded index fibre for point-to-point connections was established for bidirectional data transfer on 850/1300nm wavelength. Protocol is a fibre optic Fibre Channel.

MIL-STD-1760E Class I also reserved two bi-directional fibre optic interfaces between the aircraft and stores on PINs U and Y as a growth potential for future applications. At the moment, ‘the use of fibre optic interfaces by a mission store shall not occur until the optical and logical (protocol) characteristics of the fibre optic interfaces are added to this standard’ (see MIL-STD-1760E, 5.2.11 [6]).

Airbus Defence and Space technology has been investigating programmes for HSDN (High-Speed Data Network) optical bus protocols for several years. The investigation led to a mature product family of fibre optic data transmission (and optical sensing) technologies Highspeed Optical Reconfigurable NETwork (HORNET®), which are protected by several

DOI 10.5162/ettc2018/6.1

patents. Data rates of 1 Tbps are realistic for non-DAL implementations in laboratory environments, while data rates of more than 10 Gbps are realistic for DAL-A use. Initial product applications on A/C have already been implemented, combining the HSDN and Basic Mission Chain (BMC) functionalities to enhance customer experience throughout the operational chain. Airbus Defence and Space currently defines Maintenance, Repair and Operation (MRO) guidelines and concepts for standard installations of high-speed optic networks on any A/C.

The results of these investigations will have an impact on future MIL-STD-1760 fibre optic interfaces and are currently the subject of international standardisation.

E1553® / STANAG 7221

E1553® / STANAG 7221 (AAVSP-02, Edition A) [9] is a high-speed network designed for using the same wiring as MIL-STD-1553B. The motivation was to retain existing cables by adding a B-RTDB (Broadband – Real-Time Data Bus) on an existing MILBUS.

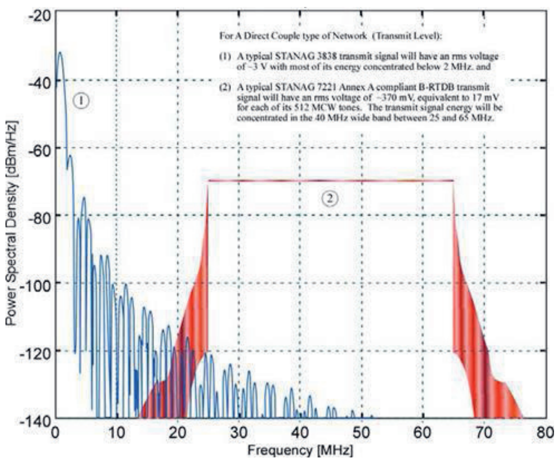

Fig 9: Typical B-RTDB Waveform representation [9]

Fig 9: Blue is the low band (1) of the legacy MILBUS operation. B-RTDB (in red) will operate on the high band (2) within a frequency between 25 and 65 MHz.

The principle is similar to the use of Digital Subscriber Lines (DSL) on an analogue telephone line for internet connection at home

The high band can alternatively be used for an additional high-speed MILBUS with BC and RTs, or for mass data transfers (example videos). The theoretical data rate is 100 Mbps when MIL-STD-1553B transfers on the low band are enabled.

250 Mbps should be possible on E1553 on an extended high band and without transfers on the low band (information is not conformed).

For evaluation purposes we used the E1553 demonstrator from Edgewater. The evaluation system worked well with the demonstrator's reference bus couplers.

For a random selection of bus couplers in an existing A/C, the transfer rate (bandwidth) was than less than 100 Mbps, in one case only 50.2 Mbps (Fig 10, 11.)

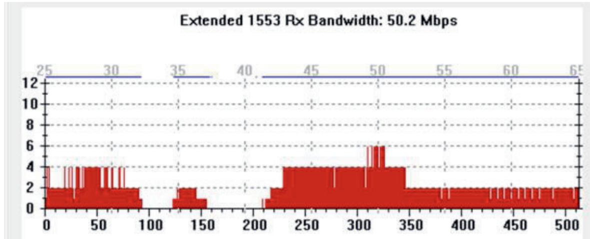

Fig 10: A B-RTDB tone map from the high band

The evaluation on an existing A/C (cockpit and weapon bus) was in the range of between 40 and 75 Mbps.

To find the discrepancy, we analysed the MILBUS couplers at a frequency of between 0.2 and 100 MHz, red (25 – 65MHz) is the relevant high band.

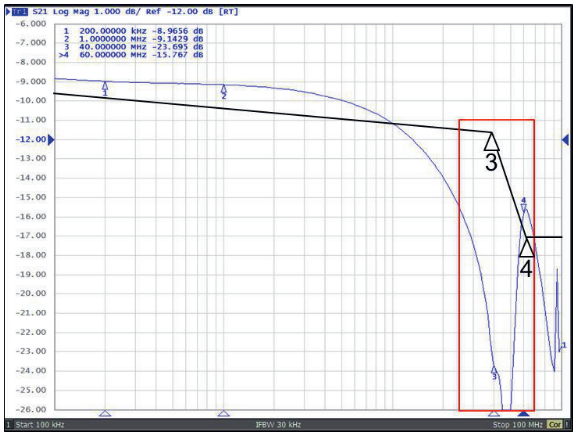

Fig 11: Coupler of an existing A/C

Explanation:

Coupler of an existing A/C (Fig 11): The specification of STANAG 7221 is not fulfilled; the deviation was up to 10 dB more attenuation at the relevant high band. This is the reason for a reduced data rate (Shannon Criteria).

The reference coupler from the evaluation kit is fully STANAG 7221 compliant (Fig 12).

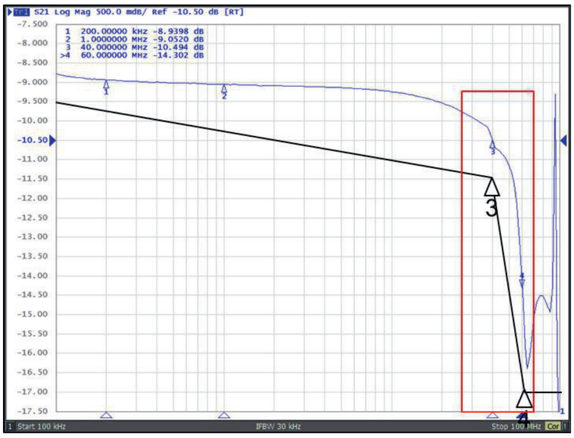

Fig 12: Reference coupler from the E1553 evaluation system

Remark: All couplers were fully compliant with MIL-STD-1553B, but not necessarily compliant with STANAG 7221.

See also the note in STANAG 7221 / AAVSP-02 A.3.2.1: 'These specifications do not apply to components used in actual legacy platforms. Expected baseline performance from an existing legacy platform can only be established by carrying out a system characterization' [9].

Other test results:

The attenuation of all newer MIL-STD-1553B compatible cables evaluated was no problem.

A B-RTDB protocol on the high band had almost no influence on bus performance and the bit error rate (noise immunity) on the legacy MIL-STD-1553B bus transfers on the low band.

If it is critical to install new cables, STANAG 7221 is an interesting approach to implement a data mass transfer between two systems by using an existing MILBUS network with a realistic data rate of a about 20 to 75 Mbps on the high band. Replacing all legacy MIL-STD-1553 LRUs by keeping the old cables and couplers was not considered as an option.

Currently we have no activities on STANAG 7221.

Conclusion

MIL-STD-1553B remains relevant for military A/C product upgrade programmes. MILBUS will also be a relevant communication system in the next generation weapon systems. Due to the very long product life cycle on military A/C, we do not expect MIL-STD-1553B to be replaced in the coming decades.

With new programmes, however, a partial replacement by modern products has already taken place.

Electric Fibre Channel has been established as an avionics bus in the new US fighter programmes and the FC-AE-1553 protocol is a direct replacement and high data rate upgrade of MILBUS. This protocol is already part of the MIL-STD-1760E for the military aircraft/store interconnection system.

However, for non-safety critical mission systems, image processing and sensor fusion, the trend in Europe is clearly towards Ethernet. The technology for MILBUS via Ethernet is also of interest for military avionics.

For both technologies, Fibre Channel and Ethernet based, an improvement by an increasing amount of fibre optics (instead of copper cables) is the foreseeable future. There has already been considerable progress made in standardisation.

EFABUS/EFEx for Eurofighter has not been used in any other programme.

STANAG 7221 B-RTDB will certainly find a place in some upgrade programmes in my opinion.

MILBUS without shielding was a question that came from space industry and from commercial consumer market. It is not known whether this technology is actually supported.

In commercial aviation I know of some applications where MILBUS with its high electromagnetic immunity was installed instead of ARINC 429 on modern carbon fibre composite laminate A/C structures. One application was for parts of the Airbus A350-XWB Wide Body Jet Airliner flight control system.

The author

Dipl.-Ing. Helmut Plankl is expert in data communication and test systems at Airbus Defence and Space Military Aircraft in Manching, which is located between Nuremberg and Munich, Germany.

In this position, Helmut has 30 years of experience in the field of system design verification and validation, technical problem solutions and aspects of continuous product and process improvement.

He is responsible for technology projects to improve economy and efficiency of ground testing facilities for civil and military air systems.

In the field of electrical and fibre optic communication systems, he is a recognised specialist for MILBUS and deterministic communication protocols and has been consulted on many European programmes. He was involved in the development of EFABUS/EFEx. He was one of the first to conduct studies on E1553 in Europe.

One focus of his work is the improvement of methods, engineering tools and diagnostic systems to improve the safety and reliability of wired and fibre optic airborne communication systems.

Helmut and his extended team hold some patents and are members of global standardisation groups. The AIDASS® test support system is one of the products developed by this team.

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