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FIBRE OPTIC DATA TRANSMISSION SYSTEMS FOR HELICOPTERS

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ABSTRACT

This paper considers that as modern military aircraft become ever more complex, the EMC-related problems associated with the design, development, manufacture and installation of equipment interconnection will reach a critical level. These problems can only worsen with the introduction of composite airframe components.

The paper then proposes that fibre optics can offer a solution to these problems. When fibre optics are used to interconnect the various avionic systems in the electrically hostile environment of an aircraft, the airframe manufacturer is freed from the EMC-related problems associated with systems interconnection. Further benefits of fibre optics include improved safety through elimination of spark hazard, the capability for vastly increased signal data rates due to higher bandwidth and potential cost and weight savings.

This paper describes how the necessary technology is now becoming well understood through various study and rig demonstration programmes. Further, it outlines a number of potential application areas, ranging from digital data transmission to video/display data distribution.

The paper then describes some of the technology development activities so far undertaken in support of the leading applications. It concludes with a discussion of the work that has yet to be done in order that fibre optics can be considered for general application.

1. INTRODUCTION

The potential benefits offered by fibre optics to data transmission systems have long been recognised. The main benefits are immunity to electromagnetic interference, lack of electromagnetic emission and increased bandwidth.

Due to the high density of electrical systems within modern aircraft, significant problems are encountered with electromagnetic interference between systems, signal lines and power lines. As a result the potential application areas of fibre optic data transmission systems in the aircraft are varied. They range from audio intercomms, through digital data bus to video distribution networks and control systems.

This paper considers the experience gained from a number of research and development programmes aimed at developing fibre optics for data transmission. The works has, in the main, been funded by UK MoD through the Royal Aerospace Establishment (RAE) at Farnborough.

2. BACKGROUND

WHL has been actively involved in developing the benefits offered by fibre optics, as applied to helicopters, for some years. The integration of increasingly complex avionic systems poses a number of problems for the aircraft manufacturer, many of which focus around the question of electromagnetic compatibility (EMC).

The use of fibre optics for data transmission will provide the designer with a solution to many of these problems, as fibre optics are neither susceptible to interference, nor do they radiate. As well as offering greater systems integrity and a vast bandwidth capability, fibre optics allow the designer freedom with respect to the routeing of cable assemblies. This leads to a consequent reduction in the design and development effort required.

More generally, in order to support the increased levels of systems integration required in modern military aircraft the aircraft/avionics industry is making use of data bus technology to interconnect and integrate the various avionic systems and sub-systems. MIL-STD-1553B(1) the 1 Mbit/s, serial, command/response, time division multiplexed data bus standard is the first generally accepted avionic data bus to be developed. It is now being applied to a number of aircraft programmes.

It is generally accepted that future aircraft programmes will require a greater data transfer capability than is available from MIL-STD-1553B. Higher speed data bus standards are currently evolving for this purpose. In order to support these standards, optical data bus technology must be developed accordingly.

3. RIG AND STUDY PROGRAMMES

3.1 Optical Implementation of MIL-STD-1553B

Two programmes of work, both funded by UK MoD through the Royal Aerospace Establishment, have provided experience of optical implementations of MIL-STD-1553B. The first programme allowed the design, construction and evaluation of a laboratory based fibre optic implementation of MIL-STD-1553B. The design of this system was based upon the requirements of a medium payload helicopter fit, such that the appropriate design decisions were identified and addressed. The second programme actually involved the installation of a fibre optic data bus into a Lynx helicopter allowing the design process to be repeated for a real application.

Whilst the requirements were provided by the application, and by the Standard itself, a number of constraining factors had to be considered. These resulted from the level of maturity of fibre optic technology and the fact that MIL-STD-1553B when drafted gave no consideration to a possible optical implementation.

The requirements for the laboratory demonstration system were based on those of a real aircraft system. The key aspects of the system are considered below in turn (2).

A fibre optic data bus will be required to function in a similar manner to it's electrical counterpart and must therefore be capable of interconnecting up to 31 active terminals. The electrical bus is based on a linear T-coupled bus topology. By careful routeing of the bus cable it can use the near minimum amount of cable to interconnect the terminals, reducing cost and weight. A fibre optic implementation should do likewise.

It was considered important that the optical data bus be based on a passive distribution network, ie. that no optical signal regeneration should be employed. Any signal regeneration would detract from the transmission system all those benefits that made the adoption of fibre optics attractive in the first place.

Considering the distribution of avionic equipment in the airframe, it soon became apparent that in helicopters, avionic Line Replaceable Units (LRUs), which will become the terminal equipments to be interconnected by the bus, are physically grouped in zones or avionic equipment bays and are not evenly distributed throughout the airframe. This was to dictate the configuration of the bus architecture, as the bus is required to physically interconnect the equipments within zones and between zones, using the minimum of fibre cable. An interconnect topology, referred to as the 'local star', was developed for this application and is considered appropriate for optically interconnecting groups of avionic equipments in helicopters for a range of applications, Figure 1.

At the time of the study it was decided that light emitting diodes (LEDs) should be used as the active optical components, in preference to laser diodes. This was because they were more readily available and more amenable to this sort of application. Laser diodes, however, have the potential for producing more optical power. Current technology lasers are significantly improved in terms of reliability etc in comparison with their early counterparts.

For the reasons of ease of manufacture, test, installation, and repair of cable assemblies, multiway connectors were chosen in preference to fusion splicing. However, these connectors are used at the expense of optical attenuation and cost.

Because no consideration was given to optical implementation of the Standard when it was drafted, problems arose when considering the optical signalling/coding.

Direct (baseband) encoding was initially proposed but was not considered suitable for a number of reasons. Firstly the electrical signal has three states; +ve, -ve and zero. An optical signal can in effect be only on or off.

Direct (baseband) encoding of the tri-level Manchester signal would require that the -ve (electrical) signal and the signal off condition are treated as one and the same and encoded as light off. The +ve electrical signal would then be encoded as light on. The drawback to this approach is that, when decoding the optical signal, it is not possible to discriminate between the -ve signal and the signal off condition. This will mean that it is impossible to determine the end of the message without introducing some complex message timing circuitry.

A more fundamental problem is that this direct encoding technique is not suitable where a wide intermessage dynamic range is required. This is because the effective intermessage gap time may be as short as the longest period within a message during which there is no signal transition. Therefore, the receiver sensitivity recovered between messages will also be present during a message. Relatively small levels, of 'noise' (optical reflections, power supply transients, short term source thermal effects etc) will give rise to false signal transitions and hence decoding errors.

For these reasons, a derivative of Frequency Shift Keying (FSK) was chosen as the optical modulation technique as it offers better immunity to these various second order effects. It does this by introducing additional transitions into the message and therefore does not allow the receiver to recover to full sensitivity until the message is finished. It also allows the simple coding and decoding of the tri-level Manchester data bus signal.

The +ve electrical data bus signals are coded as one frequency, the -ve electrical data bus signals are coded as a second frequency, and when the electrical bus would be quiet the optical bus is also quiet. Upon decoding, the tri-level Manchester signal, including the end of the message, can be easily reconstituted.

Since the demonstration of the optical MIL-STD-1553B data bus rig many of the constituent parts have been developed and enhanced. In particular, the electro-optic interface has now been implemented in chipset form, allowing project applications to be a practical reality. Connector, cable and coupler technology has also matured considerably allowing the implementation of a full interconnect-capability system on the RAE's experimental Lynx helicopter.

3.2 Multiple Channel Data Networks

One of the previously mentioned MoD funded work programmes, as well as providing an optical implementation of MIL-STD-1553B also demonstrated multiple channel optical data transmission(3). It did this by simultaneously transmitting high speed digital video and optical MIL-STD-1553B data over the same fibre optic bus network.

To achieve this, the two different channels were wavelength division multiplexed (WDM). By careful selection of the optical wavelengths and the associated detectors, and by virtue of the relative power levels on the network, it was possible to ensure that the video channel (running at 1500 nm) was insensitive to the MIL-STD-1553B data (running at 850 nm), and that the 850 nm channel was insensitive to the video data.

The video signal was digitally encoded at 100 Mbit/s and was used to modulate a 1500 nm laser source for transmission over the fibre optic bus. A suitable receiver and digital decoder were used to recover the video signal and display it on a monitor, without the need for an optical demultiplexer.

Whilst this was a simple demonstration of wavelength division multiplexing (see Figure 2) it provided a very sucessful demonstration of a technique with vast potential. Work is in hand in a number of areas to demonstrate and apply the technique to systems with a large number of channels; the implications of which are considered later.

4. APPLICATION AREAS

The areas where fibre optics can be benefically applied to avionic systems are manifold. The most obvious and well researched is the general avionics data bus. However, fibre optics are just as relevant to flight control, audio intercomms and video/sensor/display systems. Each area is therefore considered in turn together with any special requirements/constraints that will impact upon a potential optical solution.

4.1 General Avionics Data Busing

As previously mentioned, the MIL-STD-1553B (equivalent to DEF STAN 00-18 (Part 2)) (4) avionics data bus has become the defacto standard for military avionics data busing. This standard makes use of a copper wire transmission medium with a data rate of 1 Mbit/s. The use of an optical transmission medium will make this already robust system substantially immune to EMI and free from electromagnetic emissions. However, as mentioned earlier certain problems have to be overcome to realise a satisfactory optical implementation of MIL-STD-1553B due to the fact that when drafted, no consideration was given to the possibility of an optical implementation of the Standard.

As discussed in section 3.1 two major problem areas must be addressed - network topology and modulation technique. Considerable effort has been expanded in this area resulting first in the demonstration of a laboratory based rig, secondly the development of miniaturised optical interface components and most recently flight demonstration on an experimental aircraft.

The application of fibre optics to MIL-STD-1553B is now well understood with appropriate standards becoming available both in the US (MIL-STD-1773) and the UK (proposed as a supplement to DEF STAN 00-18 (Part 2)). Project applications can now be considered without significant risk penalties.

Following on from MIL-STD-1553B, the medium term solution to an increased data transfer requirement can be best solved by the use of a multiple speed data bus, such as that proposed in study Stanag 3910. This system makes use of a conventional MIL-STD-1553B data bus to control the sequence of data transmission over a higher speed data channel, running at 20 Mbit/s.

The proposed study Stanag suggests three possible implementations; (i) separate electrical control and data channels, (ii) electrical control and optical data channels and (iii) optical control and data channels wavelength division multiplexed, making use of the same transmission medium.

The European Fighter Aircraft (EFA) project has selected option (ii), embodied in the EFABus standard, as its main avionic data bus system. Components and interface electronics are being developed accordingly.

In the longer term, the solution to increased data transfer requirements will take the form of the 'High Speed Data Bus'. A number of different, but similar high speed bus standards are being developed all of which make use of a token passing protocol, logical ring interconnection and operate at between 50 and 100 Mbit/s. Optical data transmission is considered in each case. Suggested applications of a high speed data bus are the US LHX and ATF programmes.

4.2 Flight Control Systems

In order to achieve the levels of performance required from new and developing aircraft designs, there is a trend towards the use of Fly-by-Wire (FBW) in preference to conventional mechanical control linkages. Computer controlled FBW systems provide the opportunity to be able to extract the full potential from the aircraft in terms of exploiting the available flight envelope. However it does unfortunately introduce a serious problem in terms of susceptibility to EMI. Due to the flight and safety critical nature of the FCS these EMI problems must be reduced as much as possible. The application of fibre optics certainly offers the required level of immunity to interference.

Fibre optics can be considered for FCS applications starting at the inceptor displacement sensors, through signalling to and from the FCS computer to the control signals to the actuators. In support of an optically signalled FCS, one requires a suitable data transmission protocol to allow the transfer of data to and from the FCS computer. Flight criticality requirements will impact upon the protocol chosen necessitating high integrity transmission of data and not all existing protocols are considered appropriate for high integrity applications.

4.3 Audio Intercomms

One potential application of fibre optics that has received little consideration to date is the intercomm system. Clearly this is an application which will make use of the EMC related benèfits of fibre optic signalling rather than the band width capability.

Current intercomm systems are typified by their requirement to interconnect a large number of sources and sinks, transmitting analogue signals in a particularly adverse environment. EMI induced noise and distortion are major problems, potentialy compromising the integrity of the messages being transmitted. The use of an optical transmission medium, even as a direct replacement for the electrical interconnection arrangement will considerably improve the quality of the message transmission. However, to further benefit from the introduction of fibre optics, use could be made of various data busing techniques, implying digital encoding of the audio signals.

4.4 Video and Sensor Data Distribution

With the introduction of the electronic flight instrument system (EFIS), has come the need to transmit and distribute video and sensor data to the display systems. Military aircraft have additional requirements compared to civil aircraft in that many of the mission systems generate and receive video imagery for use by the pilot and crew. A requirement therefore exists to transmit and distribute a large number of different display images, between a number of source and sinks within the less than perfect electromagnetic environment of the aircraft.

The possiblity of using a common format for the video data, and common display heads does allow the opportunity of vastly improving the level of redundancy, and hence survivability of the system. In addition, the use of digital coding for the video signals will greatly simplify image processing, image overlay and image manipulation in general.

An additional optical technique, that of wavelength division multiplexing can be applied to great effect in such a system, allowing a number of separate data channels to share a common optical data path. To facilitate this, the different channels are encoded and modulated using different wavelengths (or colours) of light. Replication of the physical data path will provide damage and failure tolerance in the normal way. Further, the system is very much more failure tolerant, as all data channels can exist on each data path.

5. TECHNOLOGY STATUS

Certain avionic applications of fibre optics have already been researched and demonstrated extensively, a notable example being MIL-STD-1553B. However, there are a number areas where development is still required in order to support the range of applications considered above. These developments concern, primarily, the problems associated with the productionisation and in-service maintenance of optical fibre systems in general. Connectors, cable, couplers, production tooling, in-service repair equipment are all at varying stages of development. Few are yet fully satisfactory in all respects.

However, a number of relatively simple avionic applications are coming to the fore and it is these applications that will surely drive the final stages of component development. Alongside these component developments are a number of technology developments which will enable more advanced and capable data transmission systems to be realised. For example the technology required to support multi-channel networks is already being transferred from the commercial market and is being developed and enhanced against the rather more demanding requirements of the military avionic sector. As a result it will soon be suitable for rig demonstrations of avionic applications.

6. CONCLUSIONS

Considerable progress has been made in recent years in the development of fibre optic systems for avionic applications and project applications are now being considered in earnest.

The benefits to be gained are far reaching and concern not only improvements in the EMC related aspects of inter-system signalling but also the ability of the medium to transmit vast quantities of data. Multi-channel networks, where, for example, general data busing, video/sensor display data and audio comms signals could make use of the same physical network would offer considerable savings in weight, and complexity, whilst offering the potential for considerably increased levels of redundancy and survivability.

7. ACKNOWLEDGEMENTS

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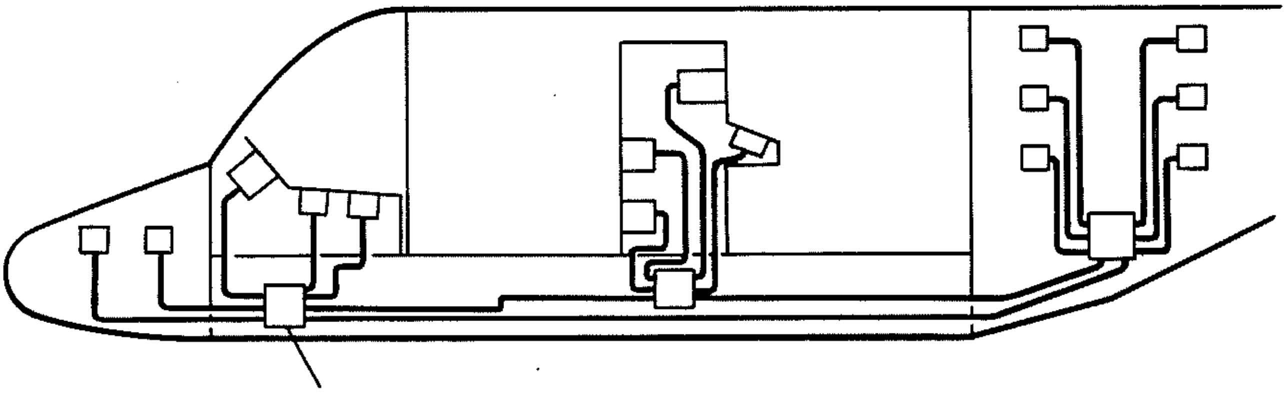

Figure 1
LOCAL TRANSMISSIVE STAR COUPLED FIBRE OPTIC DATA BUS SCHEMATIC

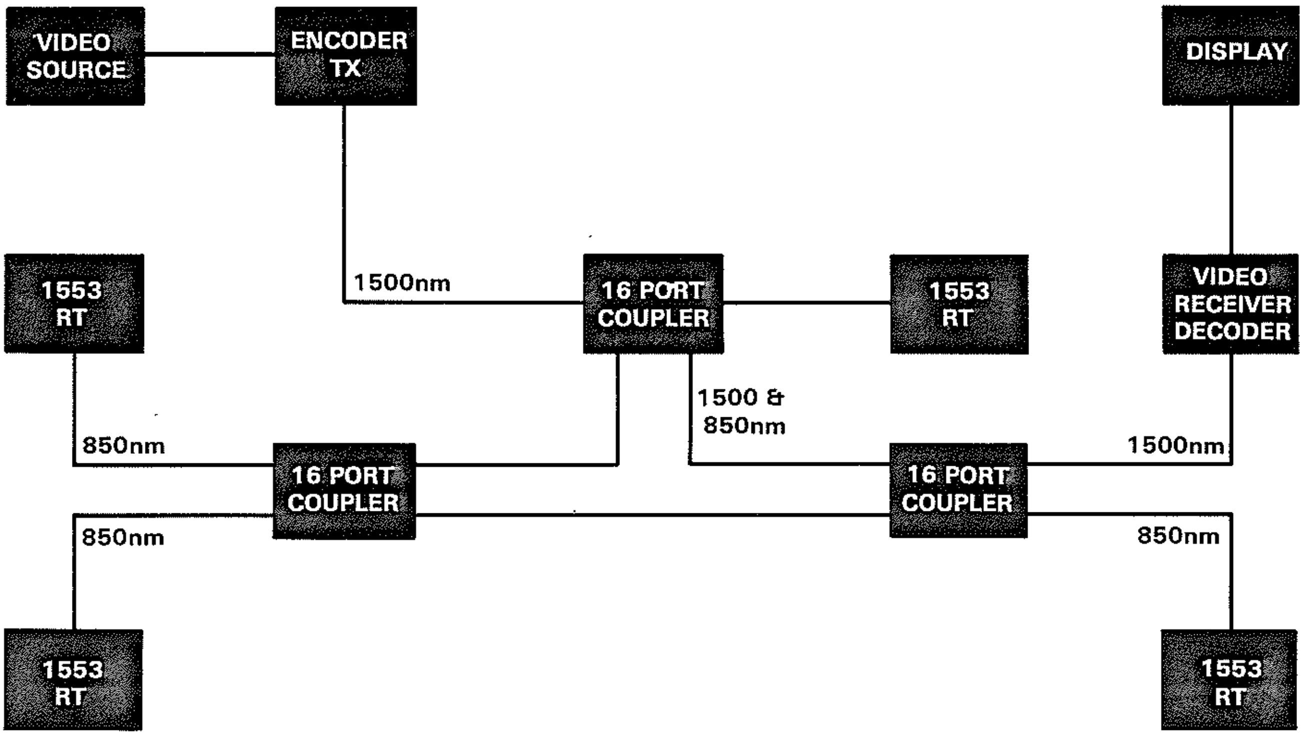

Figure 2
TWO CHANNEL WDM RIG DEMONSTRATION