

## FIBRE-OPTIC HARNESS STUDY PHASE II

### Repair and Maintenance Strategy

HS2/SI/058/T.5.1

LS-RPT-3484

#### Task 5

#### Summary:

Report on the Repair and Maintenance strategy for FOHS2. The report summarises and builds on the work performed under task 5. The format and content of the document were openly discussed at a one day meeting held at Smiths Industries on 12<sup>th</sup> November 1998.

#### Distribution

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## 1. INTRODUCTION

This document aims to encapsulate all of the recommendations generated by the Fibre Optic Harness Study on the topic of Repair and Maintenance. It contains;

- Information on all current fault notification, location and repair techniques and which situations they should be used in.
- Information on symptoms that indicate a fault in an optical fibre harness and which faults they relate to.
- A definitive list of potential harness faults.
- General good practices for maintenance of optical fibre harnesses.
- Design recommendations to ease the maintenance of harness.

This document has not been written to be read cover to cover. It is suggested that once the introduction has been read, the [Top level Map](#) and other links are used to navigate about the document. Links are shown in blue. In this way the document can be dipped into at any starting point, be it a specific fault with a component or a general query on OTDR's, and from there all the relevant information and topics can be reached. References to other Harness Study documents are included for further information.

In the Locate/Isolate and Repair sections, each technique has a classification table like the one shown below (Figure 1);

Embedded	Open	First Line	Depot
✓ / x	✓	x	✓

**Figure 1 Technique Classification Table**

This table indicates whether the technique is suitable for use with embedded harnesses or open harnesses or both. It also shows if the technique can be used for front line maintenance or depot maintenance. These categories, or similar, have been defined in several Harness Study documents [1, 2, 3]. To recap;

- Open Harness – the harness is predominantly visible and connectors are accessible.
- Embedded Harness – a harness installed in an inaccessible part of the airframe or enclosed in a conduit. Assumes access to in-line connectors and visual inspection of the cable is not possible.

Some harnesses will fall between these two categories e.g. a cable may run through a conduit but the connectors at both ends may be accessible. However, to simplify the document, the two general cases described above will be used.

- First Line – implies the aircraft is operational for the military or in-service with an airline. In this situation equipment will be limited to robust, portable, relatively low cost equipment requiring minimal specialist skills.

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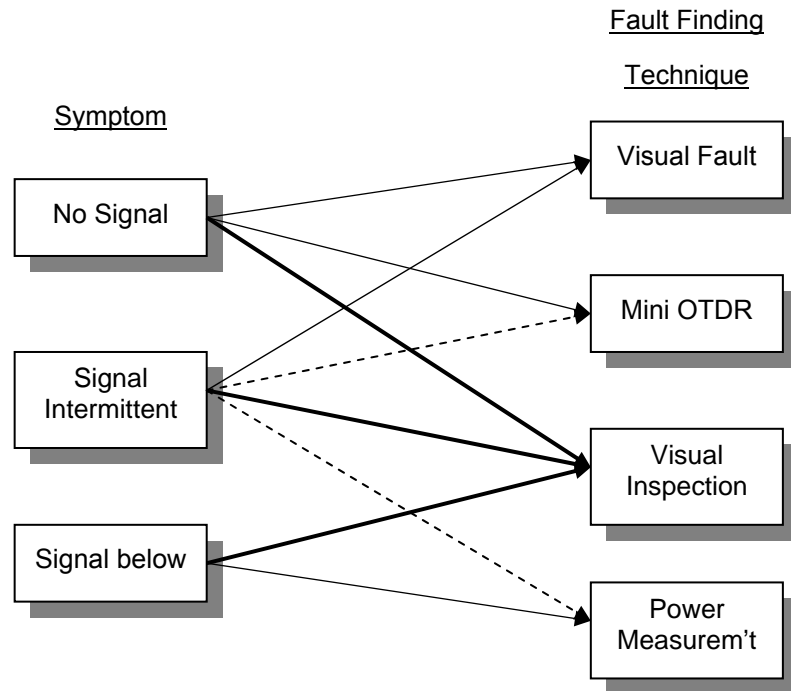
- Maintenance Depot – the dedicated maintenance facility for the aircraft. The full range of equipment and skilled operators is available.

The repair strategy for a given fault will depend heavily on the scenarios described above. The diagrams on the following two pages (Figure 2, Figure 3) show generic prioritised fault location techniques for a given symptom depending on the scenario. It is envisaged that any specific optical fibre harness installation will have its own tables and also a similar ones for repair techniques.

In the Faults section (Section 6), for each fault the repair techniques are listed in order of preference and the symptoms are listed in order of likelihood. So for each fault, the optimal repair is the one nearest the top of the list which is applicable to the scenario as described above.

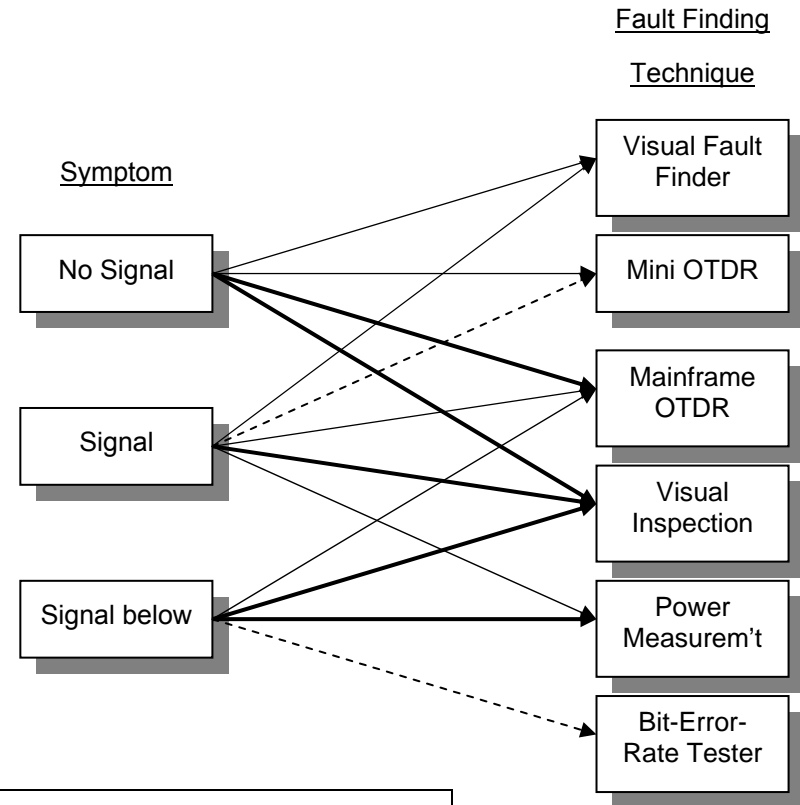
Go to [Top level Map](#).

**`Open' Harness – First Line Fault Finding**



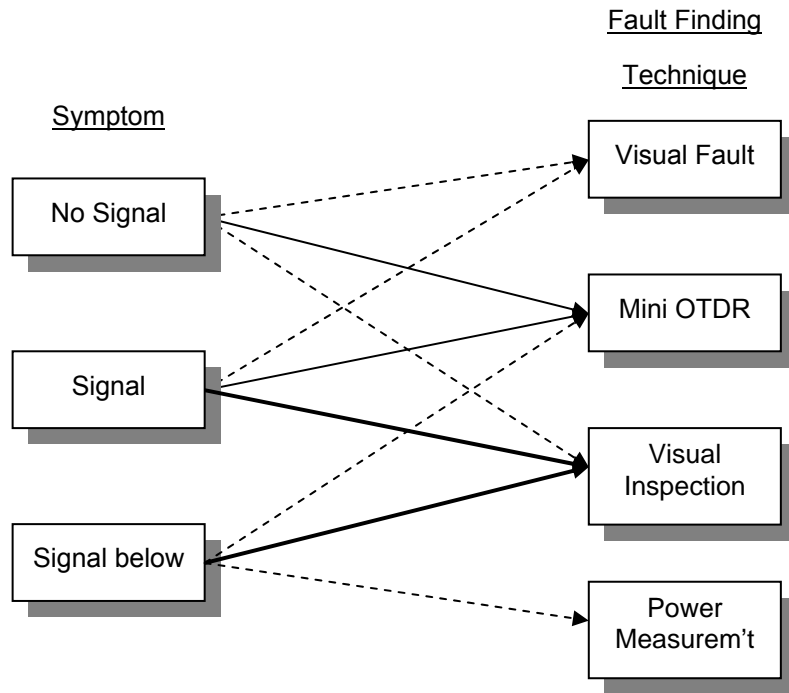
—————> recommended technique  
 —————>  
 - - - - -> may be useful

**`Open' Harness – Scheduled Maintenance Fault Finding**



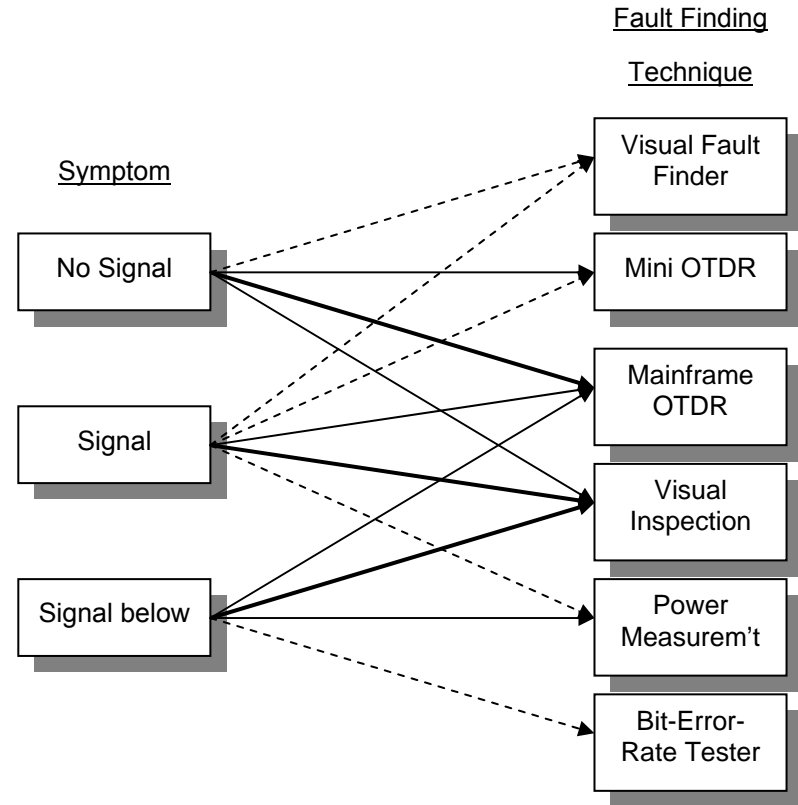
**Figure 2 Fault Finding for a Generic Open Harness**

**'Embedded' Harness – First Line Fault Finding**



—————> recommended technique  
 —————>  
 - - - - -> may be useful

**'Embedded' Harness – Scheduled Maintenance Fault Finding**



**Figure 3 Fault Finding for a Generic Embedded Harness**

## **2. TOP LEVEL MAP**

### *Fault Notification*

*BIT*

*Scheduled Maintenance*

*Failure*

### *Symptoms*

*Complete loss of optical power*

*Drop in optical power*

*Intermittent loss of power*

*Gradual degradation*

*Increase in Optical Power*

*Latent Fault Symptom*

*Increased Back Reflection*

### *Locate / Isolate*

*OTDR*

*Visible fault locator*

*Inspection*

*BIT information*

*Power measurement*

*Substitution*

### *Faults*

*Connector*

*Backshell*

*Fibre*

*Cable*

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*Conduit*

*Coupler*

*Splice*

*Repair*

*Replace*

*Splice*

*Structural*

*Re-terminate*

*Re-polish*

*Routing*

*Cleaning*

*Dormant*

*Tools*

*Design*

*Recommendations*

*References*

### **3. FAULT NOTIFICATION**

A fault notification will arise from one or more of three sources; Built-In-Test (BIT), scheduled maintenance, or failure of equipment dependent upon the harness.

#### **3.1 BIT**

##### **3.1.1 Description**

Built-in-Test (BIT) is used for fault analysis at the system level. The term 'system level', when applied to an avionics unit or module, incorporates microprocessors, circuit boards, media access controllers, transmitters, receivers, couplers and optical links. The focus of the Harness Study is to find and repair faults in the fibre optic harness, external to the avionics unit, but to do this it is necessary to understand how a system will help identify faults through its own built-in-test features. The built-in-test features should identify a fault to a device or a portion of the harness.

It is expected that BIT functionality will be provided at various layers from the application, down through the operating system and hardware drivers to the hardware itself. The fault analysis techniques at the system level for data communications will concentrate mainly on the hardware driver and hardware layers.

For further details on built-in-test, refer to [4].

##### **3.1.2 Mechanisms**

The hardware driver layer is where the chosen communication protocol sits in software. Functions within this protocol that error check the data transferred using parity, CRC or similar will form the built-in-test.

At the hardware layer, monitoring of voltage levels, currents, temperatures, optical powers etc. could occur and provide indication of failure or impending failure. Potential techniques for achieving this are;

- Transmitter power monitoring – Photodiodes on the rear of laser cavities provide the opportunity to monitor the output from transmitters.
- Broadcasting – Sending a signal to a specified receiver and checking for arrival.
- Half power at power up – Booting the system with all transmitters at half power. Failure of the system to operate (after operating previously under these conditions) could indicate system degradation.
- Built-in attenuators – Similar to the idea above. The attenuation on an optical link is increased until it fails e.g. fails a Bit Error Rate (BER) test. The attenuation at which this occurs is noted. A decrease in this value over time could indicate degradation of the link. Testing the entire network in this way could be time consuming and limited to scheduled maintenances (see below).

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### 3.1.3 Symptoms

BIT may isolate a fault to the transceiver, or link / path depending upon network architecture and sophistication. A fault in one of the components of the link would result in one of the following symptoms;

- *Complete loss of optical power.*
- *Drop in optical power.*
- *Intermittent loss of power.*
- *Increase in Optical Power.*

Back to [Fault Notification](#).

Back to [Top level Map](#).

## 3.2 SCHEDULED MAINTENANCE

### 3.2.1 Description

Scheduled maintenance is the pre-determined time at which the status and performance of the harness is checked and compared against previous benchmarks. It also provides an opportunity to identify and rectify latent and apparent faults.

Un-scheduled maintenance is not considered here as it is something done in response to a fault notification rather than something that provides a fault notification.

### 3.2.2 Procedures

Various procedures have been identified that could be used as the basis for a scheduled maintenance of a fibre optic harness.

#### 3.2.2.1 Visual Inspection

During a scheduled maintenance it is not recommended that connectors are demated to visually inspect the fibre end faces as this introduces the potential for contamination. This should only be done as part of a fault location procedure. Visual inspection during scheduled maintenance should therefore be restricted to checking for damage to cables and connector housings.

#### 3.2.2.2 Harness Footprinting

A record of the performance of an optical fibre assembly that can be used as a reference (or 'footprint') is a recognised method for maintenance of commercial optical networks. Future measurements on a particular harness, or other essentially identical harnesses, can be compared against this reference to determine their level of acceptability or the presence of in-service degradations, for example. The footprint can be based on a number of harness characteristics. The most common techniques are based on optical power measurement and OTDR analysis.

Optical power measurement will provide a footprint representative of the harness performance in-service provided the procedures developed in the Test and Measurement task are followed. A single power measurement gives an overall footprint of the harness section under test but will be of limited value for future fault diagnostic

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purposes. A series of optical loss measurements where in-line connectors are accessed will provide a more detailed 'footprint' that will enable faults to be isolated to particular harness components. The drawbacks of this approach are the fact that connectors have to be de-mated and mated leading to potential contamination problems, and that it is a time consuming process, especially for complex harnesses.

An OTDR is potentially an ideal means of generating a reference footprint requiring only a single measurement to characterise the entire harness under test. Furthermore, comparison between current and previous traces can be performed automatically by the OTDR completely de-skilling the fault location and diagnosis operation. This method has been adopted in the telecomms and commercial data comms industries. However, in general current OTDR technology struggles to meet the specific requirements of airborne optical harnesses, in particular spatial resolution (dead zone) performance. Nevertheless, there are certain specialist instruments, notably the Opto-Electronics Inc. OFM1020, which may meet avionic specifications. The results obtained from this instrument for the point-to-point harnesses installed on the A340 landing gear demonstrator appear to support this view [5]. Unfortunately, at the stage when the instrument was evaluated it was still under development and the front end/display functions were somewhat limited. Consequently, no meaningful hard copy record could be obtained. Opto-Electronics Inc. claim that this instrument is being developed specifically to meet the US Aerospace industry requirements for the footprinting of optical harnesses. Its major drawback is its cost – one off price in the UK is around £50k. This will limit its use to manufacturing and scheduled maintenance applications.

### 3.2.2.3 Systems Diagnostics/BIT

A thorough run through of the BIT system may be carried out at scheduled maintenance. The system diagnostics may be based on those described in the previous section such as the attenuation measurement technique. The system diagnostics used at scheduled maintenance may be more detailed/time consuming than those used whilst the aircraft are in service and targeted at finding latent faults.

### 3.2.2.4 Cleaning

Routine cleaning of fibre end faces is not required but if a connector is de-mated, for example, to allow OTDR footprinting, it may need to be cleaned. Cleaning, rather than being considered a maintenance procedure, is considered a repair procedure (see section 7.7).

### 3.2.3 Faults

Faults in the following components may be identified by maintenance actions;

- *Connector*
- *Backshell*
- *Fibre*
- *Cable*
- *Conduit*
- *Coupler*

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- *Splice*

Back to *Fault Notification*.

Back to *Top level Map*.

### **3.3 FAILURE**

#### **3.3.1 Description**

Failure of a harness component would be noticed when the system dependent on the link fails. Ideally, BIT or Maintenance would pick up the latent fault before it resulted in a direct fault or harness malfunction but this is clearly not always the case e.g. for battle damage. A failure is the most difficult point from which to start a repair procedure as it provides the least information as to the location or type of fault.

#### **3.3.2 Symptoms**

A failure of a component of the harness could have the following symptoms;

- *Complete loss of optical power*
- *Drop in optical power* – providing the drop is to below the link threshold.
- *Intermittent loss of power*
- *Gradual degradation* – that has gone unidentified reaching the link threshold.
- *Increased Back Reflection*

#### **3.3.3 Faults**

These symptoms may be due to a failure of a;

- *Connector*
- *Backshell*
- *Fibre*
- *Cable*
- *Conduit*
- *Coupler*
- *Splice*

Back to *Fault Notification*.

Back to *Top level Map*.

## 4. SYMPTOMS

Unless the fault notification also provided the location of the faulty component e.g. maintenance identifying a damaged backshell, the first piece of information on a fault will be a symptom. For an optical harness these can be categorised as follows;

### 4.1 COMPLETE LOSS OF OPTICAL POWER

#### 4.1.1 Description

No light is received at the detector. Failure of the link.

#### 4.1.2 Notification

Loss of optical power may be detected by;

- *BIT* – ideally BIT would detect a symptom of this kind first.
- *Failure* – a complete loss of optical power would bring about a failure of the dependent system.
- *Scheduled Maintenance* – if such a symptom was previously undetected it would definitely be picked up at scheduled maintenance.

#### 4.1.3 Locate /Isolate

The following methods may be used to locate isolate the fault. The methods are presented in general order of preference although the choice will depend on the accessibility of the fault and the availability of equipment.

- *BIT information* – would provide the area on the harness to investigate.
- *Visible fault locator* – would be a quick and easy way to find the fault.
- *Power measurement* – could be used instead of a visible fault locator.
- *Inspection* – having isolated the faulty item using the techniques above, inspection may reveal the source of the problem.
- *OTDR* – an OTDR may be used but simpler techniques would suffice.
- *Substitution* – Substitution could be used if the problem area had been narrowed down to a few LRI's.

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### 4.1.4 Faults

A complete loss of power may be caused by the faults with the following components;

- *Connector*
- *Fibre* – possibly within a *Backshell* or *Conduit*.
- *Coupler*
- *Splice*

Back to *Symptoms*.

Back to *Top level Map*.

## 4.2 DROP IN OPTICAL POWER

### 4.2.1 Description

Optical power at the receiver is lower than previous data suggests it should be. This could vary from being slightly down on power budget with the system performing without problems to loss of considerable power causing the system to malfunction.

### 4.2.2 Notification

Drop in optical power may be detected by;

- *BIT* – sufficient drop in optical power to cause a link to malfunction would be found by BIT.
- *Failure* – again, if the optical power drop is sufficient, a failure may occur.
- *Scheduled Maintenance* – it is quite likely that a link will continue to operate with a slight drop in optical power. In this case the fault may not be recognised until scheduled maintenance.

### 4.2.3 Locate /Isolate

The following methods may be used to locate isolate the fault

- *BIT information* – would provide the area on the harness to investigate.
- *OTDR* – could find the point where the loss was occurring.
- *Power measurement* – would require previous data for comparison.
- *Visible fault locator* – would only be effective where a fibre break was the problem and the flare was visible through the jacket.
- *Inspection* – of end faces for contamination which is a common cause of drop in optical power.

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- *Substitution* – Substitution could be used if the problem area had been narrowed down to a few LRI's.

### 4.2.4 Faults

A drop in power may be caused by the following faults

- *Connector*
- *Fibre* – possibly within a *Backshell* or *Conduit*
- *Coupler*
- *Splice*

Back to *Symptoms*.

Back to *Top level Map*.

## 4.3 INTERMITTENT LOSS OF POWER

### 4.3.1 Description

Optical power at the receiver is sometimes to budget but at other times has been lost along the link.

### 4.3.2 Notification

Intermittent loss of power may be detected by;

- *BIT* - intermittent loss of power would be detected by BIT at the hardware interface level as error checking would reveal a problem.
- *Failure*
- *Scheduled Maintenance* - this type of symptom could be missed if scheduled maintenance is not thorough.

### 4.3.3 Locate /Isolate

The following methods may be used to locate/isolate the fault;

- *BIT information* – would provide the area on the harness to investigate.
- *OTDR* – not ideal as an OTDR may miss an intermittent power loss.
- *Visible fault locator* – if the loss of power was considerable or complete a visible fault locator would be useful.
- *Power measurement* – as with an OTDR – a single measurement may miss an intermittent power fault.

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- *Inspection* – if the loss was due to, for example, intermittent bending of the fibre beyond its short term bend radius, inspection could locate it.
- *Substitution* – Substitution could be used if the problem area had been narrowed down to a few LRI's.

### 4.3.4 Faults

Intermittent loss of power may be caused by the following faults

- *Connector*
- *Splice.*

Back to *Symptoms*.

Back to *Top level Map*.

## 4.4 GRADUAL DEGRADATION

### 4.4.1 Description

Light received at the detector diminishes over time. This would show up as gradual degradation when footprinting the system.

### 4.4.2 Notification

Gradual degradation of the link may be detected by;

- *BIT* – gradual degradation will only be seen by BIT of data when the link stops operating correctly. Other aspects of BIT such as a half power test or attenuator test should provide the first evidence of gradual degradation.
- *Failure* – a gradual degradation of a link should be spotted before it causes a failure.
- *Scheduled Maintenance* – a symptom like this should be found at scheduled maintenance when footprint data is available.

### 4.4.3 Locate /Isolate

The following methods may be used to locate/isolate the fault;

- *BIT information* – would provide the area on the harness to investigate, but only if the degradation had been spotted by BIT which is not definite. A half power test or attenuator test should provide the first evidence of gradual degradation.
- *OTDR* – an OTDR could spot gradual degradation but only when used with a footprint i.e. in a scheduled maintenance scenario.

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- *Power measurement* – would give results that were easier to interpret as gradual degradation than an OTDR. Again, footprint data would be required.
- *Inspection* – if the fault was due to gradual deterioration of a cable, for example, inspection could locate the fault.
- *Substitution* – Substitution could be used if the problem area had been narrowed down to a few LRI's.

### 4.4.4 Faults

A gradual loss of power may be caused by the following faults

- *Connector*
- *Splice*
- *Coupler*.

Back to *Symptoms*.

Back to *Top level Map*.

## 4.5 INCREASE IN OPTICAL POWER

### 4.5.1 Description

Light power level at the receiver is increased. This can be a problem if it is sufficient to saturate the receiver. Increase in power is unlikely to be a fault in the harness but more likely a transmitter fault.

### 4.5.2 Notification

An increase in optical power may be detected by;

- *BIT* – an increase in optical power will be detected by BIT if receivers are saturated and data errors are introduced.
- *Failure* – an increase in optical power can cause a failure in the same way a decrease might.
- *Scheduled Maintenance* – footprinting would highlight a symptom like this.

### 4.5.3 Locate/Isolate

The following methods may be used to locate/isolate the fault;

- *BIT information* – would provide the area on the harness to investigate but as mentioned above, the fault is more likely to be at the transceiver. BIT should be able to locate the transceiver.

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- *OTDR* - comparison with a footprint would not find a transceiver fault but if the problem was on the harness, this could identify it.
- *Power measurement* - comparison with a footprint would not find a transceiver fault but if the problem was on the harness, this could identify it.

### 4.5.4 Faults

An increase in optical power may be caused by faults in the following components:

- *Liquid ingress*

Back to *Symptoms*.

Back to *Top level Map*.

## 4.6 LATENT FAULT SYMPTOM

### 4.6.1 Description

Symptoms that indicate the possible presence of a latent fault. These are less clear cut than optical symptoms and would predominantly be the result of a visual inspection e.g. a frayed cable or a tight bend in the fibre. A latent fault, by definition, has no discernible effect on the optical power.

### 4.6.2 Notification

A latent fault symptom would be detected by;

- *Scheduled Maintenance* – inspection is the only way to find latent faults as, by definition, they have no effect on the optical performance of the harness.

### 4.6.3 Locate /Isolate

The following methods may be used to locate underlying latent fault;

- *Inspection* – good inspection practices should find the latent fault.

### 4.6.4 Faults

A latent fault symptom can occur in the following components;

- *Connector*
- *Backshell*
- *Conduit*
- *Cable*.
- *Coupler*
- *Splice*

Back to [Symptoms](#).

Back to [Top level Map](#).

## 4.7 **INCREASED BACK REFLECTION**

### 4.7.1 Description

The issue of back reflection has not been thoroughly investigated within the study, partly due to the fact that transceivers were not included. Back reflection can damage transmitters so it is an area of concern.

### 4.7.2 Notification

- *BIT* – if performance of a transmitter was affected.
- *Scheduled Maintenance* – an extra source of back reflection would show up on an OTDR footprint.
- *Failure* – back reflection can permanently damage a transmitter.

### 4.7.3 Locate/Isolate

- *BIT information* – would provide the area on the harness to investigate.
- *Power measurement* – is less useful for back reflection as the actual amount of light will be small compared to the light throughput so may not be noticed.
- *OTDR* – can measure sources of back reflection.
- *Visible fault locator* – if the back reflection is due to a fibre break.
- *Inspection* – if the back reflection is due to end face damage.

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### 4.7.4 Faults

A latent fault symptom can occur in the following components;

- *Connector*
- *Fibre*
- *Coupler*
- *Splice*

Back to [Symptoms](#).

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## 5. LOCATE / ISOLATE

Fault location techniques for fibre optic harnesses are analysed in [1]. Fault finding techniques and strategies will play a key role in restoring and maintaining the integrity of aircraft fibre-optic systems. Unless appropriate solutions are available the aircraft operator could incur significant down time, cost, and inconvenience as a result of procuring aircraft that incorporate fibre-optic technology. The problem is exasperated by the fact that the fibre-optic networks in question could be relatively complex, incorporating fan-out connection paths (enabled by passive couplers or active switches, for example) and may be harnessed into relatively inaccessible areas of the airframe.

Criteria considered when assessing potential fault finding techniques included:

- The effectiveness of the technique for likely fault scenarios.
- The cost of equipment.
- The skill level and time required to perform the technique.
- The size, weight, power requirements, and robustness of equipment.
- Safety issues.

The first factor that will influence the choice of fault location technique is the type of harness – inaccessible, embedded or open. Several of the techniques described below cannot be used on an embedded or inaccessible harness – see the classification boxes (for an explanation see the [Introduction](#)).

### 5.1 OTDR

Embedded	Open	First Line	Depot
✓	✓	Mini-OTDR	✓

#### 5.1.1 Description

Optical Time Domain Reflectometry is a single ended diagnostic technique that relies on the backscatter of light from ‘imperfections’ in an optical fibre. Basically, a pulse of light (usually from a laser) is launched into the fibre by the Optical Time Domain Reflectometer (OTDR) and a detector records the backscattered signal. By timing the backscattered light with respect to the incident pulse and by recording its intensity, fibre attenuation, event location, event insertion loss, event back reflection, and other characteristics of the fibre-optic system under test can be inferred. It is thus, potentially a powerful fault analysis technique. Where optical loss measurement is concerned, OTDRs may be suitable as a means of ‘footprinting’ the harness for maintenance purposes. However, unless the instrument incorporates specifically tailored launch conditions these will not be representative of the harness performance in service (*i.e.* will not measure ‘usable power’ as defined in the Test & Measurement task).

On top of the basic functionality discussed above, OTDRs can be designed to automatically interpret information from multiple events and present them in user

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friendly form. Signal processing software can potentially: identify an event and locate it relative to a preceding event or the instrument bulkhead; identify the cause of the event; measure insertion loss increase from preceding event; measure total link loss; analyse only those events over a certain *dB* threshold; zoom in on sections of the network; *etc.* Many automatic fault finding algorithms (and indeed fault finding strategies in general) rely on comparison of the current trace with a previously stored 'footprint' [1].

To summarise, OTDRs are good for locating faults in inaccessible areas. OTDRs may not be necessary in many situations when simpler techniques would do the job adequately. The data obtained from star coupler systems can also be difficult to interpret as reflections from multiple arms of the harness return to the OTDR at the same time. Although they can find faults in inaccessible areas they are currently only accurate to the order of a metre (a result of their development for the telecomms market) which may not be sufficient to locate an exact connector, for example.

### 5.1.2 Usage

An OTDR may be used when the following symptoms occur;

- *Complete loss of optical power*
- *Drop in optical power*
- *Intermittent loss of power*
- *Gradual degradation*
- *Increase in Optical Power*
- *Increased Back Reflection*

Back to [Locate / Isolate](#).

Back to [Top level Map](#)

## 5.2 VISIBLE FAULT LOCATOR

Embedded	Open	First Line	Depot
x	✓	✓	✓

### 5.2.1 Description

This technique is based on the injection of visible light into the fibre-optic system under test. Defects such as fibre breaks or cracks scatter this light. If the cable or connector housing allows, this results in flare being visible at, or close to, the location of the fault.

This is an appealing technique being easy to perform and requiring only the visual fault locator. The harness study has procured a commercial product – the EXFO 'Pocket Pal'. It is based on a red (635nm) laser diode, housed in a 'mag-lite' type package, and is battery powered. A white light or visible LED based device could just as easily be used. The only restriction on the source is that it is eye safe. By pulsing the source (~Hz) its 'detectability' to the eye can be enhanced – this option is available on the 'Pocket Pal'. Also, by connectorising the source efficient coupling into the harness can

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be achieved. The price for such devices should be < £100 making them viable for all fault finding scenarios.

The major draw back to the technique is that most current avionic harness components are packaged in opaque materials and/or installed in conduit or visually inaccessible areas of the airframe. The Filotex 1416B avionic cable, however, is partially translucent in the red as are the ceramic ferrules used in most connectors.

### 5.2.2 Usage

Visible fault locators may be used with the following symptoms;

- *Complete loss of optical power*
- *Drop in optical power*
- *Intermittent loss of power*

Back to [Locate / Isolate](#).

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## 5.3 INSPECTION

Embedded	Open	First Line	Depot
x	✓	✓	✓

### 5.3.1 Description

There are two areas to inspection – inspection of the fibre end faces and inspection of the cable and connector housing (which requires no de-mating).

Visual inspection of the fibre end face with the naked eye or with the aid of a microscope (typically a portable instrument such as the Prior Scientific 'Priorspec') is an important fault finding technique. Assuming the termination end face can be visually accessed, then inspection is in most situations entirely adequate for determining levels of contamination and damage. Harness Study partners have inspected many connector end face types for this and other projects. In terms of skill levels and equipment required, it is a technique suitable for all fault finding scenarios from manufacturing through to first line maintenance.

Visual inspection of the harness construction is to be the same as for existing electrical harnesses. The only difference is that fibre has a smaller minimum bend radius than most electrical cabling so inspection for potentially fault inducing bends is an additional requirement.

Regular inspection of harness components (if accessible) is the only viable way to control latent faults. Even then many latent faults are either not visible, e.g. sub-layer damage or are too small to visualise even with a microscope, e.g. micro-cracking in silica components. The schedule for such inspections will have to be determined through in-service experience.

Inspection of multi-way connectors can be more complicated, especially if the end faces are recessed. Most inspection microscopes are designed solely for viewing

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single terminations but modified microscopes which are able to hold and view multi-way connectors are appearing. Some multi-way connectors can be partially de-assembled to provide better access to the end faces. This is beneficial for cleaning procedures as well as inspection.

### 5.3.2 Usage

Inspection may be used when the following symptoms occur;

- *Complete loss of optical power*
- *Drop in optical power*
- *Intermittent loss of power*
- *Gradual degradation*
- *Latent Fault Symptom*

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## 5.4 BIT INFORMATION

Embedded	Open	First Line	Depot
✓	✓	✓	✓

### 5.4.1 Description

As well as signalling a fault, built-in-test (BIT) can also play a part in fault location. In particular, some of the other techniques covered here, such as power measurement and OTDR analysis, ideally require a-priori BIT information to rationalise the number of fault possibilities.

### 5.4.2 Usage

BIT may be used with the following symptoms.

- *Complete loss of optical power*
- *Drop in optical power*
- *Intermittent loss of power*
- *Gradual degradation*
- *Increase in Optical Power*

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**5.5 POWER MEASUREMENT**

Embedded	Open	First Line	Depot
x	✓	✓	✓

**5.5.1 Description**

Provided appropriate launch and detection conditioning is applied, optical power measurement is the recommended technique for determining attenuation in 'useable power' through an avionic fibre-optic harness or harness component. If compared to a previous such measurement of the system, a measurement of a control sample, or a theoretical prediction, the presence of a localised fault or distributed degradation (due to ageing, for example) in the harness can be deduced.

Optical power measurement can also be used for fault location given prior knowledge that a fault has been detected, e.g. from BIT. If the symptom is 'signal below threshold' i.e. optical power loss to below the power at which the link can operate then the use of appropriate conditioning is still recommended. For 'no signal' or 'intermittent signal' type faults this is much less critical. In fact, a tailored overfilled or underfilled launch may be advantageous in certain cases, e.g. a significant underfill may minimise non-critical loss mechanisms that would otherwise confuse/distract the operator. In some senses this case is analogous to visual fault finding (especially when used for continuity checking) except that an optical power meter is used in place of the eye.

Optical power measurement is intrinsically a double ended test. Thus, whatever the symptom, in order to localise the fault or loss mechanism further, access to in-line connectors within the harness is required for the test source and/or the detector. The technique is therefore far less applicable to 'embedded' harnesses than to 'open' harnesses. By accessing in-line connectors in open harnesses and then taking appropriate optical power measurements, a fault can be localised to a particular connectorised section of the harness. This can then be repaired, cleaned, or replaced depending on the maintenance policy adopted. Having taken appropriate maintenance action, optical power measurement also has a role to play in confirming the level of functionality of the harness.

The technique itself is easy to perform and interpret but is probably more time consuming than some of the others described in this report. Another potential drawback is that power measurement cannot find the position of a fault on a cable so for a long run between connectors e.g. on a point-to-point link its usefulness is reduced.

**5.5.2 Usage**

Power measurement may be used with the following symptoms;

- *Complete loss of optical power*
- *Drop in optical power*
- *Intermittent loss of power*
- *Gradual degradation*

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- *Increase in Optical Power*

Back to *Locate / Isolate*.

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## 5.6 **SUBSTITUTION**

Embedded	Open	First Line	Depot
x	✓	✓ / x	✓

### 5.6.1 Description

In a simple optical link with few components, substitution may be used. If a component is replaced with another known-good component and the symptom disappears then the fault has been located and repaired. This technique is only applicable to accessible harness components and relies on a supply of substitute components which may not always be available.

### 5.6.2 Usage

Substitution may be used with the following symptoms;

- *Complete loss of optical power*
- *Drop in optical power*
- *Intermittent loss of power*
- *Gradual degradation*
- *Increase in Optical Power*

Back to *Locate / Isolate*.

Back to *Top level Map*.

## 6. FAULTS

For each fault, the symptoms are presented in order of likelihood. Similarly, repair techniques are presented in order of preference. So for each fault, the optimal repair is the one nearest the top of the list which is applicable to the scenario (embedded / open harness and front line / depot maintenance).

### 6.1 CONNECTOR

A discussion of failure modes in fibre optic terminations is given in [6].

#### 6.1.1 Particulate ingress

In general mated connectors are not susceptible to contamination, however an unmated connector half or a loose connector may become contaminated via the ingress of one or contaminant e.g. salt, sand, grit etc.

##### 6.1.1.1 Symptom

- *Drop in optical power*
- *Complete loss of optical power*
- *Gradual degradation*

##### 6.1.1.2 Location

- Refer to the relevant symptom section.

##### 6.1.1.3 Factors influencing assessment

- The severity of the contamination.
- Subsequent damage caused by the contamination, particularly to the fibre end face – see *Endface damage*.
- Damage to the connection mechanism – see *Fouled connection mechanism*.
- Type of connector – multi-way connectors are more difficult to clean and re-terminate than single way.

##### 6.1.1.4 Repair

- *Cleaning* – should be attempted first.
- *Re-polish* – if contaminant is particularly stubborn or has caused light damage to end face.
- *Dormant* – if connector can be cleaned but equipment is not available.
- *Re-terminate* – if termination has been contaminated beyond cleaning or polishing.

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- *Replace* – replace entire cable as an alternative to re-termination.

## 6.1.2 Liquid ingress

### 6.1.2.1 Symptom

- *Drop in optical power*
- *Latent Fault Symptom* – liquid may not affect the optical performance but could damage the connector e.g. when frozen.
- *Increase in Optical Power* – some liquids can improve the optical path across the connector (depending on their refractive index) causing a slight increase in optical power.
- *Gradual degradation*

### 6.1.2.2 Location

- Refer to the relevant symptom section.

### 6.1.2.3 Factors influencing assessment

- The severity of the contamination.
- Subsequent damage caused by the contamination e.g. see *Endface damage*.
- Chemical properties of the contaminant e.g. corrosiveness.
- Type of connector – multi-way connectors are more difficult to clean and re-terminate than single way.

### 6.1.2.4 Repair

- *Cleaning* – should be attempted first.
- *Re-polish* – if contaminant has caused light damage to end face.
- *Dormant* – if connector can be cleaned but equipment is not available.
- *Re-terminate* – if termination has been damaged beyond cleaning or polishing.
- *Replace* – replace entire cable as an alternative to re-termination.

## 6.1.3 Fibre grow in

Excess strain on the fibre or poor adhesion between fibre and ferrule can lead to fibre grow in.

### 6.1.3.1 Symptom

- *Drop in optical power*

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- *Complete loss of optical power*
- *Gradual degradation*

#### 6.1.3.2 Location

- Refer to the relevant symptom section.

#### 6.1.3.3 Factors influencing assessment

- Fibre grow in cannot be repaired without replacing the connector.
- Type of connector – multi-way connectors are more difficult to re-terminate than single way.

#### 6.1.3.4 Repair

- *Re-terminate*
- *Replace* - entire cable as an alternative to re-termination.
- *Dormant* - if available.

### 6.1.4 Fibre grow out

Excess strain on the fibre or poor adhesion between fibre and ferrule can lead to fibre grow out.

#### 6.1.4.1 Symptom

- *Drop in optical power*
- *Complete loss of optical power*
- *Gradual degradation*

#### 6.1.4.2 Location

- Refer to the relevant symptom section.

#### 6.1.4.3 Factors influencing repair

- Fibre grow out cannot be repaired without replacing the connector. It cannot be polished back as it will continue to grow out.
- Type of connector – multi-way connectors are more difficult to re-terminate than single way.

#### 6.1.4.4 Repair

- *Re-terminate*
- *Replace* - entire cable as an alternative to re-termination.
- *Dormant* - if available.

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### 6.1.5 Cable retention

#### 6.1.5.1 Symptom

- *Latent Fault Symptom* - detached cable strength members.

#### 6.1.5.2 Location

- Refer to the relevant symptom section.

#### 6.1.5.3 Factors influencing assessment

- Is fibre termination under strain ?

#### 6.1.5.4 Repair

- *Re-terminate*
- *Replace*

### 6.1.6 Loose connector coupling

#### 6.1.6.1 Symptom

- *Intermittent loss of power*

#### 6.1.6.2 Location

- Refer to the relevant symptom section.

#### 6.1.6.3 Factors influencing assessment

- Is the connector damaged or has it simply worked loose?
- Type of connector – multi-way connectors are more difficult to re-terminate than single way.

#### 6.1.6.4 Repair

- Tighten connector – using correct procedure and tooling.
- *Re-terminate* – if connector is damaged.
- *Replace* – replace entire cable as alternative to re-termination.
- *Dormant* – if available.

### 6.1.7 Fouled connection mechanism

#### 6.1.7.1 Symptom

- *Complete loss of optical power*
- *Drop in optical power*

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- *Intermittent loss of power*

#### 6.1.7.2 Location

- Refer to the relevant symptom section.

#### 6.1.7.3 Factors influencing assessment

- Is damage as result of contamination or permanent?
- Type of connector – multi-way connectors are more difficult to re-terminate than single way.

#### 6.1.7.4 Repair

- *Cleaning* – if contamination is suspected.
- *Re-terminate*
- *Replace* – entire cable as an alternative to re-termination.
- *Dormant* – if available..

### 6.1.8 Broken fibre within connector

#### 6.1.8.1 Symptom

- *Complete loss of optical power*
- *Drop in optical power*
- *Intermittent loss of power*

#### 6.1.8.2 Location

- Refer to the relevant symptom section.

#### 6.1.8.3 Factors influencing assessment

- Type of connector – re-termination of a large multi-way connector may be inefficient.

#### 6.1.8.4 Repair

- *Re-terminate*
- *Replace* - entire cable as an alternative to re-termination.
- *Dormant* – if available.

### 6.1.9 Endface damage

#### 6.1.9.1 Symptom

- *Drop in optical power*

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- *Increased Back Reflection*
- *Intermittent loss of power*
- *Gradual degradation*

#### 6.1.9.2 Location

- Refer to the relevant symptom section.

#### 6.1.9.3 Factors influencing assessment

- Type of connector – multi-way connectors are more difficult to re-terminate than single way.
- Severity and depth of damage.

#### 6.1.9.4 Repair

- *Re-polish* – if endface damage is light.
- *Re-terminate* – if damage cannot be removed by re-polishing.
- *Replace* – entire cable as an alternative to re-termination.
- *Dormant* – if available.

### 6.1.10 Over-tightened coupling mechanism

#### 6.1.10.1 Symptom

- *Drop in optical power*

#### 6.1.10.2 Location

- Refer to the relevant symptom section.

#### 6.1.10.3 Factors influencing assessment

- Is connector damaged?
- Type of connector – multi-way connectors are more difficult to re-terminate than single way.

#### 6.1.10.4 Repair

- Loosen mechanism – if connector is not damaged.
- *Re-terminate* – if connector is damaged.
- *Replace* – as an alternative to re-termination.
- *Dormant* – if available.

Back to *Connector*.

Back to *Top level Map*.

## 6.2 BACKSHELL

### 6.2.1 Strangulation

#### 6.2.1.1 Symptom

- *Drop in optical power*
- *Complete loss of optical power*

#### 6.2.1.2 Location

- Refer to the relevant symptom section.

#### 6.2.1.3 Factors influencing assessment

- Can backshell be replaced without re-termination ?

#### 6.2.1.4 Repair

- Free fibres without re-terminating.
- *Re-terminate* – if backshell cannot be repaired separately.
- *Replace* – entire cable as an alternative to re-termination.
- *Dormant* – if available.

Back to *Backshell*.

Back to *Top level Map*.

## 6.3 FIBRE

### 6.3.1 Micro-bending

Micro-bending is where the fibre is bent into 'ripples' of millimetre bend radii within the cable.

#### 6.3.1.1 Symptom

- *Drop in optical power*
- *Increased Back Reflection*

#### 6.3.1.2 Location

- Refer to the relevant symptom section.

#### 6.3.1.3 Factors influencing assessment

- Proximity of fault to connector.
- Length of fibre affected.

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#### 6.3.1.4 Repair

- *Replace* – replace affected item.
- *Splice* – if the length of fibre affected is short and sufficiently far away from a connector.
- *Dormant* – if available.

#### 6.3.2 Macro-bending

##### 6.3.2.1 Symptom

- *Drop in optical power*
- *Latent Fault Symptom*

##### 6.3.2.2 Location

- Refer to the relevant symptom section.

##### 6.3.2.3 Factors influencing assessment

- Has fibre sustained damage?
- Length of fibre affected.

##### 6.3.2.4 Repair

- *Routing* – re-route to avoid bending.
- *Replace* – if fibre has been kept bent more tightly than the short term minimum bend radius as damage may have been incurred.
- *Splice* – if bent section can be removed.
- *Dormant* – if available.

#### 6.3.3 Fibre damage

##### 6.3.3.1 Symptom

- *Complete loss of optical power*
- *Drop in optical power*
- *Intermittent loss of power*
- *Increased Back Reflection*

##### 6.3.3.2 Location

- Refer to the relevant symptom section.

##### 6.3.3.3 Factors influencing assessment

- Damaged fibre must be replaced

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- Length of fibre affected
- Proximity to connector

### 6.3.3.4 Repair

- *Replace* – replace affected item.
- *Splice* – if sufficient spare fibre is available.
- *Dormant* – if available.

Back to *Fibre*.

Back to *Top level Map*.

## 6.4 CABLE

### 6.4.1 Cable damage

#### 6.4.1.1 Symptom

- *Latent Fault Symptom*

#### 6.4.1.2 Location

- Refer to the relevant symptom section.

#### 6.4.1.3 Factors influencing assessment

- Depth of cable layers affected – chafing may only affect the jacket but a split may go deeper.
- Environment in which cable resides.

#### 6.4.1.4 Repair

- *Structural* – in a benign environment, with damage to the outer jacket, taping may be used.
- *Replace* – the affected item.
- *Splice - if the damage is deep enough to pose a threat to the fibre.*

Back to *Cable*.

Back to *Top level Map*.

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## 6.5 CONDUIT

### 6.5.1 Break

#### 6.5.1.1 Symptom

- *Complete loss of optical power*
- *Latent Fault Symptom*

#### 6.5.1.2 Location

- Refer to the relevant symptom section.

#### 6.5.1.3 Factors influencing assessment

- A complete break in a conduit will almost definitely occur at the same time as damage to cable and fibre.
- Replacing conduit may involve re-terminating cables so that they can be pulled through ?

#### 6.5.1.4 Repair

- *Structural* – procedure should be the same as for electrical harness conduit.
- *Replace* – may be very time consuming.

### 6.5.2 Kinking or Crushing

#### 6.5.2.1 Symptom

- *Latent Fault Symptom*
- *Drop in optical power*

#### 6.5.2.2 Location

- Refer to the relevant symptom section.

#### 6.5.2.3 Factors influencing assessment

- Could permanent damage to the cable or fibre have occurred?

#### 6.5.2.4 Repair

- *Structural* - procedure should be the same as for electrical harness conduit.
- *Replace* – may be very time consuming.

Back to *Conduit*.

Back to [Top level Map](#).

## 6.6 **COUPLER**

### 6.6.1 Fibre break within package

#### 6.6.1.1 Symptom

- *Complete loss of optical power*
- *Drop in optical power*
- *Intermittent loss of power*
- *Increased Back Reflection*

#### 6.6.1.2 Location

- Refer to the relevant symptom section.

#### 6.6.1.3 Factors influencing assessment

- A fibre break within a coupler package cannot be repaired without replacing the coupler.

#### 6.6.1.4 Repair

- *Replace* – a fault within a coupler cannot be repaired on-aircraft.
- *Dormant* – if available.

### 6.6.2 Fibre break in flying lead

#### 6.6.2.1 Symptom

- *Complete loss of optical power*
- *Drop in optical power*
- *Intermittent loss of power*

#### 6.6.2.2 Location

- Refer to the relevant symptom section.

#### 6.6.2.3 Factors influencing assessment

- Length of flying lead and position of break.

#### 6.6.2.4 Repair

- *Splice* – if sufficient fibre.
- *Replace* – entire coupler.

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- *Dormant* – if dormant coupler is available.

Back to *Coupler*.

Back to *Top level Map*.

## **6.7 SPLICE**

### 6.7.1 Contamination

#### 6.7.1.1 Symptom

- *Drop in optical power*
- *Complete loss of optical power*
- *Intermittent loss of power*

#### 6.7.1.2 Location

- Refer to the relevant symptom section.

#### 6.7.1.3 Factors influencing assessment

- A splice should be sealed so contamination indicates that the splice needs to be replaced.
- Amount of spare cable available for repair.

#### 6.7.1.4 Repair

- *Splice* - if the previous splice has left sufficient cable to repeat the procedure.
- *Replace* - although the presence of a splice would indicate that replacement of the item is not the preferred technique.

### 6.7.2 End face alignment

#### 6.7.2.1 Symptom

- *Drop in optical power*

#### 6.7.2.2 Location

- Refer to the relevant symptom section.

#### 6.7.2.3 Factors influencing assessment

- Amount of spare cable available for repair.

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#### 6.7.2.4 Repair

- *Splice* - if the previous splice has left sufficient cable to repeat the procedure.
- *Replace* - although the presence of a splice would indicate that replacement of the item is not the preferred technique.

### 6.7.3 End face preparation

#### 6.7.3.1 Symptom

- *Drop in optical power*

#### 6.7.3.2 Location

- Refer to the relevant symptom section.

#### 6.7.3.3 Factors influencing assessment

- Amount of spare cable available for repair.

#### 6.7.3.4 Repair

- *Splice* - if the previous splice has left sufficient cable to repeat the procedure.
- *Replace* - although the presence of a splice would indicate that replacement of the item is not the preferred technique.

### 6.7.4 Fluid Ingress

#### 6.7.4.1 Symptom

- *Drop in optical power*
- *Increase in Optical Power*
- *Intermittent loss of power*

#### 6.7.4.2 Location

- Refer to the relevant symptom section.

#### 6.7.4.3 Factors influencing assessment

- Amount of spare cable available for repair.

#### 6.7.4.4 Repair

- *Splice* - if the previous splice has left sufficient cable to repeat the procedure.

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- *Replace* - although the presence of a splice would indicate that replacement of the item is not the preferred technique.

### 6.7.5 Inadequate Strain Relief

#### 6.7.5.1 Symptom

- *Latent Fault Symptom*

#### 6.7.5.2 Location

- Refer to the relevant symptom section.

#### 6.7.5.3 Factors influencing assessment

- Vulnerability to damage.
- Amount of spare cable available for repair.

#### 6.7.5.4 Repair

- *Structural* – if splice is not vulnerable.
- *Replace* – replace item before a failure occurs.
- *Splice* – if the relief boots need to be replaced the splice may have to be repeated.

Back to *Splice*.

Back to *Top level Map*.

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## 7. REPAIR

Once the fault has been isolated a repair can be initiated. Ideally the repair strategy for a specific aircraft will be such that given the fault and scenario, a single repair technique will be appropriate.

### 7.1 REPLACE

Embedded	Open	First Line	Depot
✓ / x	✓	✓ / x	✓

Replacement issues are discussed in [7].

The decision to replace will depend on the accessibility, size, ease of repair and availability of a component. Where possible it is a preferred solution as it is quick and effective. Consideration should be given to factors affecting replacement during the design phase of the harness. A more modular harness, built up of a series of line replaceable units, would be more suited to replacement repairs.

Replacement is also the only option for components damaged beyond repair by other techniques.

Note Replacement does not include Re-termination which is a separate repair procedure (see section 7.4).

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### 7.2 SPLICE

Embedded	Open	First Line	Depot
x	✓	✓	✓

If a fibre optic cable is damaged in between connectors it can be repaired with a splice. A splice is a permanent reconnection of the fibre that should be able to last throughout the service lifetime of the cable.

A means of repairing damaged fibre-optic cable in-service is considered an integral part of the maintenance philosophy for airborne fibre-optic systems. Given the constraints of working on the aircraft, heat cured adhesives, fusion splicing, and time consuming and/or complex termination processes are out of the question. A simple, robust technology that fulfils these requirements is the mechanical splice.

There are many different commercially available mechanical splice techniques, identified in a Harness Study review [8]. However, as they are mainly aimed at the telecommunications market, very few meet aerospace requirements. The Harness study found that the two most mature approaches for application in an aerospace environment appeared to be those offered by Aurora and Amphenol. Aurora's splice was evaluated under the MOD funded 'Fibre-Optic Workstation' project with

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disappointing results. Amphenol's impact mount splice was procured by the Harness Study for an equivalent analysis [9, 10]. Initially Amphenol developed the splice (based largely on IRR acquired from a small US firm called Valdor) for the Canadian Army and it is this version that the Harness Study is investigating. An aerospace version based on the same technology is currently under development at Amphenol.

To summarise, splicing would be the ideal solution when replacement of the cable is not an option. Splices are designed to last the lifetime of the cable so the repair would be permanent. The drawbacks are lack of suitable technology, complicated assembly procedures, and that the physical size of splices prevents them from being used close to connectors. At the time the Harness Study reached completion no fully qualified splicing solution was available.

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### 7.3 STRUCTURAL

Embedded	Open	First Line	Depot
x	✓	✓	✓

Where damage is to the cabling rather than to the fibre itself it may be possible to use a structural repair e.g. taping. The decision to use a structural repair will depend on the depth of the damage on the cable.

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### 7.4 RE-TERMINATE

Embedded	Open	First Line	Depot
x	✓	✓	✓

Retermination is defined to mean the attachment of a connector (or termini within a connector) to the cable 'on aircraft'. The technique can be used to replace a damaged connector by "reterminating" although it is equally applicable to repair mid-loom where two "reterminations" can be performed and mated – a procedure that could be used as an alternative to splicing.

An ideal re-terminating solution would;

- Be able to be performed in very confined areas.
- Be able to restore the mechanical strength of the cable.
- Be able to perform satisfactorily in the environment over the life of the repair (hopefully 25 years).
- Require minimal time and skilling to perform termination.

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Four generic techniques for re-termination have been identified in by the Harness Study and the topic is covered in detail in [11, 12]. The techniques are;

- Pot and Polish – attachment of fibre to connector is by some form of adhesive – similar to a standard termination.
- Crimp and Cleave – developed for plastic fibre – obtaining a good quality cleave with glass fibre is difficult.
- Crimp, Cleave and Polish – as above with an extra polishing step suitable for glass fibre.
- Pre-Inserted Fibre – depends on a good cleave and requires adhesive.

All of these techniques follow the procedure of an initial preparation of the cable, attachment of the connector to the cable, end face preparation and a final assembly.

The main failure mechanism seen on existing installations of fibres in aircraft have been failures very close to a connection, induced mainly by maintenance actions. There are going to be many occurrences where the time and cost implication of stripping out a loom and replacing it are not a satisfactory solution. This is why the avionics industry needs a re-termination capability.

The findings of the study suggest that the best approach, currently, is to reterminate to the same standard of initial manufacture, where possible. This would draw from the developments into miniaturisation of tools such as ovens and polishing fixtures.

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### 7.5 RE-POLISH

Embedded	Open	First Line	Depot
x	✓	✓	✓

If cleaning fails to eliminate the fault, re-polishing of the fibre end face may be required. This may be due to a particularly stubborn contaminate or physical damage to the glass of the fibre.

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### 7.6 ROUTING

Embedded	Open	First Line	Depot
✓	✓	✓	✓

Routing and other installation issues are discussed in [13, 14, 15].

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Good routing is predominantly a technique for minimising the risk of a system failure and enabling access to the harness for inspection repair. Both of these areas are covered during the design stage of the harness. However routing, or more specifically, re-routing is also necessary as part of a repair and good harness design can make this simpler. Re-routing is often required in conjunction with re-termination as the re-termination process shortens the length of the cable. With the introduction of extra path length taken up in the initial routing, a re-route can provide sufficient extra length that the cable is still long enough to reach its destination. A drawback of this technique is that additional clipping points need to be provided on the airframe which may be limited by available space.

Use of fibre loops to provide spare fibre has some serious drawbacks. If the harness is routed through convoluted conduit it is not an option. In an open harness, loops in the proximity of an LRI are vulnerable to damage or excess bending during LRI maintenance. A more suitable solution would be to position any fibre loops away from connector backshells, avionics racks, LRI's and components and in a suitably accessible low maintenance zone.

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## 7.7 CLEANING

Embedded	Open	First Line	Depot
x	✓	✓	✓

Cleaning issues are reported in [16, 17, 18].

Optical connectors, by their very nature, are a means of accurately aligning the associated fibres to allow maximum optical power. Any contamination on the mating faces will affect the optical signal and the requirement is to ensure that the contact faces are clean on assembly and remain so. Contamination of the connector body is also an a major concern since the ferrules are often spring loaded and any foreign matter may cause incorrect operation.

To achieve minimum losses the ferrules can be specified to be clean on delivery of the harness and efforts can be made to ensure they are kept clean by use of protective dust caps, but sooner or later, through accident or as a result of other procedures, the disconnected items will be subject to contamination.

Factors that affect the choice of cleaning procedure are;

- Type of connector – single termini, multi-termini, expanded beam and hybrid optical/electrical connectors all require different procedures.
- The type of contamination – liquid, particulate and combined contaminants have different cleaning characteristics.
- The degree of contamination – a low level of contamination may only require the ferrule end face to be cleaned but more extensive contamination may require the connector housing to be cleaned too.

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- COSHH limitations – especially when chemicals are involved.

Cleaning techniques that have been evaluated are;

- Lint free cloth/bud – simply wiping with a dry, lint free material.
- Chemicals/solvents – used in conjunction with a wipe.
- Compressed air/gases – used to blast away contaminant.
- Polyester tapes – specially designed material for fibre optics which comes in bud form or on a reel in a 'cassette'.

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## 7.8 **DORMANT**

Embedded	Open	First Line	Depot
✓	✓	✓	✓

The issues surrounding installation of dormant components are discussed in [19].

The use of dormant fibres would allow replacement of damaged fibres within a harness without the need for removal of the harness or introduction of new fibre into the harness. However including dormant fibres within a system would introduce a number of technical problems.

- Protection of the unconnected termini on the dormant spare.
- Weight penalties.
- Whether to route the dormant alongside its live counterpart, risking simultaneous damage.
- Whether to use un-terminated or pre-terminated dormant components.

The decision to install dormant fibre will have to be made at the design phase. In the case when it has been installed, the switch to the dormant fibre is likely to be a last option scenario.

Repair by installing a dormant must be followed by a permanent repair or replacement of the damaged cable.

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## **8. TOOLS**

The repair and Maintenance procedures discussed call for the use of a variety of tools, in this section a generic view is given of available tools.

### **8.1 FAULT LOCATION**

#### **8.1.1 Optical Time Domain Reflectometers (OTDR)**

OTDR's are discussed in section 5.1

- *OTDR*

See also references [1, 5]

#### **8.1.2 Visible Fault Locator**

Visible Fault locators are discussed in section 5.2

- *Visible fault locator*

See also [1].

#### **8.1.3 Inspection**

Inspection tools are discussed in section 5.3

- *Inspection*

Reference is also made to FOHS2 task 4 "Inspection and Fault Analysis" reference [20, 21].

#### **8.1.4 Power Measurement**

Power measurement is discussed in section 5.5

- *Power measurement*

Reference is also made to FOHS2 task 1 "Test and Measurement" references [22, 23]

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## **8.2 MAINTENANCE TOOLS**

### **8.2.1 Cleaning**

A variety of cleaning tools for Fibre Optic connectors are available ranging from, lint free tissues, clean air canisters, solvents, cotton buds to more sophisticated tape systems.

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Issues include health and safety (solvents etc.), access especially on multiway and recessed connectors, removal as opposed to moving contaminant.

A more detailed account can be found in [17].

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### **8.3 REPAIR TOOLS**

#### **8.3.1 Retermination**

Retermination will require portable versions of the factory termination tools associated with the selected connector, similar to those found in the Termination Workstation, This includes

- Cutters
- Cleavers
- Curing oven
- Polisher

See [11] and FOHS2 Task 2 "Termination Methods and Tools" [24].

#### **8.3.2 Splice**

The tools required to implement a splice are usual specific to the splice technology selected, in addition preparation tools are required e.g.

- Cutters
- Strippers
- Cleavers
- Polishers

For a review of Splice technologies see [8].

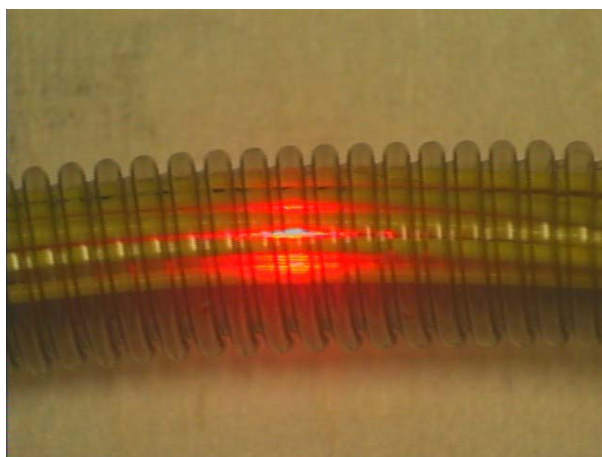
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## 9. DESIGN RECOMMENDATIONS

It has been recognised throughout the Study that Repair and Maintenance issues should be recognised and accommodated throughout the harness and installation design process. A number of general but key points are highlighted.

- **Component selection** - Ease of repair and maintenance should be considered in component selection e.g. multi-way connectors with easy access for cleaning and inspection. Secure fitting dust caps should always be used [25]
- **Fibre cable selection** - Visible fault locators are useful tools but are only effective if the fibre has a translucent jacket and cable. Use of more translucent materials in conduit and raceways would also aid the use of visible fault locators (see Figure 4).



**Figure 4 Visible Fault Locator Used in Conjunction with Translucent Conduit**

- **Access** - The accessibility of sections of the harness is a key factor in the selection of a Repair and Maintenance procedure. Interconnect elements such as connectors which are subject to maintenance should be located to ease access.
- **Identification** - Cable should be readily identifiable as carrying optical fibres.
- **Risk areas** - Connectors should not, when possible, be located adjacent to sources of liquid or particulate contamination.
- **Cable marking** - Cable marking should be considered to:
  - Identify available excess length of fibre available for splice or retermination.
  - As a "yard stick" to physically locate faults from OTDR measurements.
- **Dormant Spares** - Provision of dormant spares should be considered if sections of the harness are not accessible for repair, it is further

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recommended that the dormant fibre be routed separately as it is recognised that the mechanism or agent which has damaged the initial installation may have damaged the dormant spare if co-located.

- **Replacement** - Replacement is considered as a viable repair procedure which would find most application where the harness is routed in vulnerable areas e.g. moving parts or heavy maintenance. It is prudent in such situation to locate connectors etc. to ease the replacement of the harness section.
- **Routing for Re-termination** – Repair of damaged cable often requires excess fibre length which has to be incorporated into the harness. Techniques for achieving this are discussed in [13].

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## **10. REFERENCES**

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- [1] HS2/BS/043/T.5.1 'Location and Diagnostics of Faults in Aircraft Fibre Optic Harness'.
- [2] HS2/SI/002/T.5.1 'R&M requirements'.
- [3] HS2/WH/028/T.5.4 'Compilation of Repair and Maintenance Procedures'.
- [4] HS2/WH/080/T.X.X 'BIT Aspects of Inspection and Fault Analysis. Detect-Locate-Isolate- Repair'.
- [5] HS2/BA/045/T.6.1 'Task 6: Demonstration 1 Report'.
- [6] HS2/BS/036/T.2.1 'Failure Modes in Optical Fibre Terminations'.
- [7] HS2/II/012/T.5.A 'Replacement'.
- [8] HS2/BS/051/T.5.1 'Review of Commercial Fibre Optic Splice Technology'.
- [9] HS2/BS/057/T.5.1 'Initial Evaluation of Amphenol Impact Mount Splice'.
- [10] HS2/UE/024/T.5.1 'Report Listing Test Data Due to the Effects of Temperature on Impact Mount Splices'.
- [11] HS2/WH/070/T.5.A 'Retermination'.
- [12] HS2/LA/007/T.2.1 'Termination Procedures for evaluation by FOHS Partners'.
- [13] HS2/BA/043/T.5.1 'Routing'.
- [14] SDF/B86/A/115/0384 'Looming Practices and Installation - Final Report'.
- [15] HS2/BA/010/T.3.2 'Identification of Important Control Parameters'.
- [16] HS2/UE/014/T.5.1 'Report on Analysis of Maintenance Procedures – Cleaning'.
- [17] HS2/UE/022/T.5.A 'Cleaning of Fibre Optic Connectors'.
- [18] HS2/SI/064/T.5 'Cleaning Presentation'.
- [19] HS2/BA/042/T.5.1 'Redundancy'.
- [20] HS2/WH/059/T.4.2 'Inspection Criteria Document'.
- [21] HS2/LA/008/T.4.1 'Inspection Criteria Document'.
- [22] HS2/BS/056/T.1.1 'Design and Construction of Filters to Modify the Near and Far Field Distributions of Fibre Test Leads'.
- [23] HS2/BS/060/T.1.1 'Suggested near and Far Field Launch conditions for the Eurofighter Fibre'.
- [24] HS2/BS/048/T.2.A 'Classification of Fibre Cable Stripping Tools'.
- [25] HS2/WH/065/T.5.1 'End Protection'.