



AEROSPACE INFORMATION REPORT

AIR6552™/2

Issued 2021-04

High-Resolution Optical Reflectometry Network End-to-End Data Link Evaluation System

RATIONALE

There is a need for a robust optical performance monitoring system that is capable of detecting, localizing, and isolating impairments as well as assisting in failure prediction of the physical layer of a fiber optic network. High-resolution optical reflectometry can characterize and map the optical link.

1. SCOPE

This document establishes methods to obtain, store, and access data about the health of a fiber optic network using a commercially available high-resolution reflectometer. This document is intended for:

- Managers
- Engineers
- Contracting Officers
- Third Party Maintenance Agencies
- Quality Assurance

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP6283 In-Service Fiber Optic Inspection, Evaluation and Cleaning, Best Practices, Physical Contact Termini

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SAE WEB ADDRESS:

Full document details: SAE AIR6552_2

For more information on this standard, visit
<https://www.sae.org/standards/content/AIR6552/2/>

Documents

Document Sharing Hub

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

- ARP5061 Guidelines for Testing and Support of Aerospace, Fiber Optic, Inter-Connect Systems
- ARP5602 A Guideline for Aerospace Platform Fiber Optic Training and Awareness Education
- AS5675 Characterization and Requirements for New Aerospace Fiber Optic Cable Assemblies - Jumpers, End Face Geometry, Link Loss Measurement, and Inspection

2.2.2 ANSI Accredited Publications

Copies of these documents are available online at <http://webstore.ansi.org/>.

- ANSI Z136.1-2007 American National Standard for Safe Use of Lasers
- ANSI/TIA-440-B-2004 Fiber Optic Terminology

2.2.3 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

- IEC 60825-1 Laser Safety Equipment Classification (Safety of Laser Products)
- IEC 60825-2 Safety of Optical Fiber Communication Systems
- IEC 60825-4 Laser Guards

2.2.4 NASA Publications

NASA Technical Services, NASA STI Program STI Support Services, Mail Stop 148, NASA Langley Research Center, Hampton, VA 23681-2199, 757-864-9658, Fax: 757-864-6500, <http://ntrs.nasa.gov/>.

- NASA-STD-8739.5 Fiber Optic Terminations, Cable Assemblies, and Installation

2.2.5 NAVAIR Publications

Available from Naval Air Warfare Center - Aircraft Division (Code AB43300), 48298 Shaw Rd., Building 1461, Patuxent River, MD 20670-1900.

- NAVAIR 01-1A-505.4 Installation and Testing Practices Aircraft Fiber Optic Cabling

2.2.6 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

- FED-STD-1037 Glossary of Telecommunications Terms
- MIL-DTL-38999 Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, and Breech Coupling), Environmental Resistant, Removable Crimp and Hermetic Coupling, General Specification for

MIL-PRF-29504 Termini, Fiber Optic Connector, Removable, General Specification for

MIL-STD-1678 Fiber Optic Cabling Systems Requirements and Measurements

2.2.7 ARINC Publications

Available from ARINC, 2551 Riva Road, Annapolis, MD 21401-7435, Tel: 410-266-4000, www.arinc.com.

ARINC Specification 600-19 Air Transport Avionics Equipment Interfaces

ARINC Report 805 Fiber Optic Test Procedures

ARINC Report 806 Fiber Optic Installation and Maintenance

ARINC Report 807 Fiber Optic Training Requirements

2.2.8 Other Applicable References

Understanding Fiber Optics, 5th Edition, Jeff Hecht, ISBN 0-13-117429-0

Fiber Optics Installer and Technician Guide, Bill Woodward, Emile B. Husson, ISBN: 0-7821-4390-3

Cabling: The Complete Guide to Copper and Fiber-Optic Networking, 4th Edition, Andrew Oliviero, Bill Woodward, ISBN: 978-0-470-47707-6

3. OPTICAL TIME DOMAIN AND OPTICAL FREQUENCY DOMAIN REFLECTOMETRY MEASUREMENT TECHNIQUES

While an optical loss test set (OLTS) can measure end-to-end loss, it cannot isolate and measure the performance of any specific feature within the link, and it requires access to both ends of the link (thus, two operators). The time domain/spatial differentiation of an optical time domain reflectometer (OTDR) can be used to characterize individual events along an optical link for insertion loss (IL) and back reflectance (BR), e.g., connectors, spliced fibers, and effects of installation (e.g., tight bends in a fiber optic cable). Important features of this method of testing are that it is non-destructive and that it only requires access to a single input end of the fiber, following initial end to end testing in both directions to establish a baseline for future measurements or fault finding.

An OTDR is based on direct time-of-flight measurement of short optical pulses. The high sensitivity necessary to detect the weak RBS (typically -70 dB for single mode [SM] fiber with 1 ns pulses), combined with the need for high speed detection, matching the short optical pulses required for high resolution, requires unusual detection technology. Current high resolution OTDRs use photon-counting detection. As this type of detection has limited intrinsic dynamic range (DR), some OTDR models therefore have two operating modes: a so-called Rayleigh mode, which measures the Rayleigh backscatter (RBS) level and therefore can measure insertion loss in the link under test (LUT) but not the reflection values; and a so-called Fresnel mode, which measures reflections in the link under test (LUT) but lacks the sensitivity necessary for RBS measurements. Some models, based on a modified version of photon-counting detection, which increases the dynamic range (DR) of the detection system, can measure both RBS and strong reflections on the same trace.

CAUTION

As the detection system in OTDRs is very sensitive to stray light, prior to running an OTDR optical link test the operator should ensure that the optical link under test is not transmitting and that the end device is de-energized. Alternatively, if measurement of live fibers is required an OTDR should use a different wavelength (e.g., for testing SM fiber systems in the S- or C-bands [1310 nm and 1550 nm] the OTDR could work in the monitoring band around 1625 nm). In this case proper filtering of the live wavelength is necessary to screen it from the OTDR detector.

OTDRs can be designed for any type of fiber and for most optical wavelengths. It is also possible to have multiple wavelengths and a capability to measure different types of fibers in a single instrument. Use of a mode conditioner for measuring multimode (MM) fiber with a SM OTDR is also possible (as with OFDRs) but not recommended, as it reduces the DR of the system. It is preferable to have dual systems, with separate SM fiber and MM fiber outputs.

The OTDR screen generally displays distance calculated from time of flight and the fiber index of refraction in the horizontal axis and intensity in the vertical axis. Standard OTDRs, which are designed for long distance applications, usually use a logarithmic vertical scale, as the attenuation over long distances may cover several orders of magnitude. As the attenuation is an exponential function this has the added advantage of presenting the trace as a straight sloped line. For short haul applications the attenuation is usually negligible, so for instruments using the Rayleigh mode the vertical scale can be linear. As the reflection levels to backscatter level may cover several orders of magnitude, OTDRs showing both RBS and reflections have to use a logarithmic scale.

The following sub-sections detail two methods of high resolution OTDR or OFDR measurement currently being used in the aerospace industry.

3.1 Backscatter

OTDRs used in the telecommunication industry measure the return signal produced by Rayleigh backscatter and are typically designed for long-distance measurements (>1000 m) with a resolution in the multi-centimeter range. This type of OTDR is not easily suited to measuring short length optical links (<200 m) found in aviation and aerospace applications. However, specialist high resolution OTDRs have been designed with a resolution in the low centimeter range (20 to 30 cm) and that have the ability to characterize short lengths, down to a few meters. These can be adapted to most aviation and aerospace applications; however this type of high resolution OTDR is typically optimized for use with SM fibers and requires the utilization of “special to type” launch cables or adapters to allow the measurement and testing of MM fiber optic links. High resolution devices can also be classed as optical frequency domain reflectometers (OFDR) using optical backscatter reflectometry (OBR).

The basic principles of an OBR are to launch short, high power optical pulses of swept frequency into the fiber under test and to detect back scattered optical power from events within the optical fiber link. The detected signal, based on the time delay of the reflected light compared to the launched light, provides a detailed image of the local loss distribution or reflections along the optical fiber link caused by any attenuation mechanisms or events occurring within the link, e.g., connectors, bends, crushing, etc.

3.2 Photon Counting

OTDRs using photon counting techniques do so by transmitting optical pulses of 1 ns width, generating very short detection windows. The detection window is defined by the distance d the optical pulse travels during its duration:

$$d = ct/n$$

where:

c = speed of light in vacuum (2.99×10^{10} cm/s)

t = pulse duration in seconds

n = group index of refraction in the fiber core, typically around 1.47

To measure the distances of features or “events” in a fiber link it is therefore necessary to know the index of refraction accurately, and this may vary from one fiber to another, or even slightly between two different production lots of the same type.

Figure 1 shows a comparison of an OTDR with a 1 ns pulse width compared to an OTDR with a 3 ns pulse width. The OTDR scans the detection windows one step at a time and adds variable attenuation at each step to achieve one pulse for one count max. The resulting trace is a histogram of the different number of counts. This method produces a “zero” dead zone and a high resolution range of 1 to 10 cm, resulting in more accurate measurements of length and identification of positions of events within an optical link. Photon counting OTDRs also have the capability of measuring SM or MM fibers without the need for additional optimizing launch cables or adapters. Figure 2 shows an example of the sampling of a fiber link using photon counting techniques.

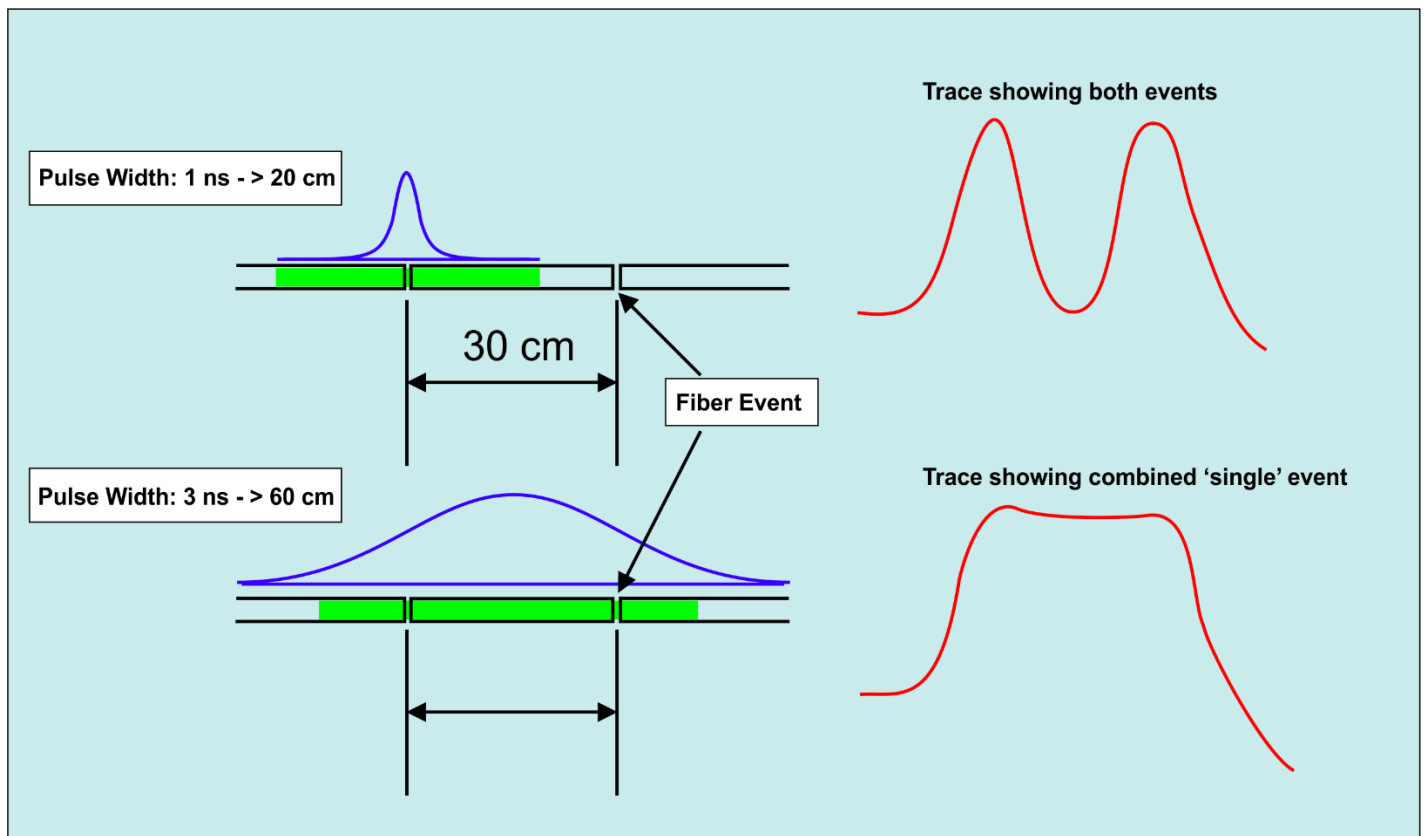


Figure 1 - Comparison of two close events with a 1 ns pulse width OTDR and a 3 ns pulse width OTDR

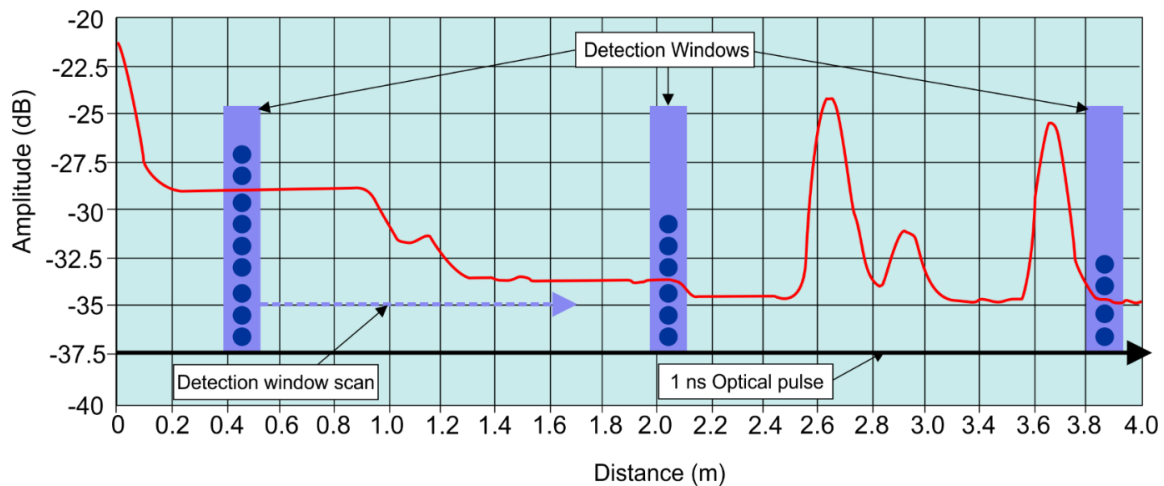


Figure 2 - Example of sampling using photon counting techniques

3.3 General Features

As both techniques detailed in 3.1 and 3.2 are based on reflectometry, this section describes general features common to both types.

Reflectometric traces are built from two different elements:

- Horizontal sections

These are produced by the effects of Rayleigh backscattering (RBS) of the light propagating down the fiber. Fibers with inherently higher losses such as plastic optical fiber (POF) produce considerably more sloped sections.