



AEROSPACE RECOMMENDED PRACTICE

ARP6366™

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Fiber Optic Sensor Specification Guidelines for Aerospace Applications

RATIONALE

Use of fiber optic sensor systems in the aerospace industry is expected to grow as the benefits and unique sensing solutions are understood. Guidance is needed for writing fiber optic sensor specifications to supply a comprehensive and widely-accepted vocabulary, parameters, and practices for fiber optic sensors for aerospace applications. Adoption of fiber optic sensors on aerospace platforms will benefit from improved coordination between developers, specifiers, program managers, and end users.

ARP6366 has been reaffirmed to comply with the SAE Five-Year Review policy.

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1. SCOPE

ARP6366 defines a comprehensive and widely-accepted set of specification guidelines to be considered by those seeking to use or design fiber optic sensors for aerospace applications. Some of the most common applications for fiber optic sensing within aerospace include inertial guidance and navigation (gyros) and structural monitoring (temperature, strain, and vibration sensing). Common sensor infrastructure elements include: transmitting and receiving opto-electronics (e.g., sources and receivers); multiplexing and demultiplexing optics; optical cabling; and signal processing (both hardware and firmware/software).

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.

AIR6258	Fiber Optic Sensors for Aerospace Applications
ARP5061	Guidelines for Testing and Support of Aerospace, Fiber Optic, Inter-Connect Systems
ARP5062	Recommended Test Fluids for Electrical Components Used on Aircraft Exterior or for Ground Support Near Aircraft
ARP6283	In-Service Fiber Optic Inspection, Evaluation and Cleaning, Best Practices, Physical Contact Termini
AS5405	Mechanical Splice for Aerospace Fiber Optic Cables
AS5658	Platform/Subsystem Common Interface Control Document Format
AS5675	Characterization and Requirements for New Aerospace Fiber Optic Cable Assemblies - Jumpers, End Face Geometry, Link Loss Measurement, and Inspection
AS6506	Fusion Splice for Aerospace Fiber Optic Cables

2.1.2 Military Specifications

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

MIL-PRF-24623	Performance Specification Sheet: Splice, Mechanical, Simplex Fiber Optic Cable, Aircraft
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2.1.3 Other Publications

ANSI Z136.2	Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources
ARINC 806	Fiber Optic Installations and Maintenance
ARINC 807	Fiber Optic Training Requirements

ASTM E251-92	Standard Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages
RTCA DO-160	Environmental Conditions and Test Procedures for Airborne Equipment
ITU-T G.657	Characteristics of a bending-loss insensitive single-mode optical fiber and cable

2.1.4 Other References

Yin, S., Ruffin, P., and Yu, F., editors, Fiber Optic Sensors, CRC Press, New York NY, 2008.

Udd, E. and Spillman, W., Field Guide to Fiber Optic Sensors, SPIE Press, Bellingham WA, 2014.

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

The appendices of this specification cite specific references for guidance in selection of components and practices for specific applications.

AIR6031	Fiber Optic Cleaning
AS5590	Connectors, Fiber Optic, Advanced, Circular or Rectangular, Plug and Receptacle, Environment Resistant, Removable Termini
AS5675	Characterization and Requirements for New Aerospace Fiber Optic Cable Assemblies - Jumpers, End Face Geometry, Link Loss Measurement, and Inspection
AS6282	Fiber Optic Harsh Environment Test Methods Standards Cross Reference

2.2.2 Military Specifications

MIL-DTL-38999	Detail specification: connectors, electrical, circular, miniature, high density, quick disconnect (bayonet, threaded, and breech coupling), environment resistant, removable crimp and hermetic solder contacts, general specification for
MIL-DTL-83526	Detail specification sheet: connector, fiber optic, circular hermaphroditic, bulkhead, low profile without strain relief, jam-nut mount, 2 and 4 positions, expanded beam
MIL-PRF-28876	Performance specification connectors, fiber optic, circular, plug and receptacle style, multiple removable termini
MIL-PRF-49291	Performance specification: fiber, optical, general specification
MIL-PRF-64266	Performance specification connectors, fiber optic, circular, plug and receptacle style, multiple removable genderless termini, environment resisting general specification for
MIL-STD-1678	Fiber Optics Test Methods and Instrumentation
MIL-STD-1760	Department of defense interface standard: aircraft/store electrical interconnection system

2.2.3 Other Publications

ARINC 801	Fiber Optic Terminus
ARINC 803	Fiber Optic Design Guidelines
ARINC 805	Fiber Optic Test Procedures
EN 2591	Elements of Electrical and Optical Connection - Test Methods
EN 3197	Design and Installation of Aircraft Electrical and Optical Interconnection Systems
EN 3733	Aerospace Series - Connector, Optical, Circular, Single Channel, Coupled by Self-Locking Ring, Operating Temperature up to 150 °C Continuous
EN 3745	Aerospace Series - Fibers and Cables, Optical, Aircraft Use - Test Methods
EN 3909	Aerospace Series - Test Fluids and Test Methods for Electrical and Optical Components and Sub-Assemblies
EN 4531	Aerospace Series - Connectors, Optical, Circular, Single and Multipin, Coupled by Triple Start Threaded Ring - Flush Contacts
EN 4533	Aerospace Series - Fiber Optic Systems, Handbook, Parts 1 through 4
EN 4626	Aerospace Series - Connectors, Optical, Rectangular, Multicontact, Rack and Panel, Quadrax Cavity, 2.5 mm Diameter Ferrule - Operating Temperatures -65 to 125 °C (Cable Dependent) - Flush Contacts
EN 4639	Aerospace Series - Connectors, Optical, Rectangular, Modular, Multicontact, 1.25 Diameter Ferrule, with Removable Alignment Sleeve Holder
EN 4640	Aerospace Series - Connectors, Optical, Rectangular, Rack and Panel, Multicontact, 1.25 Diameter Ferrule, with Removable Alignment Sleeve Holder
EN 4644	Aerospace Series - Connector, Electrical and Optical, Rectangular, Modular, Rectangular Inserts, Operating Temperature 175 °C (or 125 °C) Continuous
EN 4645	Aerospace Series - Connectors, Optical, Circular, Single and Multipin, Coupled by Threaded Ring, Self-Locking 1.25 mm Diameter Ferrule with Removable Alignment Sleeve Holder
FOTP-71	Procedure to Measure Temperature - Shock Effects on Fiber Optic Components
TR 4542	Guidance for Fluid Tests

2.3 Acronyms

ADOCS	Advanced Digital Optical Control System
AEEC	Airline Electronic Engineering Committee (a branch of ARINC)
AGC	Automatic Gain Control
AOPT	Advanced Optical Position Transducer
APC	Angled Physical Contact
APD	Avalanche Photo Diode
ARD	Aerospace Resource Document
ARINC	Aeronautical Radio, Inc., a major aerospace standards organization now affiliated with SAE
ARP	Aerospace Recommended Practice
ASIC	Application Specific Integrated Circuit
AWG	Array Waveguide Gratings
BER	Bit-Error-Rate

BIT	Built-In-Test
C ³ I	Command, Control, Communications and Intelligence
CCD	Charge-Coupled-Device (detector array)
CW	Continuous Wave (not sine wave, pulsed, or otherwise modulated in time)
CWDM	Coarse Wavelength Division Multiplexing
CMOS	Complementary Metal Oxide Semiconductor
DOD	Department of Defense
DWDM	Dense Wavelength Division Multiplexing
EMC	Electromagnetic Compatibility
EMI	Electro-Magnetic Interference
EN	European Norm
EMP	Electro-Magnetic Pulse
FADEC	Full Authority Digital Engine Control
FBG	Fiber Bragg Grating
FP	Fabry-Pérot
FSR	Free Spectral Range
FWHM	Full Width at Half Maximum
GHS	Global Harmonized System
HALT	Highly Accelerated Life Test
IDP	Integrated Detector Preamplifier
IEC	International Electrotechnical Commission (based in Geneva)
IL	Insertion loss (loss of power due to insertion of a component in a link)
LED	Light Emitting Diode
LD	Laser Diode
LPG	Long Period Grating
MI	Michelson Interferometer
MT	Multifiber Termination
MT	Mechanical Transfer
MZI	Mach-Zehnder Interferometer
OBR	Optical Backscatter Reflectometer
ODS	Ozone Depleting Substance
OFCS	Optical Fiber Communication System
OFDM	Optical Frequency Division Multiplexing
OFDR	Optical Frequency Domain Reflectometer
OTDR	Optical Time Domain Reflectometer
PC	Physical Contact (connector)
PCB	Polychlorinated Biphenyls
PCF	Photonic-Crystal Fiber
PD	Photodiode
PIN	Positive-Intrinsic-Negative photo diode, commonly used as a light detector
PSD	Position Sensitive Device
RL	Return Loss
REACH	Registration, Evaluation, Authorisation and Restriction of Chemical Substances
SDS	Safety Data Sheets (formerly known as Material Safety Data Sheets – MSDS)
SDM	Spatial- Division Multiplexing
SLD	Superluminescent Diode
SWAMP	Severe Wind and Moisture Problem
TDM	Time Division Multiplexing
UPC	Ultra Physical Contact (connector)
WDM	Wavelength Division Multiplexing

3. OPTICAL SENSING TECHNOLOGY

The range of fiber optic sensing applications is growing rapidly, particularly within aerospace. Some of these include measuring temperature, strain, acoustics, vibration, static and dynamic pressure, magnetic field strengths, acceleration, rotation, and chemical and biological compound detection. This is due to well-known characteristics of fiber optics, such as design flexibility, compactness, high sensitivity, in-situ measurements, and immunity to external electromagnetic interference.

3.1 Sensing System Considerations

Fiber optic sensing technologies have many applications in research, development, aerospace, defense and commercial markets, such as diagnostics and process control. The various applications for optical sensors require knowledge of optical, material, and environmental properties that affect sensor performance. There are many types of optical sensors for specific applications. They each require specific optical components, opto-mechanical configurations, and detection architectures to meet a myriad of requirements. Some examples are presented in the following sections, such as variable-coupling fiber optic sensors, Fiber Bragg Gratings, Fabry-Perot sensors, Michelson interferometers, diffractive wavelength-modulated sensors, optical frequency domain reflectometry, fluorescence lifetime-based sensors, fiber optic distributed temperature sensors, quantum-confined Stark effect for semiconductor-based optical modulators, magneto-optic effect, magneto-optic Kerr effect and strain-optic sensing. A brief description of these sensor types is found in Appendix A.

Optical sensors are electrically nonconductive, immune to EMI, lightweight, and noncorrosive. Sensor measurements can often be performed near high voltage, sources of electromagnetic interference, and in explosive environments. Because of the multi-point form factor and relative ease of signal multiplexing, optical fiber sensors are an ideal alternative to conventional electrical sensors. In contrast, with more traditional sensing technologies like electrical sensors, the manufacturing methods and very highly elastic behavior of the fiber optic itself, fiber optic sensors can be highly reliable and stable over time, making them an excellent option for long-term structural health monitoring over decades. Stemming from the inherently low transmission loss of optical fiber, optical sensing systems can also interrogate optical fiber sensors over long distances with the use of modest optical power and low-loss fiber arrays. With fiber optics, temperature resolution of ~ 0.1 °C, and strain resolution of ~ 0.7 , microstrain are readily achievable. Additionally, depending on the type of sensing technology (elaborated below), dozens of optical sensors can be integrated to communicate over a single fiber with ranges over 10 km away from the interrogation sub-system.

Some typical considerations for the operation and installation of optical fiber sensors include:

- Physical dimensions
- Thermal shock
- Mechanical shock (operational and non-operational)
- Steady state temperature and humidity
- Cold and high storage temperature
- Altitude
- Altitude immersion
- Aerospace fluid exposure
- Salt atmosphere
- Sand and dust exposure
- Fiber integrity tests
- Attachment

- Environmental durability
- Connector and receptacle durability
- ESD
- Attachment method
- Cyclic strain
- Temperature cycling
- Vibration
- Steady state life
- Cyclic moisture
- Hermetic seal
- Outgassing
- Flammability
- Interconnect cable routing
- EMI and EMC
- Radiation (ionizing and non-ionizing)
- Thermal vacuum

Performance considerations for fiber optic sensors include:

- Measurand
- Accuracy
- Resolution
- Stability
- Calibration
- Repeatability and reproducibility
- Dynamic range
- Linearity
- Sensitivity
- Response time, speed, latency

3.2 Specific Sensor Considerations

Some rational considerations should be made for sensor design and deployment to assure optimal correlation of the measurand with the measured signal. For many optical sensors, this is the subject of rigorous work. There are two basic approaches for design and deployment:

- Process Based - Instructions for sensor design and deployment are given. The focus is for the instructions, when followed, to provide adequate performance.
- Requirement Based - The desired sensor performance is specified. The focus for designers is to achieve the desired performance, using methods of their choice.

Table 1 - Some sensor installation considerations for fiber optic sensors, by sensor type

Sensor Type	Consideration
Light Detection	The sensor is within the illuminated region and at the proper angle.
Light Detection, Relative	No impairment should affect the stability of the system, causing other than the desired change to be measured.
Light Detection, Spectral	The sensor system must be sensitive across the spectra to be measured and provide known spectral response to assure proper calibration.
Strain	The orientation of the strain sensor should match, as closely as possible, the direction of the measured strain.
Pressure	Sensor should be functional over the range of system bias.
Altitude	Sensor should be functional over the range of system bias.
Temperature	Sensor should not affect temperature of the body being measured.
Temperature versus Position	Sensor should add little thermal mass, which would affect gradient.
Humidity	Sensor sample volume should be minimized to reduce hysteresis.
Ice Detection	Sensor should be impervious to significant blocking ice formation.
Linear Displacement	Hysteresis should be kept to a minimum.
Rotation Angle	Hysteresis should be kept to a minimum.
Rotation Speed	Time resolution of the optical detector.
Flow Rate	Cross section of flow varies; sensor should be placed appropriately.
Fluid Level	For continuous fluid level sensors: sensor captures desired average level. For point fluid level sensors: dynamics of the fluid level point are tracked.
Electrical Voltage	Likely to be an extrinsic sensor.
Electric Field	Likely to be an extrinsic sensor.
Chemical Sensor, Fluid	Durability and sensitivity to the specific type of chemical – appropriate to expected lifetime under exposure. Durability of the transducing compound is a normal issue.
Chemical Sensor, Gas	Reaction time of the light detection system, relative to the sample exchange rate.
Chemical Detection	Likely to be an extrinsic sensor which adds sensitivity and selectivity.
Particle Sensor	Design should prevent trapping particles in the optical path and avoid erosion of the sensor itself due to particle movement.
Particle Density Sensor	Design should prevent trapping particles in the optical path.
Acoustic Properties	Matrix effects may cause intermixing of signals from different properties. Resonances within the detection bandwidth should be avoided.
Acoustic Position Sensor	Time resolution corresponds to spatial resolution.
Gyroscope	Directivity and time resolution of the light detection system.
Radiation Detection	Sensitivity to the specific type of radiation - avoid radiation damage to the sensor.

3.3 Sensor Cross Sensitivities

One of the benefits most optical fiber sensors offer can also be considered a drawback. That is, the sensors are often sensitive to more than one physical quantity. This concept is important for both sensor and system engineers to understand. Sensor and system designers need to design and package sensors in a way that the sensor maximizes its response to the desired quantity (i.e., the primary sensitivity) and minimizes its response to any other quantity (i.e., the secondary, or 'cross' sensitivities). For example, Fiber Bragg Gratings (FBGs) are very sensitive to both temperature and strain. To optimize an FBG for a specific application, some manufacturers provide special packaging which enhances one response while minimizing response to the undesired measurands. From the perspective of the system engineer, the cross sensitivities need to be considered as error sources when modeling the performance of a system and processing the sensor outputs. Table 2 shows examples of typical optical fiber sensors with both their primary and secondary sensitivities.