IEC 61757-3-2

Edition 1.0 2022-03

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Fibre optic sensors –
Part 3-2: Acoustic sensing and vibration measurement – Distributed sensing

Capteurs fibroniques –
Partie 3-2: Détection acoustique et mesure des vibrations – Détections réparties

IEC 61757-3-2:2022-03(en-fr)

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FIBRE OPTIC SENSORS –

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FOREWORD

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The text of this International Standard is based on the following documents:

Draft	Report on voting
86C/1700/CDV	86C/1719/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 61757 series, published under the general title *Fibre optic sensors*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

This document is based on SEAFOM Measuring Sensor Performance Document – 02 (SEAFOM MSP-02) [1][1]. Within the framework of a type C liaison, SEAFOM proposed this document as a new work item, which was approved by the participating members of IEC SC 86C.

NOTE Except for Figure 1, Figure C.1, Figure C.2, and Figure C.3, all figures in this document were adopted from SEAFOM MSP-02 either in original or in modified form with permission from SEAFOM.

The IEC 61757 series is published with the following logic: the sub-parts are numbered as IEC 61757-M-T, where M denotes the measure and T, the technology.

1 Numbers in square brackets refer to the Bibliography.

FIBRE OPTIC SENSORS –

Part 3-2: Acoustic sensing and vibration measurement – Distributed sensing

1 Scope

This part of IEC 61757 specifies the terminology, characteristic performance parameters, related test and calculation methods, as well as specific test equipment for interrogation units used in distributed fibre optic acoustic sensing and vibration measurement systems. This document refers to the Rayleigh backscatter and phase detection method by phase-sensitive coherent optical time-domain reflectometry (ϕ-OTDR) only. Quasi-static and low frequency operation modes are not covered by this document.

Generic specifications for fibre optic sensors are defined in IEC 61757.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61757:2018, *Fibre optic sensors – Generic specification*

IEC 61757-2-2:2016, *Fibre optic sensors – Part 2-2: Temperature measurement – Distributed sensing*

3 Terms, definitions, abbreviated terms and symbols

3.1 Terms and definitions

For the purposes of this document, terms and definitions given in IEC 61757, IEC 61757-2-2:2016 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1.1
distributed fibre optic sensor
fibre optic sensor that provides a spatially resolved measurement of a measurand over an extended region by means of a continuous sensing element

[SOURCE: IEC 61757:2018, 3.5]

3.1.2
distributed fibre optic acoustic sensing system
DAS
measurement set-up consisting of a distributed fibre optic sensor connected to an interrogation unit including processor, data archive, and user interface, which can locally detect acoustic or vibration induced disturbances (phase change of the backscattering centres) in the fibre

Note 1 to entry: The alternative term fibre optic distributed vibration sensing (DVS) is also used in the industry.

Note 2 to entry: See Figure 1 for a principal DAS set-up. Pulses from a coherent source are sent into the sensor fibre through an optical circulator, which also taps the coherent Rayleigh backscattering signal to a detector for subsequent digitization and fast real-time acquisition.

Note 3 to entry: Typically, a DAS detects acoustic or vibration induced disturbances at frequencies below 2 kHz.

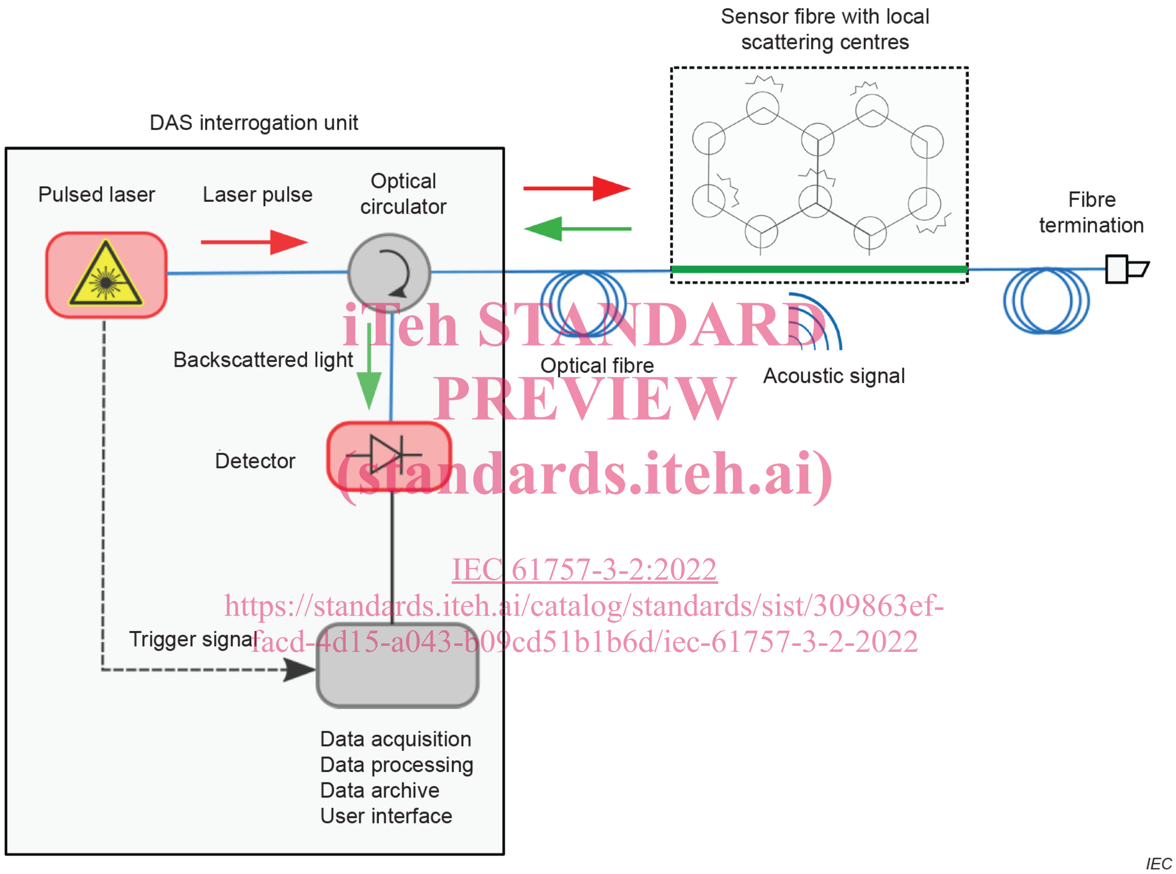


Figure 1 – Distributed acoustic sensing system

3.1.3
distance measurement range
maximum distance (specified in length units) from the interrogation unit output connector along the simulated fibre sensor within which the DAS measures an acoustic signal with specified measurement performance under defined conditions

[SOURCE: IEC 61757-2-2:2016, 3.2, modified – adapted to acoustic sensing.]

3.1.4
fibre stretcher
device where an external stimulus causes a linearly proportional amount of fibre strain uniformly across the fibre length attached

Note 1 to entry: Normally the fibre stretcher consists of a piezoelectric cylinder with an electrical stimulus.

3.1.5
interrogation unit
IU
opto-electronic instrument that is connected to the distributed fibre optic sensor and measures and records dynamic strain along the fibre

Note 1 to entry: The processor, data archive, and user interface could be combined within the IU or could be a separate unit connected to the IU. The IU provides processing functions (standardized or customized), data archiving (usually standardized), and provides an interface to control and "set" the interrogation unit, select processing options, and define and implement the data collection options (triggered, timed, or other).

3.1.6
location
optical distance (expressed in length units) from the interrogation unit output connector to a desired sample point in the simulated fibre sensor

[SOURCE: IEC 61757-2-2:2016, 3.7, modified – adapted to simulated fibre sensor.]

3.1.7
measurement time
time between independent acoustic signal measurements when making successive measurements along the simulated fibre sensor

Note 1 to entry: Equivalently, it is the time interval between successive trace timestamps under these conditions (see Figure 2).

Note 2 to entry: The interrogation rate (specified in Hz) is equivalent to the pulse rate for interrogation units that provide optical pulse interrogation. It is equal to the inverse of the measurement time (see Figure 2).

[SOURCE: IEC 61757-2-2:2016, 3.8, modified – adapted to acoustic sensing.]

3.1.8
Nyquist frequency
frequency represented by the time duration or period of half of the interrogation or sample rate, whichever is smaller

EXAMPLE For an interrogation rate of 20 kHz (20 000 samples per second), the Nyquist frequency is 10 kHz.

3.1.9
power spectrum density
PSD
square root of the power spectral density derived from time series data converted to the frequency domain data

3.1.10
sample number
sequence number of a sample in a time series

3.1.11
sample rate
rate at which raw acoustic data is output from the interrogation unit

Note 1 to entry: The maximum sample rate is equal to the interrogation rate. Sample rate applies when the interrogation rate is reduced (by decimation or otherwise) prior to being output by the interrogation unit.

3.1.12
sample point number
successively numbered spatial sample point that increases along the length of the sensor

Note 1 to entry: The first spatial sampling point starts at zero.

3.1.13
spatial resolution
mean value of the spatial sample intervals which are within the range of the increasing and/or decreasing slope of a step response generated by a locally abrupt change of the stimulus signal, expressed in length units

Note 1 to entry: The manufacturer of the interrogation unit designs and/or implements by hardware and/or software the spatial resolution, which may be controlled by the user.

Note 2 to entry: Figure 19 shows the graphical plotting approach used to determine spatial resolution.

3.1.14
spatial sample spacing
distance (expressed in length units) between two consecutive sample points in a single acoustic signal

[SOURCE: IEC 61757-2-2:2016, 3.11, modified – adapted to acoustic sensing.]

3.1.15
spatial sample point
SSP
one of the points along the simulated fibre sensor that are defined through the interrogation unit configuration or set-up and represented spatially along the fibre as uniformly spaced points from which the interrogation unit samples the backscattered light

3.1.16
strain sensitivity
ε_{sens}
noise floor of the DAS defined as a strain:

$$\varepsilon_{sens} = \frac{\lambda\, d\phi}{4\pi n G \xi} \tag{1}$$

where

λ is the operational optical (vacuum) wavelength of the DAS;

n is the refractive index of the sensing fibre (group index);

G is the spatial resolution employed by the DAS;

ξ is the photo-elastic scaling factor for longitudinal strain in isotropic material (= 0,78);

$d\phi$ is the noise floor of the system in radians.

3.1.17
time series
data set for a particular sample point, which is represented as sampled at the interrogation rate

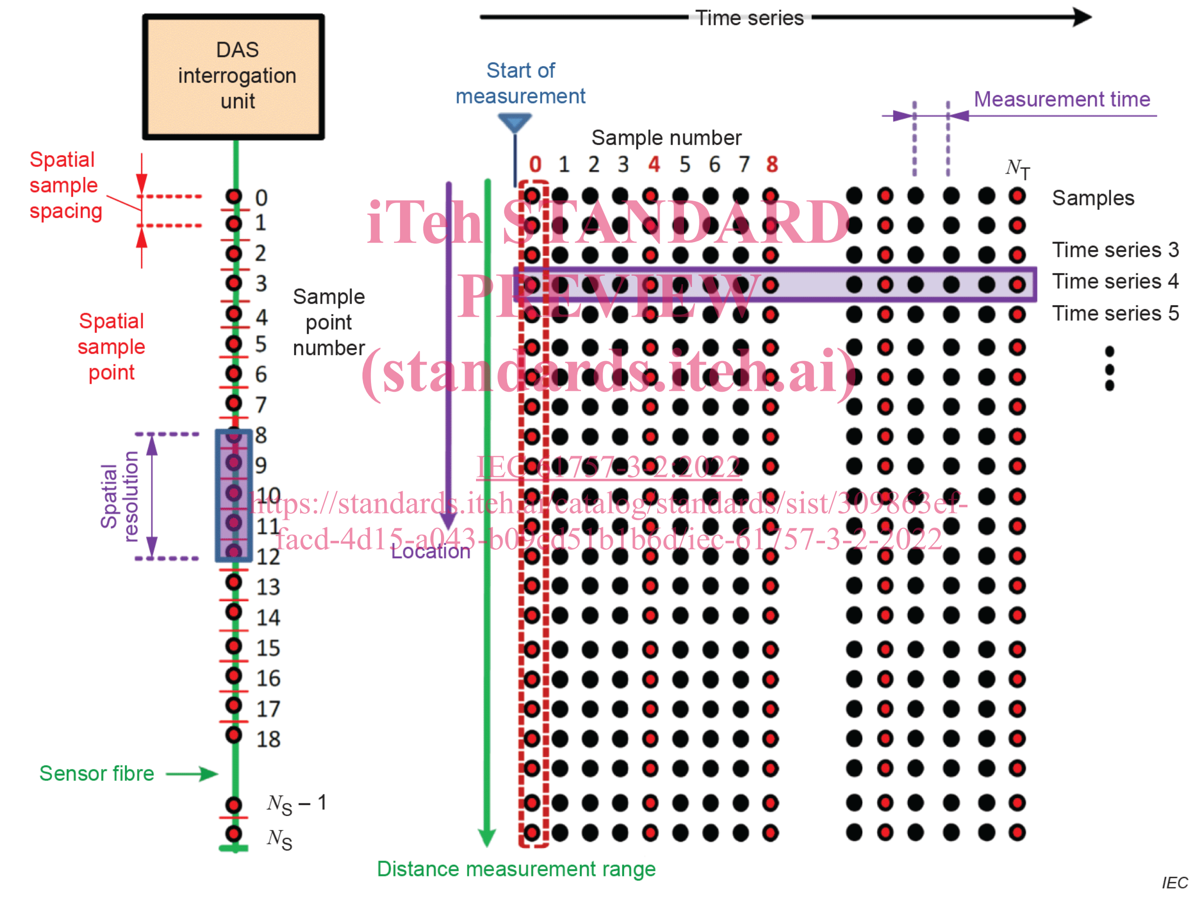
Note 1 to entry: Time series can also be represented at a sub-sample rate of the interrogation rate. Whichever rate is used, it shall be used for all tests described in this document.

Note 2 to entry: Figure 2 illustrates the signal parameters relating to time series and their spatial point identification.

3.2 Abbreviated terms

CL	crosstalk level
DAS	distributed fibre optic acoustic sensing system
FBG	fibre Bragg grating
FFT	fast Fourier transform
IU	interrogation unit

OTDR	optical time-domain reflectometry
PR	partial reflector
PSD	power spectral density
RL	reference level
SEC	section
SFS	simulated fibre sensor
SNR	signal-to-noise ratio
SR	signal response
SSP	spatial sample point
TP	test point



SOURCE: SEAFOM MSP-02 [1], reproduced with the permission of SEAFOM.

Figure 2 – Signal parameters relating to time series and their spatial point identification

3.3 Symbols

L_s	fibre stretcher length
$L_{F,tot}$	total fibre length
L_L, L_R	length of left respectively right downward sloping line
M, M_C, M_{CN}	magnitude, compensated magnitude, compensated and normalized magnitude
P	normalization factor

THD_{FT}	total harmonic distortion
με	technical unit for linear strain with a ratio of increase in length Δl to the length l_0 in the order of 10^{-6}

4 Performance parameters of a distributed acoustic sensing system

The technical performance of a DAS shall be characterized by the following performance parameters. Clause 6 describes the related test procedures to determine the parameters:

a) dynamic range (see 6.2);
b) frequency response (see 6.3);
c) fidelity [optional] (see 6.4);
d) self-noise (see 6.5);
e) spatial resolution (see 6.6);
f) crosstalk (see 6.7);
g) loss budget (see 6.8);
h) sensor reflection robustness (see 6.9).

5 Test apparatus for performance parameter determination

5.1 Simulated fibre sensor (SFS)

Each of the performance parameters shall be evaluated using a simulated fibre sensor (SFS) of an appropriate total fibre length ($L_{F,tot}$) connected to each item of IU equipment under test.

The SFS shall be arranged as shown in Figure 3. It functionally shall comprise four delay coils and three fibre stretchers that are spliced together to represent a contiguous length which is $L_{F,tot}$. In this depiction, they are all shown with optical fibre pigtails that are angle terminated with a connector type of choice at the start and end of $L_{F,tot}$. The end of $L_{F,tot}$ should have a return loss of > 50 dB.

All elements of the SFS shall be housed in an isolated chamber that provides immunity to acoustics and vibration (see 5.5).

Each of the three fibre stretchers consists of a fibre of length L_s. The fibre stretchers are located between the four delay coils and represent locations for many of the performance parameter tests. These are identified by TP_1, TP_2, and TP_3.

The lengths of delay coils 1 to 4 shall be determined by using the following relationships:

a) the lengths of delay coils 1 and 4 are set to be equal to 250 m;
b) the lengths of delay coils 2 and 3 are set to be equal to $L_{F,tot}' / 2$,

   where

   $L_{F,tot}' = L_{F,tot} - 500\text{ m} - 3 L_s$;

   $L_{F,tot}$ is the total fibre length;

   L_s is the fibre stretcher length.