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Ultrasonics – Methods for the characterization of the ultrasonic properties of materials

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Ultrasonics – Methods for the characterization of the ultrasonic properties of materials

INTERNATIONAL
ELECTROTECHNICAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ULTRASONICS – METHODS FOR THE CHARACTERIZATION OF THE ULTRASONIC PROPERTIES OF MATERIALS

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards

IEC TS 63081, which is a Technical Specification, has been prepared by IEC technical committee 87: Ultrasonics

The text of this Technical Specification is based on the following documents:

DTS	Report on voting
87/718/DTS	87/725/RVDTS

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

Words in **bold** in the text are defined in Clause 3. Symbols and formulae are in *Times New Roman + Italic*.

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

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INTRODUCTION

Many ultrasonic measurement standards contain requirements for the properties of acoustic materials to be used to construct the measurement equipment relied upon within those documents. The following are examples of such standards.

- IEC 61161 specifies amplitude reflection factor and acoustic energy absorption for reflecting targets and absorbing targets and specifies amplitude transmission coefficient for anti-streaming foils.
- IEC 61391-1 discusses reflection coefficient.
- IEC 61689 defines echo reduction and specifies limits upon its values. The terms reflection loss and transmission loss are also used, and values specified.
- IEC TS 62306 specifies transmission loss and reflection amplitude reduction.
- IEC 62359 specifies reflection coefficient and absorption.
- IEC 60601-2-37 specifies reflectance and absorption coefficient.

As the list above suggests, a wide range of terms is used to specify the properties of an acoustic material, and these terms are not used consistently across IEC documents. Furthermore, there is a degree of duplication with multiple names for the same quantity. This is further confused since there is no document within the IEC ultrasonics portfolio that defines the methods by which those properties are measured.

This document seeks to address the shortcomings by providing:

- a clear unambiguous definition of the key quantities of interest during materials characterization;
- a discussion of similar terms and how they may relate to the key quantities;
- recommended experimental methods for determining the values of key quantities.

ULTRASONICS – METHODS FOR THE CHARACTERIZATION OF THE ULTRASONIC PROPERTIES OF MATERIALS

1 Scope

This document:

- defines key quantities relevant to ultrasonic materials characterization;
- specifies methods for direct measurement of many key ultrasonic materials parameters.

This document is applicable to all measurements of properties of passive acoustic materials under drive conditions that are not subject to nonlinear acoustic propagation. Whilst there are materials properties that may be of interest in a nonlinear drive regime, these are currently outside the scope of this document.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

3.1
absorption per unit length
α
component of the attenuation coefficient (IEC 60050-801:1994, 801-23-35) that does not arise from scattering and is due only to absorption of acoustic energy within the sample

$$\alpha = \alpha_0 \left| f^{y} \right| \quad (1)$$

where

α_0 is the absorption constant (dB/(MHz^y m));

f is the frequency in MHz;

y is the frequency exponent (in general not an integer).

Note 1 to entry: For absorption, y = 2 for water, and in general y is between 1 and 2 for fluids, soft tissues and tissue mimicking materials.

Note 2 to entry: **Absorption per unit length** is expressed in units of decibel per metre (dB/m).

3.2
amplitude reflection coefficient
R_p
ratio of the pressure amplitude of an acoustic wave reflected from an interface separating two media to the pressure amplitude of a plane wave incident on that interface

$$R_p = \frac{p_\mathrm{r}}{p_\mathrm{i}} \tag{2}$$

where

p_r is the pressure amplitude of the reflected longitudinal wave, at the reflection angle θ_r;

p_i is the pressure amplitude of the incident longitudinal wave, at the incident angle θ_i

Note 1 to entry: Care should be taken with the term reflection coefficient as both amplitude and intensity forms appear in common scientific parlance. This can be particularly problematic when equations involve reflection coefficient terms, since both are dimensionless, but one varies as the square of the other. Intensity forms of reflection coefficient are more common in optics.

Note 2 to entry: In general, the equation shown can apply to reflections of different types, each at different reflection angles but all governed by Snell's law.

Note 3 to entry: **Amplitude reflection coefficient** is dimensionless as it is a ratio of quantities. It does not require the use of a calibrated receiver since measurements are relative in nature.

3.3
amplitude transmission coefficient
T_p
ratio of the pressure amplitude of an acoustic wave transmitted through an interface separating two media, to the pressure amplitude of a plane wave incident on that interface

$$T_p = \frac{p_\mathrm{t}}{p_\mathrm{i}} \tag{3}$$

where

p_t is the pressure amplitude of the transmitted longitudinal wave;

p_i is the pressure amplitude of the incident longitudinal wave

Note 1 to entry: Care should be taken with the term transmission coefficient as both amplitude and intensity forms appear in common scientific parlance. This can be particularly problematic when equations involve transmission coefficient terms, since both are dimensionless, but one varies as the square of the other. Intensity forms of transmission coefficient are more common in optics.

Note 2 to entry: In general, the equation shown can apply to transmissions of different types. For example, a longitudinal wave incident from fluid to solid at an angle will generate two transmitted waves at non-normal incidence, a shear wave and a longitudinal wave, each at different refraction angles. Each of the transmitted waves is governed by Snell's law.

Note 3 to entry: **Amplitude transmission coefficient** is dimensionless as it is a ratio of quantities. It does not require the use of a calibrated receiver since measurements are relative in nature.

3.4
backscatter coefficient
η
differential scattering cross-section per unit volume as a function of frequency for a scattering angle of 180°

Note 1 to entry: **Backscatter coefficient** is expressed in units of one per second per steradian ($\mathrm{s}^{-1}\ \mathrm{Sr}^{-1}$).

3.5
density
mass density
ρ
at a given point within a three-dimensional domain of quasi-infinitesimal volume dV, scalar quantity equal to the mass dm within the domain divided by the volume dV

$$\rho = \mathrm{d}m/\mathrm{d}V$$

Note 1 to entry: **Mass density** is an intensive quantity describing a local property of a substance.

Note 2 to entry: The concept of **mass density** may also be applied to the mass m in a domain D with a volume V, leading to the average **density** $\rho_{\mathrm{av}} = \frac{m}{V} = \frac{1}{V}\int_D \rho \mathrm{d}v$.

Note 3 to entry: **Mass density** is expressed in units of kilogram per metre cubed (kg/m^3).

[SOURCE: IEC 60050-113:2011, 113-03-07]

3.6
echo reduction
ER
reduction in pressure amplitude of an ultrasonic plane wave resulting from its reflection from an interface between two media

$$\begin{aligned} ER &= -20\log_{10}\left(\frac{p_{\mathrm{r}}}{p_{\mathrm{i}}}\right)\mathrm{dB} \\ &= -20\log_{10}\left(R_p\right)\mathrm{dB} \end{aligned} \quad (4)$$

where

p_{r} is the pressure amplitude of the reflected longitudinal wave;

p_{i} is the pressure amplitude of the incident longitudinal wave

Note 1 to entry: In general, the reflected waves are governed by elastic Snell's laws and the reduction in pressure amplitude is a function of the angle of the incidence of the plane-wave on the surface.

Note 2 to entry: **Echo reduction** is expressed in decibels (dB).

3.7
group velocity
v_{g}
velocity in the direction of propagation of a characteristic feature of the envelope of a pulse

Note 1 to entry: **Group velocity** is commonly defined in terms of angular frequency ω and wavenumber k as $v_{\mathrm{g}} = \frac{\mathrm{d}\omega}{\mathrm{d}k}$ and differs from **phase velocity** only in a dispersive medium.

Note 2 to entry: **Group velocity** is ordinarily the velocity of propagation of the energy associated with the disturbance.

Note 3 to entry: **Group velocity** is expressed in units of metre per second (m/s).

[SOURCE: IEC 60050-801:1994, 801-23-21, modified – In the definition, "non-sinusoidal disturbance" has been replaced by "pulse".]

3.8
insertion loss
IL
reduction in pressure amplitude of an ultrasonic plane wave resulting from the insertion of a sample in the acoustic path

$$IL = -20\log_{10}\left(\frac{p_s}{p_{ns}}\right)\text{dB} \tag{5}$$

where

p_s is the amplitude of the received pressure wave with the sample in the path (with sample);

p_{ns} is the amplitude of the received pressure wave without the sample in the path (no sample)

Note 1 to entry: Care should be taken as **insertion loss** is sometimes incorrectly labelled transmission loss. However, transmission loss is a more general term describing loss of signal between a source and a receiver. IEC 60050-801:1994, 801-23-39 defines transmission loss as "reduction in sound pressure level between two designated locations in a sound transmission system, one location often being at a reference distance from the source". As such it can include contributions from the directivity functions of both source and receiver as well as acoustic spreading. These are functions of the experimental configuration and not the material under investigation.

Note 2 to entry: **Insertion loss** is expressed in decibels (dB).

3.9
longitudinal wave speed
c_L
magnitude of the velocity of a free progressive longitudinal wave

Note 1 to entry: **Longitudinal wave speed** is expressed in units of metre per second (m/s).

3.10
phase velocity
v_p
velocity in the direction of propagation of a surface of constant phase

Note 1 to entry: **Phase velocity** is commonly defined as $v_p = \frac{\omega}{k}$ where ω is the angular frequency and k is the wave number.

Note 2 to entry: **Phase velocity** is expressed in units of metre per second (m/s).

[SOURCE: IEC 60050-801:1994, 801-23-20]

4 List of symbols

A	toneburst amplitude in single sample absorption coefficient measurements
A_n, A_m	amplitude of nth and mth echoes in single sample absorption coefficient measurements
A_0	area of a transducer aperture
B	bandwidth of time delay spectrometry (TDS) tracking filter
c_{CF}	**longitudinal wave speed** in the coupling fluid
c_L	**longitudinal wave speed**
e_{CFM}	excitation signal used with compensated frequency modulation (CFM)
E_{CFM}	spectral modulus of CFM signal
ER	**echo reduction**