

# **Railway applications — Ride comfort for passengers — Measurement and evaluation**

ICS 13.160; 45.060.20

# National foreword

This Draft for Development is the English language version of ENV 12299:1999.

**This publication is not to be regarded as a British Standard.**

It is being issued in the Draft for Development series of publications and is of a provisional nature because the subject matter is still under technical development requiring wider exposure. It should be applied on this provisional basis, so that information and experience of its practical application may be obtained.

Comments arising from the use of this Draft for Development are requested so that UK experience can be reported to the European organization responsible for its conversion into a European Standard. A review of this publication will be initiated 2 years after its publication by the European organization so that a decision can be taken on its status at the end of its three-year life. The commencement of the review period will be notified by an announcement in *Update Standards*.

According to the replies received by the end of the review period, the responsible BSI Committee will decide whether to support the conversion into a European Standard, to extend the life of the prestandard or to withdraw it. Comments should be sent in writing to the Secretary of BSI Technical Committee RAE/1, Railway applications, at 389 Chiswick High Road, London W4 4AL, giving the document reference and clause number and proposing, where possible, an appropriate revision of the text.

A list of organizations represented on this committee can be obtained on request to its secretary.

**Cross-references**

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled “International Standards Correspondence Index”, or by using the “Find” facility of the BSI Standards Electronic Catalogue.

**Summary of pages**

This document comprises a front cover, an inside front cover, the ENV title page, pages 2 to 89 and a back cover.

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ICS 45.060.20

Descriptors: Railway equipment, railway rolling stock, passenger transport, vibrations, measurement, vibration severity, physiological effects

English version

## Railway applications - Ride comfort for passengers - Measurement and evaluation

Applications ferroviaires - Confort de marche des  
voyageurs - Mesurage et évaluation

Bahnanwendungen - Fahrkomfort für Fahrgäste - Messung  
und Auswertung

This European Prestandard (ENV) was approved by CEN on 29 August 1997 as a prospective standard for provisional application.

The period of validity of this ENV is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the ENV can be converted into a European Standard.

CEN members are required to announce the existence of this ENV in the same way as for an EN and to make the ENV available promptly at national level in an appropriate form. It is permissible to keep conflicting national standards in force (in parallel to the ENV) until the final decision about the possible conversion of the ENV into an EN is reached.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.



EUROPEAN COMMITTEE FOR STANDARDIZATION  
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## Foreword

This European Prestandard has been prepared by Technical Committee CEN/TC 256 "Railway applications", the secretariat of which is held by DIN.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to announce this European Prestandard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

This ENV takes into account the documents listed below for the following:

|                                         |                                                              |
|-----------------------------------------|--------------------------------------------------------------|
| UIC 513                                 | Evaluation of Mean Comfort indices and definition of filters |
| ISO 2631                                | Definitions                                                  |
| BRR TR DOS 018 5/86                     | Comfort on Curve Transitions                                 |
|                                         | Comfort on Discrete Events                                   |
| UIC 518                                 | Selected testing procedures and track characteristics        |
| List of normative clauses and annexes   | Clauses 1, 2, 3, 4                                           |
|                                         | Normative Annexes A, B, C, D                                 |
| List of informative clauses and annexes | Foreword, Introduction, Clauses 5, 6                         |
|                                         | Informative Annexes E, F, G, H, K, L, M, N, P, Q, R, S       |

## Introduction

### a) General

The comfort of passengers in a railway vehicle is influenced by a number of different factors (temperature, noise, vibration etc). This European Prestandard considers only that part of the comfort influenced by the dynamic behaviour of the vehicle. This is described as Ride Comfort or as Comfort.

This European Prestandard summarizes the relevant works on the matter:

- taking into account, in mandatory form, the effects on Ride comfort for passengers of vibration exposure measured on the carbody floor (the simplified method for Mean Comfort evaluation);
- taking into account, (as recommendation), the vibration exposure measured on the interfaces (the complete method for Mean Comfort evaluation);
- taking into account, (as recommendation), the effects on Ride comfort for passengers of:
  - discrete events (Comfort on Discrete Events);
  - running on curve transitions (Comfort on Curve Transitions).

The standard is published as European Prestandard (ENV), due to

- the lack of experience in the application of the Mean Comfort measurement and evaluation criteria, based on UIC-leaflet 513, up to now experimentally approved in UIC, both for the normative part ( $N_{mv}$ ) and for the informative part ( $N_{va}$ ,  $N_{vd}$ );
- the lack of experience in the application of the recommended  $P_{de}$ ,  $P_{ct}$  comfort indexes, up to now based on the technical experience in studies and direct tests given mainly in Great Britain and in indirect tests performed by Italy, Germany and Switzerland.

Railway transport exposes passengers to vibrations related to the dynamic movements of the carbody.

The movements of the carbody transmit their effects to the human body through the following interfaces:

- in the standing position:
  - floor - feet
- in the seated position:
  - headrest - neck
  - arm rest - upper arms
  - seat - hip
  - seat - back
  - floor - feet

The type of transmission is whole-body transmission (see 3.4), which acts on the whole body through the interfaces (see 3.3 ).

The effect produced by the carbody movements considered in this ENV is:

- discomfort (effect on comfort, see 3.2), associated with relatively low levels of acceleration.

Other effects, not included in the standard, are associated with higher acceleration levels:

- health risk effect: physical damage and psychological deterioration.

This ENV applies to passengers in good health.

## b) Inclusions and exclusions

The following table lists the items included or excluded from this ENV:

**Table 1**

| Item                      | included                                                                                                                                                                                                                                                                                                                                                                               | excluded                                                                                                                                                   |
|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Effects of movements      | <ul style="list-style-type: none"> <li>- on comfort</li> </ul>                                                                                                                                                                                                                                                                                                                         | <ul style="list-style-type: none"> <li>- on health</li> <li>- on activities</li> </ul>                                                                     |
| Transmission              | <ul style="list-style-type: none"> <li>- on whole body through interfaces</li> </ul>                                                                                                                                                                                                                                                                                                   | <ul style="list-style-type: none"> <li>- on single body part</li> <li>- on whole surface</li> </ul>                                                        |
| Type of vehicles          | <ul style="list-style-type: none"> <li>- railway vehicles designed for carrying passengers</li> </ul>                                                                                                                                                                                                                                                                                  | <ul style="list-style-type: none"> <li>- other types of railway vehicles, e.g. locomotives, freight wagons</li> </ul>                                      |
| Test procedure            | <ul style="list-style-type: none"> <li>- definitions</li> <li>- reference system</li> <li>- requirements</li> <li>- measurement and evaluation rules</li> <li>- report rules</li> </ul>                                                                                                                                                                                                | <ul style="list-style-type: none"> <li>- notes or attributes related to service quality and/or passenger expectation</li> <li>- limiting values</li> </ul> |
| Position of passenger     | <ul style="list-style-type: none"> <li>- standing</li> <li>- seated</li> </ul>                                                                                                                                                                                                                                                                                                         | <ul style="list-style-type: none"> <li>- lying</li> <li>- performing specific actions</li> </ul>                                                           |
| Type of measurement       | <ul style="list-style-type: none"> <li>- indirect measurements               <ul style="list-style-type: none"> <li>- simplified measurements of Mean Comfort</li> <li>- complete measurements of Mean Comfort<sup>1)</sup></li> <li>- evaluation of Comfort on Discrete Events<sup>1)</sup></li> <li>- evaluation of Comfort in Curve Transitions<sup>1)</sup></li> </ul> </li> </ul> | <ul style="list-style-type: none"> <li>- direct measurements</li> <li>- combined measurements</li> </ul>                                                   |
| <sup>1)</sup> informative |                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                            |

### c) Characteristics of railway vehicle movements

The basic typical characteristics, referred to the type of measurement and evaluation, are:

- range of frequencies from 0 to 2 Hz for Comfort on Curve Transitions and for Discrete Events, from 0,4 to 80 Hz for Mean Comfort evaluation. For the latter, with a large part in the sub-range:
  - 0,4 up to 3,0 Hz in the lateral direction,
  - 0,4 up to 20 Hz in the vertical direction;
- relatively low level of amplitude;
- different properties, depending on the type of evaluation: stationary (Mean Comfort), non-stationary (Discrete Events), quasi-static (mean lateral acceleration on Discrete Events), dynamic with relevant transient components (peak-to-peak on Discrete Events, Comfort on Transitions), highly non-linear (on Curves, on Discrete Events), linear (Mean Comfort).

### d) Ride comfort for passengers

The Ride comfort for passengers is the complex sensation, produced on the passenger by the carbody movements of the railway vehicle, transmitted to the whole body through the interfaces.

This sensation is classified as:

- average sensation, based on the vibration applied on a long-time basis (at least some minutes),
- instantaneous sensation: a sudden modification of the average sensation, due to a short-basis event (change of mean lateral acceleration value, roll movement at significant speed, lateral jerk with possible oscillation).

Both the first and the second type of sensation are taken into account in the Mean Comfort evaluation.

The second type of sensation is taken into account in the Comfort on Curve Transitions and in Comfort on Discrete Events.

### e) Direct and indirect measurements

The quantification of Ride comfort for passengers is performed through indirect measurements, i.e. measuring and post-processing the relevant parameters (see 3.5). Other types of tests and evaluation, such as direct tests based on the direct assessment of the perceptions of tested passengers, and combined tests, including both direct and indirect tests, are not quantified in this European Prestandard.

#### f) Simplified and complete measurements for Mean Comfort

The indirect measurements are classified as simplified or complete if the measurements are taken respectively on relevant points of the carbody floor or also on the interfaces.

#### g) Summary table of procedures

The evaluation of Ride comfort for passengers is taken into account in this European Prestandard by:

- normative procedure for the quantification of Mean Comfort through indirect simplified measurements, described in the normative part, see 4.1 to 4.2,
- informative procedure for the quantification of Mean Comfort through indirect complete measurements, described in the informative part, see Annex E,
- informative procedure for the quantification of Comfort on Curve Transitions through indirect simplified measurements, described in the informative part, see Annex K,
- informative procedure for the quantification of Comfort on Discrete Events through indirect simplified measurements, described in the informative part, see Annex M.

The use of an informative procedure in addition is appropriate in situations where these aspects are of particular interest, as for example for the evaluation of behaviour of tilting vehicles running in curves.

Table 2 presents an overview of different characteristics for measurement and evaluation procedures.

**Table 2**

| Characteristics     | Mean Comfort simplified | Mean Comfort complete | Comfort on Curve Transitions        | Comfort on Discrete Events |
|---------------------|-------------------------|-----------------------|-------------------------------------|----------------------------|
| Comfort index       | $N_{MV}$                | $N_{VD}$              | $P_{CT}$                            | $P_{DE}$                   |
|                     |                         | $N_{VA}$              |                                     |                            |
| Procedure           | normative               | informative           | informative                         | informative                |
| Measuring parameter | accelerations           | accelerations         | lateral acceleration;<br>roll speed | lateral acceleration       |
| Measuring position  | floor                   | floor                 | floor                               | floor                      |
|                     |                         | floor and interfaces  |                                     |                            |

A table of possible applications, and the list of corresponding information needed, is given in 6.2.

## 1 Scope

This European Prestandard specifies a method for quantifying the effects of carbody movements on Ride comfort for passengers ("Comfort")<sup>1)</sup>.

The scope of the standard is limited to public railway services; the standard includes railway vehicles designed for carrying passengers travelling on railway lines, including secondary and suburban lines; this document can be used as a guide for other railway vehicles, for example locomotives, metros, trams, etc.

The standard applies to passengers in good health.

## 2 Normative references

This European Prestandard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European prestandard only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to applies.

|                                     |                                                                                                                                                                |
|-------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ISO 2631-1                          | Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements                                           |
| ISO 5348                            | Mechanical vibration and shock - Mechanical mounting of accelerometers                                                                                         |
| ISO 8002                            | Mechanical vibrations - Land vehicles - Method for reporting measured data                                                                                     |
| UIC 513 E <sup>2)</sup>             | Guidelines for evaluating passenger comfort in relation to vibration in railway vehicles - 1st edition 01-07-94                                                |
| UIC 518 VE <sup>2)</sup>            | Testing and approval of railway vehicles from the point of view of their dynamic behaviour - Safety - Track fatigue - Ride quality - 1st edition 01-07-95      |
| B 153 - Rp 10 <sup>2)</sup>         | Vibratory comfort: Drawing up weighting curves                                                                                                                 |
| B 153 - Rp 12 <sup>2)</sup>         | Influence of the low frequency components on the evaluation of comfort                                                                                         |
| B 153 - Rp 13 <sup>2)</sup>         | Tests on comfort in standing position                                                                                                                          |
| B 153 - Rp 17 <sup>2)</sup>         | Comfort in seated position                                                                                                                                     |
| C 116 - Rp 3 and Rp 6 <sup>2)</sup> | Geometry of the contact between wheelset and track - Part 1: Methods of measurement and analysis - Part 2: Equivalent conicity values for wheelsets in service |

## 3 Definitions

For the purpose of this standard, the following definitions apply:

### 3.1 Passengers

People travelling in a railway vehicle, without specific activities related to the transport.

### 3.2 Comfort

This is the complex sensation produced during the application of oscillations and/or inertia forces, via whole-body transmission (see 3.4) caused by the railway vehicle's carbody movements.

It is defined and measured through Comfort indexes<sup>3)</sup> as:

- Mean Comfort: a mean feeling, continuously adjusted, as evaluated through measurement following the procedures indicated in clause 4 and Annexes A, B, C, D for Comfort index  $N_{mv}$  and the procedure indicated in Annexes E, F, G, H for Comfort indices  $N_{va}$ ,  $N_{vd}$ .

<sup>1)</sup> The quantification of Ride Quality and the corresponding evaluation rules will be covered by a separate European Standard.

<sup>2)</sup> To be purchased from: UIC, Direction Générale, 16, rue Jean Rey, F - 75015 Paris

<sup>3)</sup> The base of the derivation of the comfort indexes is experimental.

- Comfort on Curve Transition: discomfort, due to a perceived curve entry or reverse transition, quantified by the recommended procedure indicated in Annex K and Annex L, as Comfort index  $P_{ct}$ .
- Comfort on Discrete Events: discomfort, due to a perceived transient oscillation on straight track, curves and curve transitions, quantified by the recommended procedure indicated in Annex M and Annex N, as Comfort index  $P_{de}$ .

### 3.3 Interfaces

They are the contact parts between the carbody and the passenger with the function of sustaining and guiding the passenger and of transmitting the weight of the same to the carbody itself.

In standing position:

- floor - feet

In seated position:

- headrest - neck
- arm rest - upper arms
- seat - hip
- seat - back
- floor - feet.

### 3.4 Whole-body transmission

This is an action transmitted to the whole body through the interfaces.

### 3.5 Indirect measurements/tests

This is a measurement or test or part of test based on measurement and post-processing of the relevant parameters (acceleration and roll speed measured in the carbody).

### 3.6 Characteristics of indirect measurements/tests

- Complete measurements: composed of measurements at the positions defined in G.3.2:
  - measurements on interfaces (see 3.3),
  - measurements on carbody floor, near to the seat.
- Simplified measurements: composed of measurements on the carbody floor at the positions defined in A.3.2 .

## 4 Mean Comfort - Simplified method

NOTE: Two methods are available for the assessment of the passenger perception of Mean Comfort:

- A simplified method based on measurement of acceleration on the floor ( $N_{mv}$ ).
- A complete method based on measurement of acceleration at the interface between passengers and the vehicle ( $N_{va}$ ,  $N_{vd}$ ).

The complete method is more highly correlated with the passenger's perception of comfort than the simplified method. For a general assessment of the ride comfort of a railway vehicle, the simplified method shall be used. For the full assessment of the ride comfort of railway vehicles (with a view to the passenger's perception of comfort), it is recommended that the complete method is used where practical.

### 4.1 Reference system

The general reference system of the railway vehicle is defined, with reference to the horizontal plane (see figure 1), according to ERRI C 116 - Rp 3 and is given here for general information.

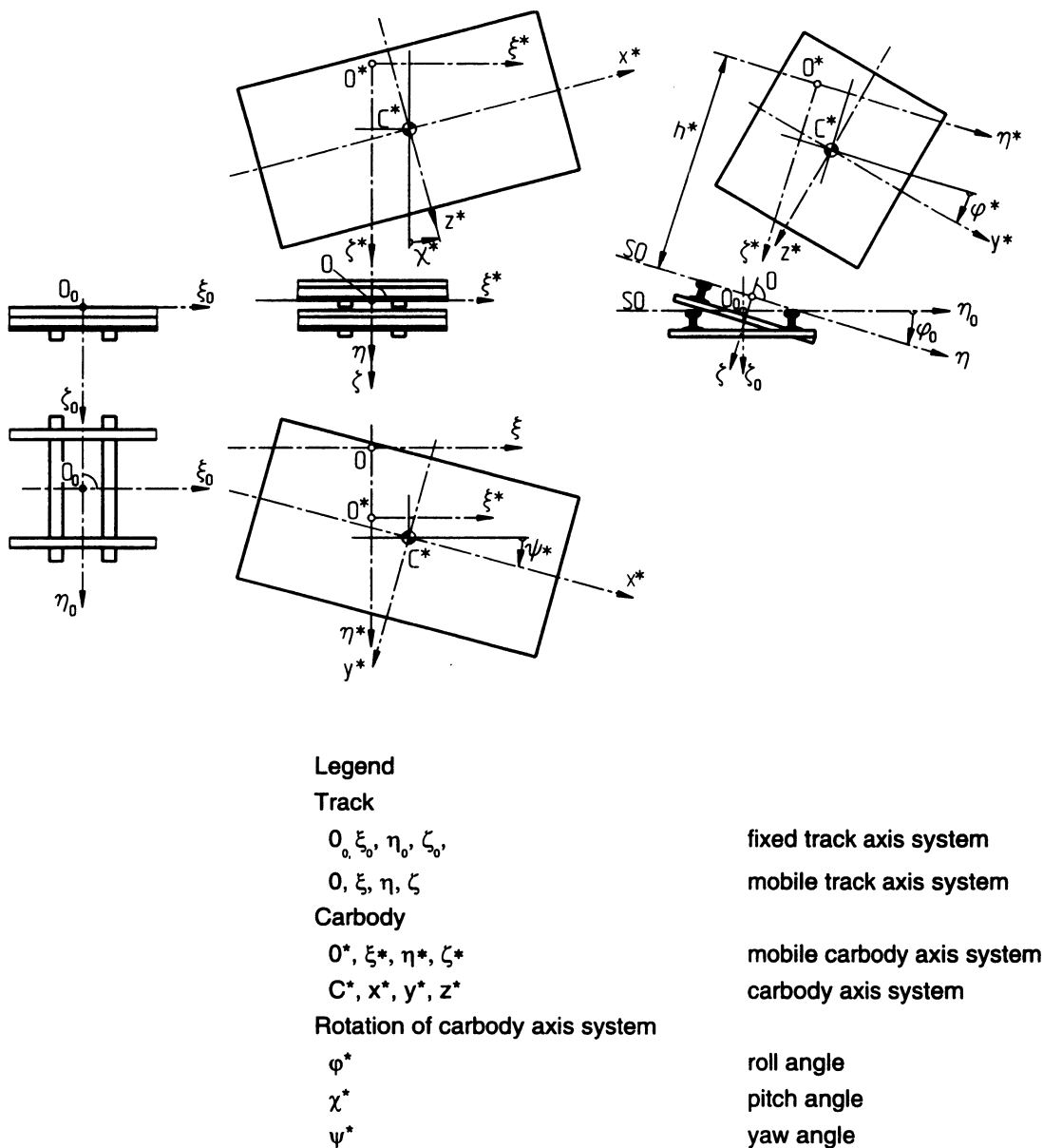


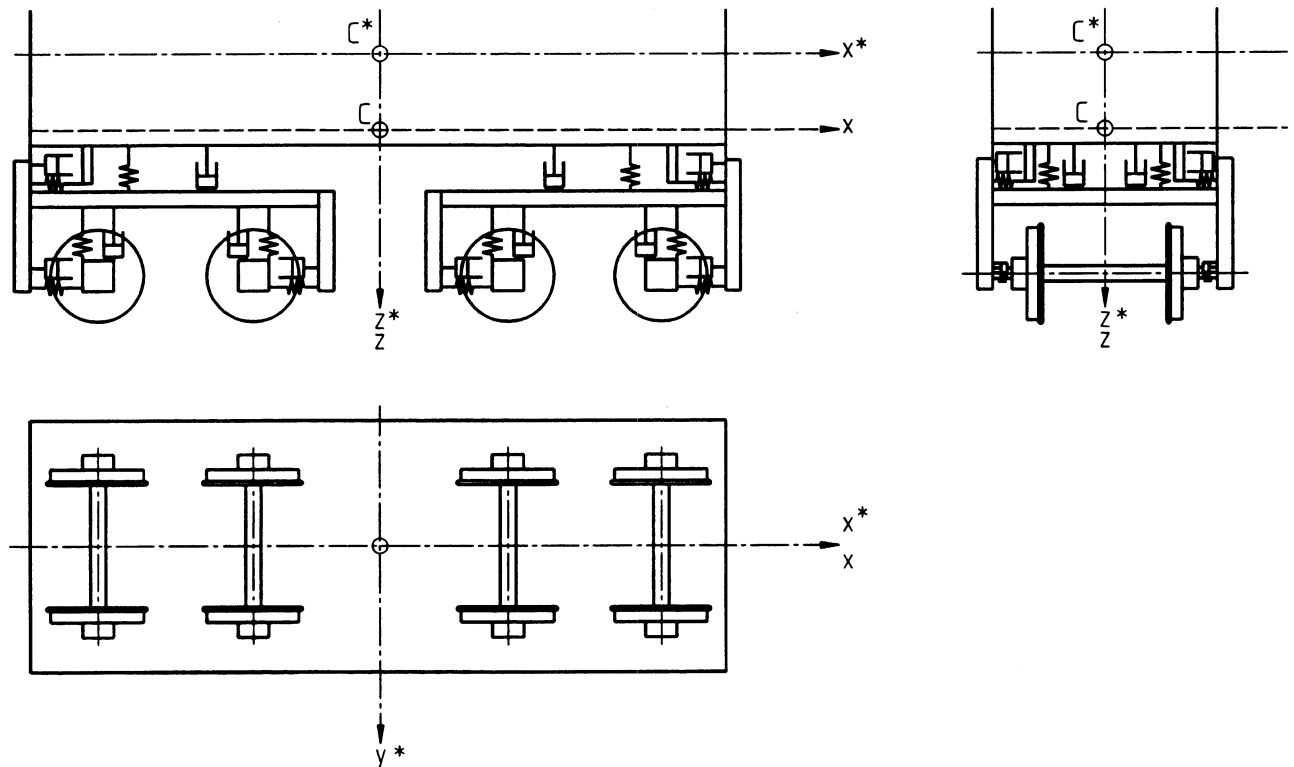
Figure 1 : General reference system

The local reference system (see figure 2 ) for the carbody and relevant parameters, is defined through:

Origin: on carbody floor, in the central position between the two body-bogie centre pivots (existing or ideally defined)

Axis:

- $z$ -axis: vertical downwards perpendicular to floor plan,
- $x$ -axis: longitudinal, in travelling sense, on floor plan,
- $y$ -axis: lateral, right-oriented in travelling sense, on floor plan.



#### Legend

C, x, y, z

carbody axis system for comfort  
evaluation

C\*, x\*, y\*, z\*

see figure 1

**Figure 2 : Local reference system**

## 4.2 Measurement and evaluation rules

### 4.2.1 General

NOTE: Application of the simplified method

This formula is a simplification of a more general but more complicated expression. The application of this formula is constrained by two conditions:

- 1) The lateral acceleration at track level shall be lower than  $1 \text{ m/s}^2$  (this excludes high speed running on track with many curves and tilting coaches).
- 2) The longitudinal vibration shall not be excessive (excluding soft seat backs and ride with traction induced longitudinal vibration).

The object is to define:

- the conditions for carrying out running tests to assess Mean Comfort evaluated using the simplified method,
- the parameters to be measured and the method to be used to obtain the assessment values.

NOTE: This clause is based on UIC 513 produced by ERRI B153 Committee. It gives a simplified procedure to assess the Mean Comfort. The complete procedure, recommended but not obligatory, is presented in Annex E.

Clause 4 and Annexes A, B, C, D constitute an application document for the railway field covering the measurement, analysis and evaluation of vibration, taking into account that mechanical vibration in a railway vehicle presents certain specific characteristics.

Application of clause 4, on the basis of the measurement of certain accelerations, will permit an evaluation to be made of Mean Comfort in a defined vehicle under defined service conditions. The minimum of information needed for the application of the method is contained in Annex C.

**Application of this method will give a comfort index for the vehicle-track system. The separate influence of the vehicle and track cannot be assessed without further information on vehicle characteristics and track layout and roughness characteristics<sup>4)</sup>.**

Application of this method under the prescribed conditions may assist in the identification of causes of discomfort.

This method is applicable to the vibration generally encountered on railway vehicles. Correct evaluation of comfort on the basis of this procedure requires rigorous observation of the procedures which it contains.

### 4.2.2 Base of the method

Mean Comfort is perceived in different ways by different people. It is therefore impossible to specify an unique assessment system which is valid for everybody.

As a result of this, the evaluation of Mean Comfort made in this standard is based on the relationship between the accelerations measured in a vehicle and the Mean Comfort rating given by a representative group of passengers for periods of 5 min.

NOTE: The method is demonstrated and validated in the reports of ERRI B153 Committee, particularly in:

|              |                                                                                                     |
|--------------|-----------------------------------------------------------------------------------------------------|
| Rp10         | Vibratory comfort: Drawing up weighting curves                                                      |
| Rp12         | Influence of the low frequency components on the evaluation of comfort                              |
| Rp13         | Tests on comfort in standing position                                                               |
| Rp17         | Comfort in seated position                                                                          |
| DT219 (B153) | Dépouillement statistique d'essais de confort pour le compte du comité B153 (exists only in french) |

### 4.2.3 Evaluation method

The evaluation method consists of the following:

- measuring the acceleration on the floor of the vehicle;  
principles to be taken into account for these measurements are given in Annex A;

<sup>4)</sup> The definition of this further information is not at the present time available. Therefore a list of possible applications of this ENV and an indication of the necessary supporting data is given in table 3 (recommended)

- signal processing in accordance with Annex B, including:
  - frequency weighting,
  - calculation of rms-values for time intervals of 5 s,
  - calculation of the cumulative distribution for a total time interval of five minutes,
  - calculation of the 95% probability sample,
  - calculation of Mean Comfort index  $N_{mv}$  at each measuring point indicated in Annex A.

The duration of the measurements shall be a multiple of five minutes. The minimum required is four zones of five minutes, each zone travelled at constant speed, which allows this method to be applied.

NOTE: No guidance is given by ERRI B153 for the combination of the  $N_{mv}$  values of the individual zones.

#### 4.2.4 Test conditions

The general test conditions are described in following subclauses. The detailed conditions may vary depending on the application. The test conditions used must be given in the test report.

##### 4.2.4.1 Test speed

Mean comfort is evaluated at normal service speed for the tested vehicle on the test section; tests at different speeds are non-mandatory.

##### 4.2.4.2 Selection of test sections

The choice of the test section has to be done in such a way that operating conditions representative of the tested vehicle are taken into account, for instance, high speed line, normal speed line, sharply curved track.

NOTE: For each type of section so defined according to ERRI B153 it should be necessary to take at least four zones of five minutes, each of them being issued from a continuous record.

##### 4.2.4.3 Track geometry and quality

A test section shall be selected in which the track geometry and quality correspond to that specified for the running speed required.

The test track is characterized according to Annex C.

The track characteristics of the sections used shall be specified in the test report (see 4.2.7).

##### 4.2.4.4 Wheel-rail contact geometry

The running behaviour of the vehicle is influenced by the wheel-rail contact geometry. For applications needing the assessment of separate influence of the vehicle, the wheel-rail contact parameters have to be quantified.

To determine numerical value of the equivalent conicity, the actual wheel profiles of the test vehicle are combined with theoretical rail profile normally used in the test zones (including inclination and gauge).

For a better interpretation of the results, it can be useful to determine equivalent conicity taking into account actual rail profiles of the test zone giving low and high conicity values.

NOTE: Advice for the calculation is given in ERRI C116 Rp3 and Rp6.

Representative conicity ranges, both on straight and in curves of radius  $\geq 2500$  m listed below:

- 0,1 to 0,4 where speed  $v \leq 200$  km/h,
- 0,1 to 0,3 where speed  $v > 200$  km/h.

The characteristics of the wheel-rail contact geometry have to be noted in the test report.

#### 4.2.4.5 Vehicle condition

The tested vehicle shall conform to the specification in all respects.

The vehicle condition shall be specified before the test, taking into account particularly the factors which may affect the passenger comfort, such as vehicle-mounted equipment, wheel irregularities, etc.

The list of the characteristics which shall be verified shall be compiled before each line test is carried out.

The vehicle shall be tested empty in normal running order; it may also be tested with other load conditions.

#### 4.2.4.6 Other conditions

For the application of this method for comfort evaluation, the position of the tested vehicle in the train is irrelevant.

It is worth noting that in particular cases the comfort level may be influenced by the position of the vehicle in the train, e.g. for a single vehicle, a vehicle at the end of the train or coupled to particular vehicles. The couplings shall be tightened as for normal service.

In the case of a multiple unit, be it articulated or not, the test specification shall stipulate which vehicles are to be used for measuring comfort. The choice of vehicles is to be guided by the constructional characteristics of the train; measurements shall be carried out in each type of vehicle (if the train includes more than one type) depending on the types of bogie used.

#### 4.2.5 Parameters to be measured

Mean Comfort is determined on the basis of accelerometer readings. These are performed at different points on the floor.

Measurement conditions are contained in Annex A.

#### 4.2.6 Values to be calculated

##### 4.2.6.1 Symbols and indices

Symbols

$a$  = rms acceleration, in  $\text{m/s}^2$

$N$  = Comfort index

Indices

$W_i$ : this superscript index relates to the weighted frequency values in accordance with the weighting curve  $i$  ( $i = a, b, d, ab, ad$ ):  
 ab: vertical direction  $W_{ab} = W_a \times W_b$   
 ad: lateral direction,  $W_{ad} = W_a \times W_d$

$a, P$ : subscript indices related to:  
 $a$ : the sensitive axis of the transducer (x, y, z)  
 $P$ : the floor interface

$k$ : subscript index indicating the quantile used  
 (k=95 for the 95th quantile)

$l$ : subscript index indicating the type of comfort  
 (MV = mean passenger)

##### 4.2.6.2 Comfort index calculation

Annex B gives the filtering and processing conditions:

- Parameters used

At floor level:  $a_{xp}, a_{yp}, a_{zp}$

- Comfort formula:

$$N_{MV} = 6 \cdot \sqrt{\left(a_{XP95}^{W_{ad}}\right)^2 + \left(a_{YP95}^{W_{ad}}\right)^2 + \left(a_{ZP95}^{W_{ab}}\right)^2}$$

If this formula is to be used for measurements carried out at the end of the vehicle, the value  $a_{XP95}$  to be taken into account is that obtained at the centre of the vehicle.

According to the application, it can be useful to calculate following partial Comfort Indexes

$$N_{MVx} = 6 \cdot a_{XP95}^{W_{ad}}$$

$$N_{MVy} = 6 \cdot a_{YP95}^{W_{ad}}$$

$$N_{MVz} = 6 \cdot a_{ZP95}^{W_{ab}}$$

#### 4.2.7 Test report

The test report shall include the test specification, the characteristics of the tested vehicle, the track characteristics and a precise description of the actual test conditions, including all necessary measurements.  
Annex D describes the presentation.

### 5 Guide for the application to other vehicles

The following clause is given for general information.

The same type of test can in principle be applied to other railway vehicles carrying passengers, only with the restriction that no partial using and no neglecting of necessary information, according to the application, can be allowed.

Also it is necessary to ensure information on track characteristics, as described in Annex C, here assumed as informative.

It can also be allowed that the total test track can be obtained by non-continuous parts, and the corresponding test recording can be admitted as non-continuous.

### 6 Guide for the interpretation of the results

The following clause is given for general information.

#### 6.1 Comfort scale

##### 6.1.1 Mean comfort

As stated by ERRI B153, the proposed scale in comfort units for  $N_{mv}$ ,  $N_{va}$ ,  $N_{vd}$  is as follows:

|                |                    |
|----------------|--------------------|
| $N < 1$        | Very comfortable   |
| $1 \leq N < 2$ | Comfortable        |
| $2 \leq N < 4$ | Medium             |
| $4 \leq N < 5$ | Uncomfortable      |
| $N \geq 5$     | Very uncomfortable |

The class width should not be narrower than 0,10, and not broader than 0,50.

##### 6.1.2 Comfort on transition and Discrete Events

A comfort scale, according to existing experience, is not available. The interpretation of the absolute values of  $P_{ct}$  and  $P_{de}$  will depend on the expectations of the passenger for particular type of service (long distance, commuter, high speed etc) but a larger value of  $P_{ct}$  or  $P_{de}$  will always indicate poorer passenger comfort.

#### 6.2 List of relevant applications

Depending on the goal of the comfort measurement, any of the indexes listed in clause Introduction g) and described in clause 4, and in Annex E, K, M can be used.

A list of possible applications, with the corresponding information on track and vehicle, are contained in table 3.

Vehicle data information is listed in table 3 and classified as follows:

V1 - General description: type of vehicle and general configuration of vehicle and running gear

V2 - Relevant vehicle design parameters: geometry, masses, type and characteristics of springs, dampers, active elements etc.

V3 - Vehicle maintenance condition: condition of parts subjected to use or wear

Table 3

| Purpose                                                                                                        | Comfort index    | Design concity | Existing concity | Design track layout | Mean / max. track irregularity | Mean standard deviation of track irregularities | Max. standard deviation of track irregularities | Standard deviation distribution of track irregularities for complete section | Average spectrum  | Envelope of spectra | Representative distance history | Complete distance history | Mechanical properties | 2)<br>Vehicle data information | Additional information                 |
|----------------------------------------------------------------------------------------------------------------|------------------|----------------|------------------|---------------------|--------------------------------|-------------------------------------------------|-------------------------------------------------|------------------------------------------------------------------------------|-------------------|---------------------|---------------------------------|---------------------------|-----------------------|--------------------------------|----------------------------------------|
| Technical specifications for vehicle demanding an absolute level of comfort                                    | $N_{MV}$         | X              |                  | X                   | X                              | X                                               | X                                               |                                                                              |                   | X                   |                                 | X                         | (X) <sup>1)</sup>     | V1 and V2                      |                                        |
|                                                                                                                | $N_{VA}, N_{VD}$ | X              |                  | X                   | X                              | X                                               | X                                               |                                                                              |                   | X                   |                                 | X                         | (X) <sup>1)</sup>     |                                |                                        |
|                                                                                                                | $P_{CT}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 | (X) <sup>1)</sup>         |                       |                                |                                        |
|                                                                                                                | $P_{DE}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 | X                         | X                     |                                |                                        |
| Type tests for vehicle demanding an absolute level of comfort                                                  | $N_{MV}$         |                | X                | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       | V1 to V3                       |                                        |
|                                                                                                                | $N_{VA}, N_{VD}$ |                | X                | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       |                                |                                        |
|                                                                                                                | $P_{CT}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 | (X) <sup>1)</sup>         |                       |                                |                                        |
|                                                                                                                | $P_{DE}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 | X                         |                       |                                |                                        |
| Comparison of vehicle comfort indexes for purposes of specifications or type tests (Relative level of comfort) | $N_{MV}$         | X              | X                | X                   | X                              |                                                 |                                                 |                                                                              | (X) <sup>1)</sup> |                     | (X) <sup>1)</sup>               |                           |                       | V1 to V3                       | For both tested and reference vehicles |
|                                                                                                                | $N_{VA}, N_{VD}$ | X              | X                | X                   | X                              |                                                 |                                                 |                                                                              | (X) <sup>1)</sup> |                     | (X) <sup>1)</sup>               |                           |                       |                                |                                        |
|                                                                                                                | $P_{CT}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     | (X) <sup>1)</sup>               |                           |                       |                                |                                        |
|                                                                                                                | $P_{DE}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     | (X) <sup>1)</sup>               |                           |                       |                                |                                        |
| Setting vehicle maintenance rules on defined track                                                             | $N_{MV}$         |                | X                | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       | V3                             |                                        |
|                                                                                                                | $P_{CT}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       |                                |                                        |
|                                                                                                                | $P_{DE}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       |                                |                                        |
| Verifying vehicle behaviour for maintenance purposes, on defined track, in comparison with other vehicles      | $N_{MV}$         |                | X                | X                   |                                |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       | V1                             |                                        |
|                                                                                                                | $P_{CT}$         |                |                  | X                   |                                |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       |                                |                                        |
|                                                                                                                | $P_{DE}$         |                |                  | X                   |                                |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       |                                |                                        |
| Checking track maintenance conditions                                                                          | $N_{MV}$         |                | X                | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       | V1 and V3                      |                                        |
|                                                                                                                | $P_{CT}$         |                | X                | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       |                                |                                        |
|                                                                                                                | $P_{DE}$         |                | X                | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       |                                |                                        |
| Changing permitted line speed                                                                                  | $N_{MV}$         |                | X                | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       | V3                             |                                        |
|                                                                                                                | $P_{CT}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       |                                |                                        |
|                                                                                                                | $P_{DE}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     |                                 |                           |                       |                                |                                        |
| Theoretical prediction (calculation)                                                                           | $N_{MV}$         | X              |                  |                     | X                              | X                                               | X                                               | X                                                                            | X                 | X                   | X                               |                           | X                     | V2                             |                                        |
|                                                                                                                | $P_{CT}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     | (X) <sup>1)</sup>               |                           |                       |                                |                                        |
|                                                                                                                | $P_{DE}$         |                |                  | X                   | X                              |                                                 |                                                 |                                                                              |                   |                     | X                               |                           | (X) <sup>1)</sup>     |                                |                                        |

1) ( ) means supplementary information, i.e. concerning track data not strictly necessary.

2) The description of vehicle conditions (V1 to V3) is contained in 6.2.

## **Annex A** (normative) **Simplified method for Mean Comfort evaluation** **Vibration measurement**

### **A.1 General**

The physical values to be measured are the translational accelerations at the floor.

The term "measuring equipment" used below covers all the equipment which permits the measurement and recording of the signals.

By "measuring technique" is meant the way in which the measuring apparatus is used to obtain the data which form the object of the test.

### **A.2 Measuring equipment**

The measuring equipment includes the following:

- transducers (accelerometers),
- amplifiers and processing filters,
- recording equipment (if necessary).
- computer for data recording including software (if available)

All this equipment together constitutes a measurement system. The characteristics of the equipment shall be consistent. The precision of the measuring equipment shall be defined both in terms of the characteristics of each component and in terms of certain characteristics of the system as a whole. The calibration of the equipment shall be verified at regular intervals in accordance with applicable standards.

#### **A.2.1 Accelerometers and processing amplifiers**

It is generally not possible to separate the transducer from its processing amplifier; these elements will be dealt with together; they have to meet the following requirements:

- the global transfer function shall be flat to within  $\pm 0,5$  dB between 0,4 Hz and 100 Hz
- non-linearity plus hysteresis:  $\leq 0,3\%$  of full scale
- lateral sensitivity:  $\leq 0,05 \text{ m/s}^2 / \text{m/s}^2$
- effect of temperature:
  - on zero:  $\leq 3\%$  of full scale
  - on sensitivity:  $\leq 5 \cdot 10^{-4}$  of full scale /  $^{\circ}\text{C}$ .

#### **A.2.2 Recording equipment**

Recording equipment shall meet the following requirements:

- flat pass band between 0 Hz and 100 Hz,
- at 100 Hz, the loss shall be less than 1 dB.

The recorded signal level shall be sufficient to allow the analysis to be carried out properly and automatically.

## **A.3 Measuring technique**

### **A.3.1 Measuring procedure**

Accelerations are to be measured at the floor.

When fixing an accelerometer to the floor, the following precautions shall be taken:

- in so far as possible, the accelerometer shall perform the same movements as that part of the structure to which the seat is fixed,
- the signal from the accelerometer shall not be modified either by operating too close to the first resonant frequency of its mounting, or as a result of the local modes of the fixing surfaces. It is therefore necessary to ensure that the mounting used for the accelerometer is as rigid as possible.

Detailed requirements are contained in ISO 5348.

### **A.3.2 Location of measuring points**

The accelerations at a given point in a vehicle are closely dependent upon the location of that point. For this reason, the measurements shall be carried out at the centre of the body and at both ends, at the seats most closely located to these positions.

NOTE: Figure A.1 shows an example of the locations of these measuring points on the floor of a conventional vehicle; figure A.2 shows the same on a double-decker vehicle.

Depending on the method used and the type of vehicle, the following measuring points are to be taken into account:

- single-deck vehicles:
  - one point at the centre and one point at each end
- double-deck vehicles:
  - one point at the centre and one point at each end of the lower deck
  - one point at the centre of the upper deck

The accelerometers shall be fixed to the floor as closely as possible to the vertical projection at the centre of the seat pan (preferably less than 100 mm from this point).

NOTE: In the case of standing position studies on urban transit stock, an accelerometer should also be placed on the vestibule floor.

Additional measuring points may be used if the purpose of the test calls for them.

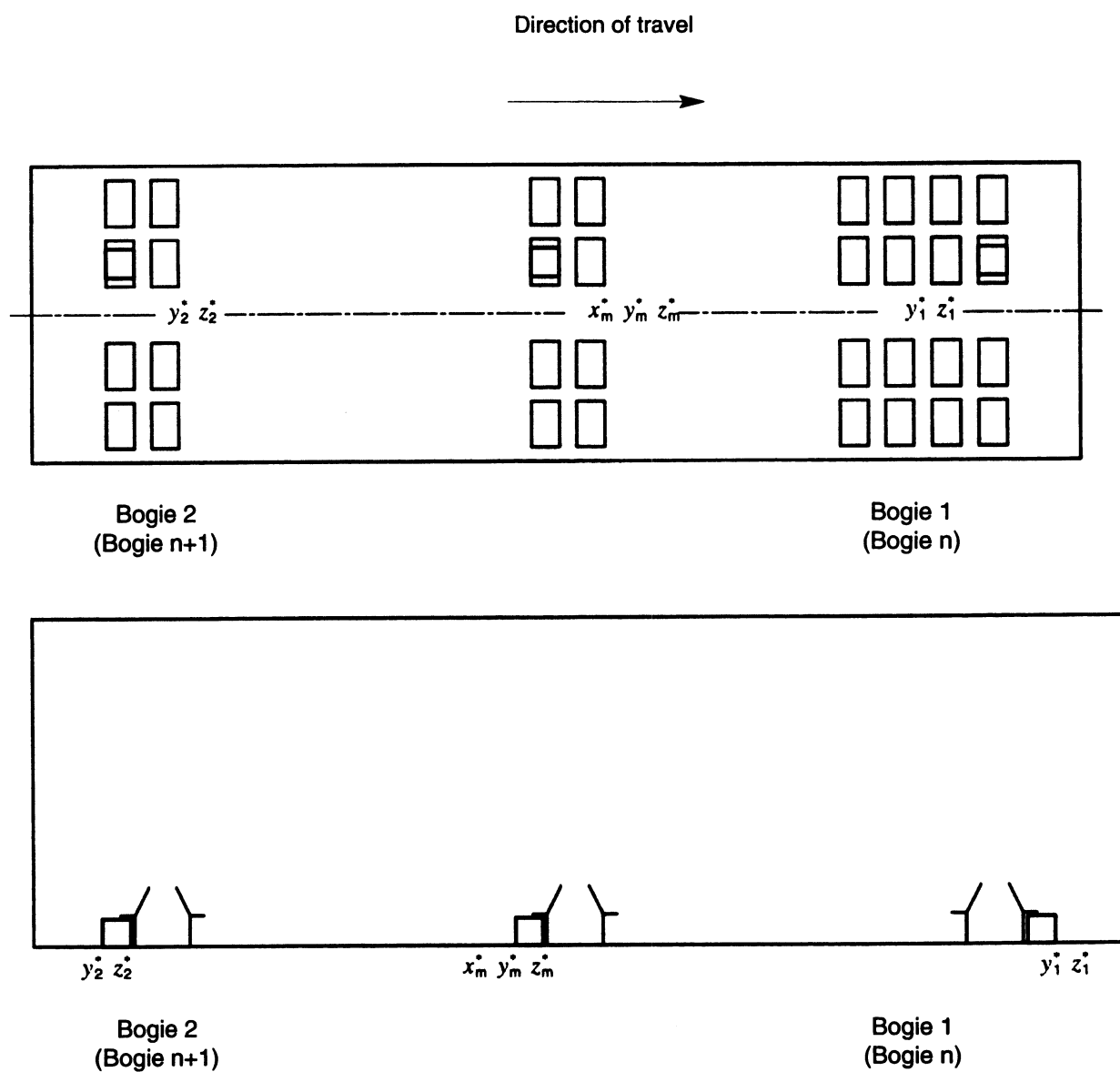


**Figure A.1: Locations of measuring points**  
Passenger coach (Conventional or articulated)

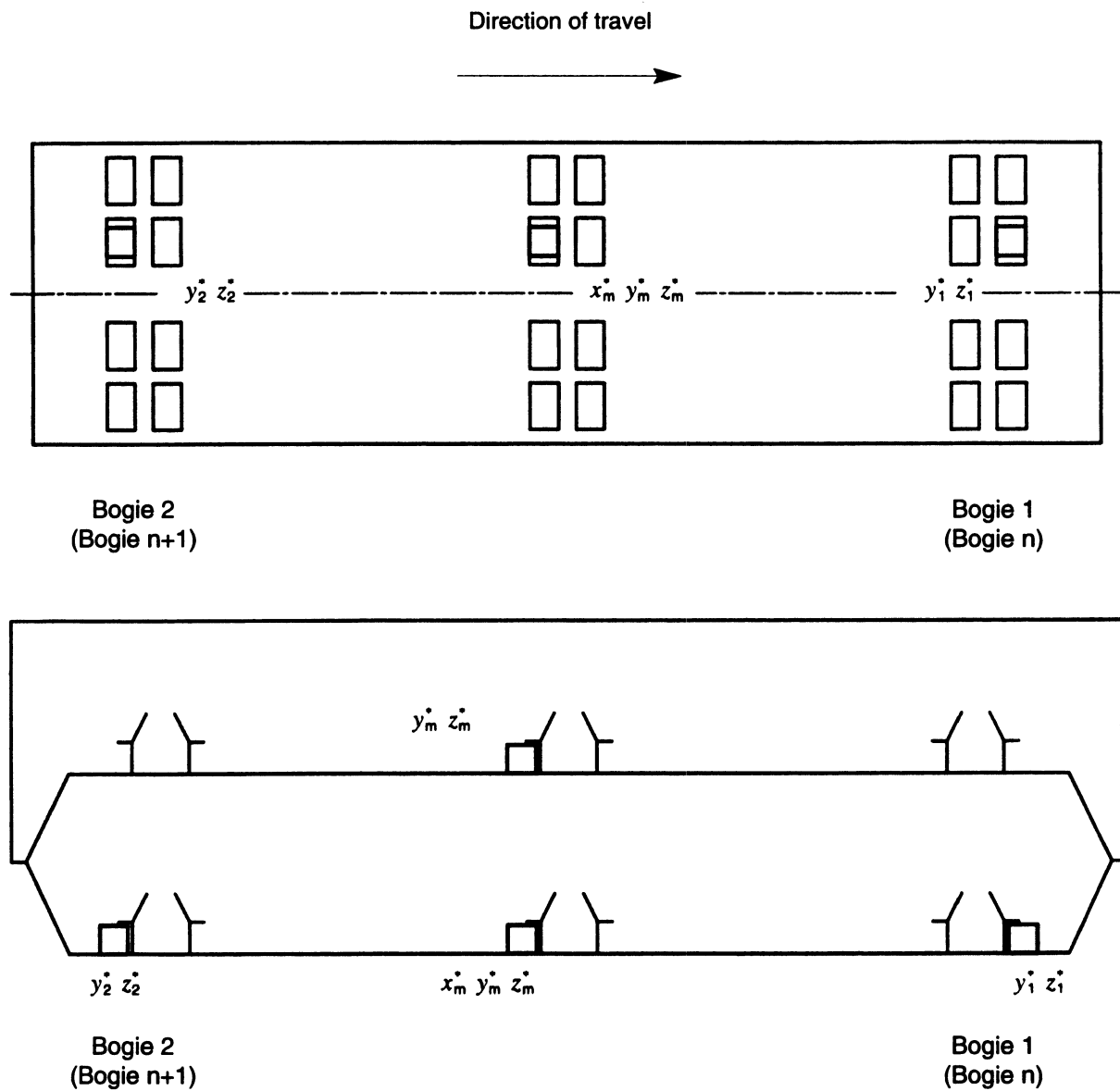


**Figure A.2: Location of measuring points**  
Double-Deck train (Conventional or articulated)

## **Annex B** (normative) **Simplified method for Mean Comfort evaluation** **Processing of measurement results**

### **B.1 Symbols and indices**

#### **B.1.1 Symbols**

|            |                                                                              |
|------------|------------------------------------------------------------------------------|
| $t$        | time, in seconds                                                             |
| $f$        | frequency, in Hertz                                                          |
| $a(t)$     | amplitude of acceleration as a function of time, in metres per square second |
| $\Delta t$ | sampling interval, in seconds                                                |
| $\tau$     | duration of one unit block, in seconds                                       |
| $N_b$      | number of unit blocks                                                        |
| $b$        | class width, in metres per square second                                     |
| $X$        | Fourier transform of the acceleration, in metres per square second           |
| $h$        | histogram of effective acceleration values                                   |
| $N_s$      | number of samples per unit block                                             |

#### **B.1.2 Indices**

- Index  $w$   
Superscript index denoting frequency-weighted values:  $a^w$ .
- Index  $l$   
Subscript index denoting unit block  $l : a_l, (a_l^w)$ .
- Index  $k$   
This index indicates the quantile  $k$  of the observation:  $h(k)$ .
- Index  $*$   
Superscript index denoting the complex conjugated number to which it refers.

### **B.2 Calculation of rms weighted values**

In order to calculate the effective weighted acceleration values, the signals recorded shall be processed using one of the following methods:

- analogue
- hybrid (analogue plus digital)
- digital

These methods are shown in figures B.3 to B.5.

### B.3 Weighting curves

In order to take account of the different degrees of sensitivity displayed by different individuals as a function of frequency, weighting curves have been established for vertical and horizontal acceleration signals (ISO TC 108 and ERRI B 153 Committee). These curves are defined in tables B.1 to B.3 and are shown in figures B.6 to B.8 of this Annex. Figure B.9 gives the tolerances which are to be respected.

The curves were determined for sinusoidal vibrations; they are considered valid for broad-band stationary vibrations.

Although each individual has his own weighting curves, the curves selected are the optimum curves for assessing mean vibration comfort.

### B.4 Statistical analysis technique

This technique is based on the following principle:

In order to take account of the fluctuating aspect of the vibrations, vibration comfort as perceived by the passenger depends on the extreme values of the weighted rms values.

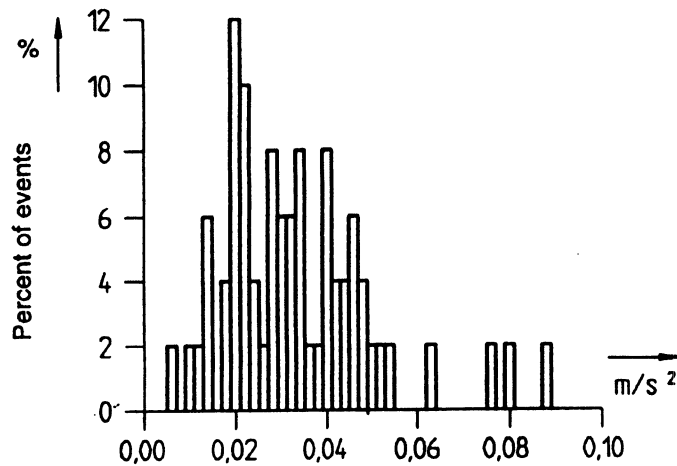
The rms-level of vibration is therefore determined over a period of 5 s in each direction and at each interface according to Annex F.

This 5-second interval is the best compromise if the lowest frequencies are to be taken into account and the rms values are to be varied over the range required.

Different types of histogram of the rms weighted values calculated every 5 s may be constructed and the 95th quantiles may be determined; these values are needed for the calculation of the comfort index  $N_{mv}$ .

The 95th quantile is obtained by cumulating values of the histogram expressed in percent beginning from lower acceleration classes up to the class where that sum becomes equal to 95% or just higher.

Two examples for the calculation of 95th quantile corresponding respectively to figures D.4 (Example 1) and D.5 (Example 2) are given in figure B.1 and B.2.



Number of samples: 60  
Minimum value: 0,005 m/s<sup>2</sup>  
Maximum value: 0,089 m/s<sup>2</sup>

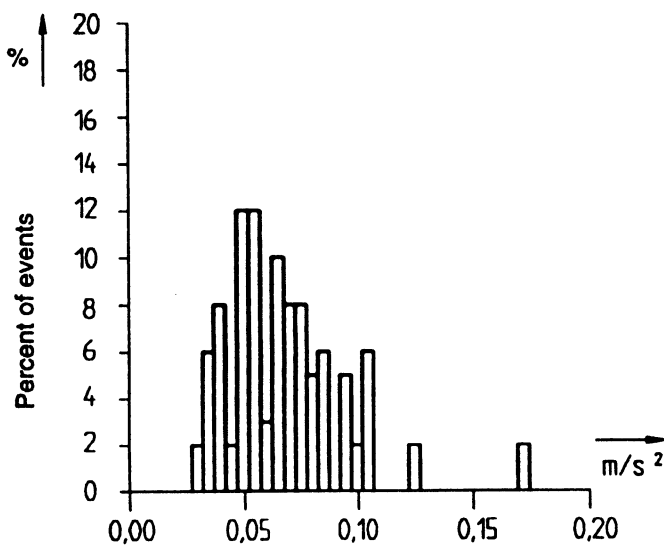
Distribution function  
50 %: 0,029 m/s<sup>2</sup>  
95 %: 0,064 m/s<sup>2</sup>

Standard deviation: 0,016 m/s<sup>2</sup>

Class width: 0,002 m/s<sup>2</sup>

$\Sigma = 95\% \geq$  95th quantile: 0,064 m/s<sup>2</sup>

Figure B.1: Example 1



Number of samples: 60  
Minimum value: 0,027 m/s<sup>2</sup>  
Maximum value: 0,172 m/s<sup>2</sup>

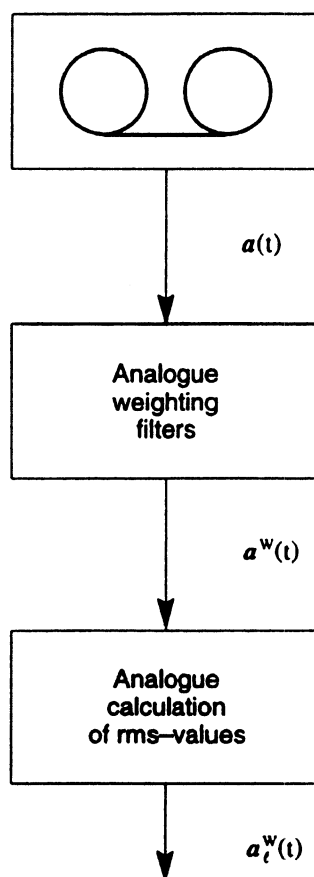
Distribution function  
50 %: 0,062 m/s<sup>2</sup>  
95 %: 0,105 m/s<sup>2</sup>

Standard deviation: 0,025 m/s<sup>2</sup>

Class width: 0,005 m/s<sup>2</sup>

$\Sigma = 96,7\% \geq$  95th quantile: 0,105 m/s<sup>2</sup>

Figure B.2: Example 2



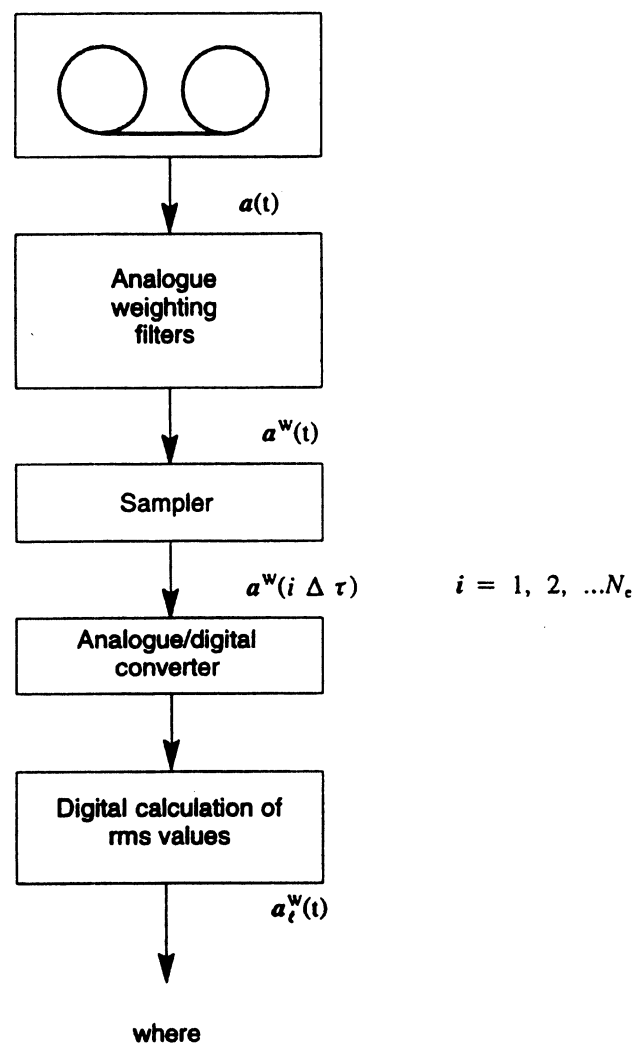
where

$$(a_t^w) = \sqrt{\frac{1}{\tau} \int_{(t-1)\tau}^{t\tau} (a^w(t))^2 \Delta\tau} \quad (\text{B.1})$$

$$\ell = 1, 2, \dots N_b$$

$$\tau = 5 \text{ s}$$

**Figure B.3: Analogue method**



$$(a_\ell^w) = \sqrt{\frac{1}{N_e} \cdot \sum_{i = (\ell-1) \cdot N_e + 1}^{\ell \cdot N_e} [a^w(i \cdot \Delta \tau)]^2} \quad (\text{B.2})$$

$$\begin{aligned} \ell &= 1, 2, \dots, N_b \\ \tau &= 5 \text{ s} \end{aligned}$$

Figure B.4: Hybrid method (analogue/digital)

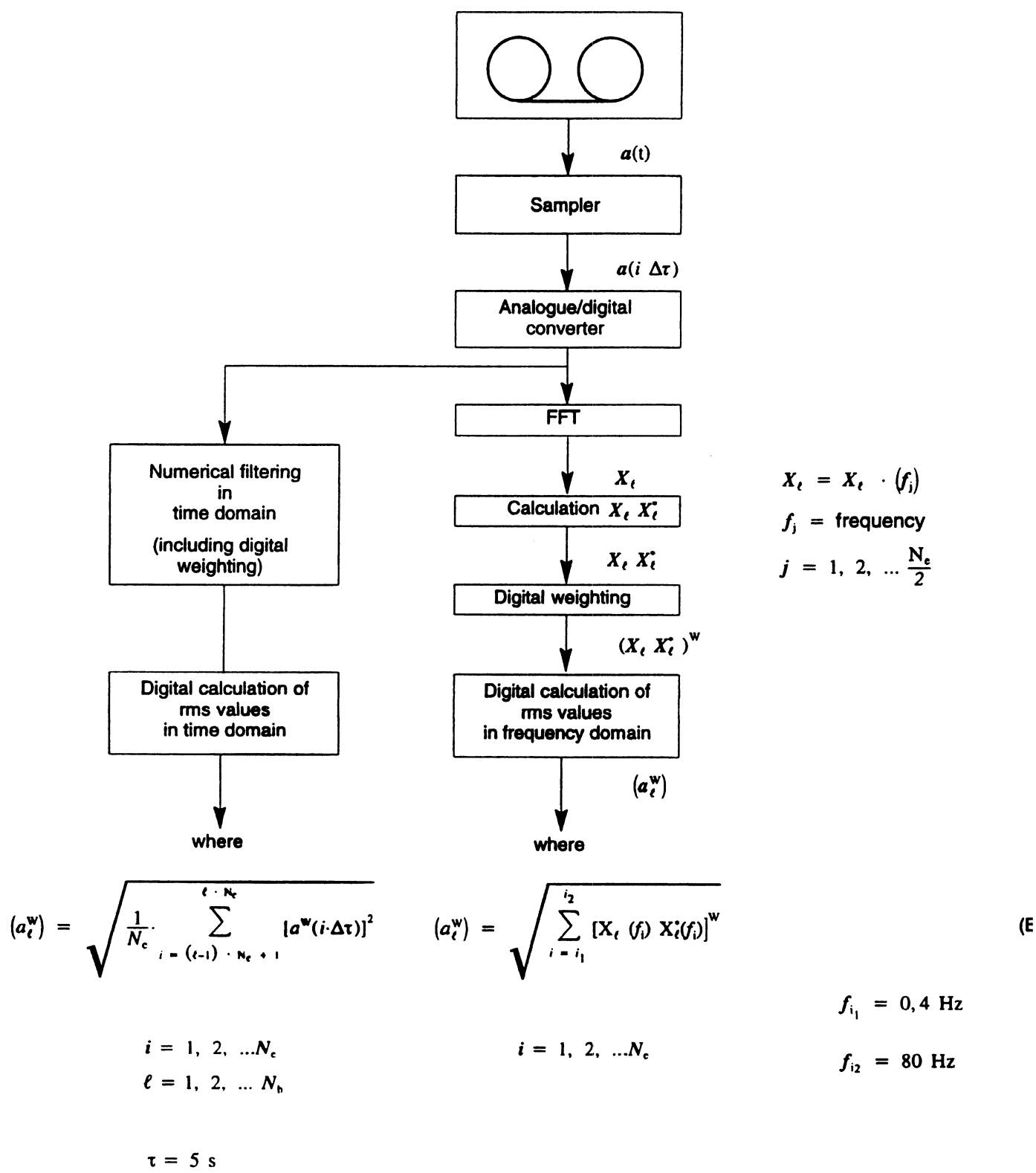


Figure B.5: Digital method