

International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

P.834.1

(04/2009)

SERIES P: TERMINALS AND SUBJECTIVE AND
OBJECTIVE ASSESSMENT METHODS

Methods for objective and subjective assessment of
speech quality

**Extension of the methodology for the derivation
of equipment impairment factors from
instrumental models for wideband speech
codecs**

Recommendation ITU-T P.834.1



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Recommendation ITU-T P.834.1

Extension of the methodology for the derivation of equipment impairment factors from instrumental models for wideband speech codecs

Summary

Recommendation ITU-T P.834.1 describes an extension of the methodology for deriving equipment impairment factors from instrumental models of Recommendation ITU-T P.834. It is intended that it primarily be applied to determine wideband equipment impairment factors $I_{e,wb}$, capturing the degradation introduced by wideband speech codecs. The resulting wideband equipment impairment factors derived by this methodology are intended to be used on the extended transmission rating scale underlying the E-model (see Appendix II of Recommendation ITU-T G.107). They will reflect the auditory impairments of the corresponding equipment in a listening-only mode.

The present methodology makes use of instrumental models (so-called "objective methods"), e.g., of the model defined in Recommendation ITU-T P.862.2. It is to be considered as supplementary to the methodology based on auditory listening-only tests, described in Recommendation ITU-T P.833.1. It will provide valid $I_{e,wb}$ values only for those codecs for which the used instrumental model produces meaningful estimations.

Speech material associated to this Recommendation is freely available on ITU-T test signal database at www.itu.int/net/ITU-T/sigdb. It is also available on a CD-ROM attached to the paper version of this Recommendation.

Source

Recommendation ITU-T P.834.1 was approved on 29 April 2009 by ITU-T Study Group 12 (2009-2012) under Recommendation ITU-T A.8 procedures.

Keywords

Codec, E-model, equipment impairment factor, impairment factor method, objective method, wideband speech transmission.

FOREWORD

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Introduction

ITU-T has introduced the impairment factor method in order to describe the joint effect of different types of degradations on the overall transmission quality. According to this method, transmission impairments can be transformed into so-called "psychological factors" which are assumed to be additive on a psychological scale. The transmission rating scale (R -scale) underlying the E-model (see [ITU-T G.107]) is assumed to reflect such a psychological scale.

The impairment factor method allocates a value of impairment to each parameter describing the transmission channel, and then allows the simple addition of these impairments to determine the overall impairment. The overall transmission rating R is finally calculated by subtracting the overall impairment from the maximum value R_{max} . Whereas the R -scale and the E-model have originally been formulated for narrow-band (300-3400 Hz) speech transmission only, Appendix II of [ITU-T G.107] presents an extension of this scale to wideband (50-7000 Hz) speech transmission. Although a complete wideband version of the E-model is not yet available, Appendix IV to [ITU-T G.113] provides values for wideband equipment impairment factors $I_{e,wb}$, which describe the degradation resulting from selected wideband speech codecs on the extended R -scale. This Recommendation describes a methodology on how $I_{e,wb}$ values can be derived for other wideband speech codecs, based on the results of so-called "objective methods".

Recommendation ITU-T P.834.1

Extension of the methodology for the derivation of equipment impairment factors from instrumental models for wideband speech codecs¹

1 Scope

It is assumed that the reader is familiar with [ITU-T P.834].

The extension of the methodology described in this Recommendation is intended to derive wideband equipment impairment factors $I_{e,wb}$ quantifying the impairment introduced by wideband (50-7000 Hz) speech codecs. Such wideband equipment impairment factors have been introduced as a simplified measure of the degradation introduced by wideband speech codecs on the integral transmission quality from mouth to ear. They are in no way an exact description of the effects related to each individual codec or codec tandem, which may be very diverse in their perceptual nature. Instead, they represent the relative degradation in comparison to other impairments occurring in a connection.

In order to provide guidance on the quantitative amount of impairment introduced by such codecs, a framework of wideband equipment impairment factor values for several wideband speech codecs has been derived by ITU-T, see Appendix IV to [ITU-T G.113]. The derivation of these values was based on many subjective listening-only tests carried out in different test laboratories, so as to guarantee stable values for all the codecs under investigation so far, as well as their relations to each other. If new equipment impairment factor values for different codecs have to be derived, then the overall consistency with the established framework is of primary importance if results are to be obtained that are valid for network planning. The methodology described in this Recommendation was designed to fulfil this requirement.

So far, wideband speech codecs are the only wideband elements for which impairment factors have been derived. For asynchronous tandems of multiple codecs of the same type, or of multiple codecs of different types, it is assumed that individual equipment impairment factors are additive. The overall equipment impairment factor for the chain of codecs is then calculated as a simple sum of all the individual $I_{e,wbs}$. Experimental test data collected provide evidence that this simple additivity is not satisfied for all the potential combinations of codecs. These deviations from the pure additivity property are an item for further study. Impairment factor values for other wideband network elements, resulting in other types of degradations and to be used in a wideband version of the E-model, have not yet been defined and are for further study as well.

ITU-T currently recommends two methodologies for the derivation of wideband equipment impairment factors: this Recommendation and [ITU-T P.833.1]. The methodology described in [ITU-T P.833.1] is based on the results of auditory listening-only tests. The present approach, which is based on instrumental models (so-called "objective methods"), requires that the models used provide valid estimations of auditory judgements. Only in this case will the derived wideband equipment impairment factors be valid. The described methodology has been tested with the model defined in [ITU-T P.862.2], and results were found to be satisfactory in most cases.

¹ This Recommendation includes speech material which is freely available on ITU-T test signal database at www.itu.int/net/ITU-T/sigdb. The speech material is also available on a CD-ROM attached to the paper version of this Recommendation.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- [ITU-T G.107] Recommendation ITU-T G.107 (2009), *The E-model, a computational model for use in transmission planning*.
- [ITU-T G.113] Recommendation ITU-T G.113 (2007), *Transmission impairments due to speech processing*.
- [ITU-T G.722] Recommendation ITU-T G.722 (1988), *7 kHz audio-coding within 64 kbit/s*.
- [ITU-T G.722.1] Recommendation ITU-T G.722.1 (2005), *Low-complexity coding at 24 and 32 kbit/s for hands-free operation in systems with low frame loss*.
- [ITU-T G.722.2] Recommendation ITU-T G.722.2 (2003), *Wideband coding of speech at around 16 kbit/s using Adaptive Multi-Rate Wideband (AMR-WB)*.
- [ITU-T P.56] Recommendation ITU-T P.56 (1993), *Objective measurement of active speech level*.
- [ITU-T P.341] Recommendation ITU-T P.341 (2005), *Transmission characteristics for wideband (150-7000 Hz) digital hands-free telephony terminals*.
- [ITU-T P.501] Recommendation ITU-T P.501 (2007), *Test signals for use in telephony*.
- [ITU-T P.800] Recommendation ITU-T P.800 (1996), *Methods for subjective determination of transmission quality*.
- [ITU-T P.830] Recommendation ITU-T P.830 (1996), *Subjective performance assessment of telephone-band and wideband digital codecs*.
- [ITU-T P.833.1] Recommendation ITU-T P.833.1 (2008), *Methodology for the derivation of equipment impairment factors from subjective listening-only tests for wideband speech codecs*.
- [ITU-T P.834] Recommendation ITU-T P.834 (2002), *Methodology for the derivation of equipment impairment factors from instrumental models*.
- [ITU-T P.862.2] Recommendation ITU-T P.862.2 (2007), *Wideband extension to Recommendation P.862 for the assessment of wideband telephone networks and speech codecs*.

3 Definitions

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ADPCM Adaptive Differential Pulse Code Modulation

CELP Codebook-Excited Linear Prediction

MLTC Modified Lapped Transform Coding

MOS Mean Opinion Score

5 Conventions

None.

6 Experimental set-up and data processing

The present instrumental methodology is mainly based on the auditory one described in [ITU-T P.833.1], substituting the auditory test by an instrumental model, e.g., the one described in [ITU-T P.862.2]. Apart from this substitution, both methodologies are very similar.

Input to the methodology are the speech files given in Annex A (see clause 6.1). Alternatively, also other wideband-recorded speech files can be used, e.g., addressing languages not covered by the set provided in Annex A, provided that they have been recorded according to the recommendations given in [ITU-T P.800]. The speech files of Annex A are available in an original, uncoded version, as well as processed through standard ITU-T implementations of 12 reference codecs defined in clause 6.2. For the new codec under investigation, the original source material has also to be processed, in the way described in clause 6.3. Processing is necessary for the new codec alone, in double and triple tandem configuration with itself, as well as in mixed tandem configurations with other codecs defined in Table 2.

Input and output files of each codec or codec tandem are then used as an input to the instrumental model. The instrumental model will provide an estimated MOS value for each speech file pair (see clause 6.4). These MOS estimations are then used to derive an $I_{e,wb}$ for the codec under test, as described in clause 7.

6.1 Input speech material

The material that can be found at the URL provided in Annex A contains uncoded source files taken from [ITU-T P.501], as well as coded output files processed with the 12 reference codecs of Table 1. All speech material was recorded in 16-bit linear PCM (binary) files with a PC format (i.e., low byte first). The filename convention is listed in Table A.2. Users of this Recommendation may process the files on their own, starting from the source material, provided that they respect the same processing steps described in clause 6.3.

The material for the 12 reference conditions has already been processed in the way which is required for the P.834.1 methodology, see the files at the URL given in Annex A. For the codec under investigation – alone, in double and triple tandems with itself, and in mixed tandems as indicated in Table 2 – the processing has to be carried out on the pre-processed speech files (extension .axp). It is recommended to use all speech files available for this purpose, and later calculate the mean (see clause 7, Step 3). This processing procedure is described in clause 6.3.

6.2 Reference conditions

Two sets of reference conditions are to be used in Steps 1 and 4 of the methodology. For Step 1, the set of 12 reference codec conditions given in Table 1 should be processed by the instrumental model. This set has been chosen from the codecs for which values are already defined in Appendix IV to [ITU-T G.113], and they have been selected to cover the whole range of $I_{e,wb}$ values.

Table 1 – Reference conditions for Step 1

No.	Abbreviation	Codec type	Reference	Operating rate (kbit/s)	$I_{e,wb,def}$ value
1	Clean	linear PCM, 16 bits	--	--	0
2	G.722.2@23.05	CELP	ITU-T G.722.2	23.05	1
3	G.722.2@19.85	CELP	ITU-T G.722.2	19.85	3
4	G.722.2@15.85	CELP	ITU-T G.722.2	15.85	7
5	G.722.2@14.25	CELP	ITU-T G.722.2	14.25	10
6	G.722@64	ADPCM	ITU-T G.722	64	13
7	G.722.1@32	MLTC	ITU-T G.722.1	32	13
8	G.722.1@24	MLTC	ITU-T G.722.1	24	19
9	G.722@56	ADPCM	ITU-T G.722	56	20
10	G.722.2@8.85	CELP	ITU-T G.722.2	8.85	26
11	G.722@48	ADPCM	ITU-T G.722	48	31
12	G.722.2@6.6	CELP	ITU-T G.722.2	6.6	41

It is important to check the additivity of the newly derived equipment impairment factor in the framework of other equipment impairment factor values defined so far. This is done in Step 4 of the methodology. If such an additivity check is not performed, the property of a simple summation of equipment impairment factors in order to cater for codec tandems should not be regarded as valid.

Table 2 gives a minimum number of ten additional reference conditions (Nos. 13-22) which should, in any case, be processed by the instrumental model to allow for a rough additivity check. It is preferable, however, to test inter-codec tandem operations with a larger set of similar conditions, including triple tandems in different codec orders. In addition to the mixed codec tandems of Table 2, the new codec under investigation should be checked in double and triple tandem operation with itself.

Table 2 – Reference conditions for the additivity check in Step 4

No.	Tandem operation	Reference codec type	Reference codec operating rate (kbit/s)	$I_{e,wb,def}$ value
13	G.722.2@19.85*(new codec)	CELP	19.85	$3 + I_{e,wb}(\text{new codec})$
14	G.722.2@14.25*(new codec)	CELP	14.25	$10 + I_{e,wb}(\text{new codec})$
15	G.722@64*(new codec)	ADPCM	64	$13 + I_{e,wb}(\text{new codec})$
16	G.722.1@32*(new codec)	MLTC	32	$13 + I_{e,wb}(\text{new codec})$
17	G.722.1@24*(new codec)	MLTC	24	$19 + I_{e,wb}(\text{new codec})$
18	G.722@48*(new codec)	ADPCM	48	$31 + I_{e,wb}(\text{new codec})$
19	(new codec)*G.722.2@19.85	CELP	19.85	$I_{e,wb}(\text{new codec}) + 3$

Table 2 – Reference conditions for the additivity check in Step 4

No.	Tandem operation	Reference codec type	Reference codec operating rate (kbit/s)	$I_{e,wb,def}$ value
20	(new codec)*G.722.2@14.25	CELP	14.25	$I_{e,wb}(\text{new codec}) + 10$
21	(new codec)*G.722@64	ADPCM	64	$I_{e,wb}(\text{new codec}) + 13$
22	(new codec)*G.722.1@32	MLTC	32	$I_{e,wb}(\text{new codec}) + 13$
23	(new codec)*G.722.1@24	MLTC	24	$I_{e,wb}(\text{new codec}) + 19$
24	(new codec)*G.722@48	ADPCM	48	$I_{e,wb}(\text{new codec}) + 31$
NOTE – A*B designates asynchronous tandeming of codecs A and B, A followed by B.				

6.3 Processing of speech material

In addition to the processed speech material made available here, the source speech material has to be processed:

- through the codec under investigation alone;
- through the codec under investigation in double and triple tandem with itself;
- through mixed tandems of the codec under investigation with the reference codecs, as given in Table 2.

This processing of the input speech data has to follow the procedure which has been used for the provision of the reference speech material. The procedure consists of 4 steps:

- 1) The source speech file is filtered to the standard WB bandwidth (50-7000 Hz). For this purpose the filter according to [ITU-T P.341] should be used.
- 2) The filtered signal is level-aligned to an active speech level of –26 dB below the overload point of the digital system, using the procedure defined in [ITU-T P.56].
These two first steps result in the pre-processed speech files (.axp).
- 3) The pre-processed speech file is then processed through the codec under test.
- 4) In case of tandem operation, the resulting processed speech file from step 3 is processed through the second (or any following) speech codec.

6.4 Calculation of MOS estimations using the instrumental model

Instrumental models which are usable for the derivation of equipment impairment factors as described here perform a comparison between an undistorted source signal and a processed and probably distorted signal (the degradation of which is quantified). The instrumental model requires as input in each case both signals, the source signal and the distorted signal, as well as the corresponding sampling frequency. Some models also require an information about the pre-processing status of the reference signal (e.g., pre-filtered or not). For the data material made available in this Recommendation, the unfiltered sources (extension .src) as well as the pre-filtered speech files (extension .axp) are provided. It is recommended to use the pre-processed sources as reference signals for the instrumental models. The pre-filtered speech data should be used as input signals for processing of codec conditions (see clause 6.3).

The instrumental model predicts the degradation due to the coding process in terms of a mean opinion score (MOS), reflecting the perceived listening quality as it would have been determined in a listening-only test carried out according to [ITU-T P.800] and [ITU-T P.830]. Because the $I_{e,wb}$ values are expected to describe the effect of wideband speech codecs, the instrumental model

should provide valid predictions for wideband transmission scenarios. Under this provision, the described procedure can in principle be used with all instrumental models which provide an estimated value for listening quality on the MOS scale from 1 to 5 reflecting a wideband, mixed-band, super-wideband or fullband test scenario, e.g., the model according to [ITU-T P.862.2].

These estimated MOS values are the input needed for the 4-step procedure described in clause 7.

7 Derivation of wideband equipment impairment factors

Based on the instrumental MOS estimations described in clause 6, a wideband equipment impairment factor for a new wideband speech codec can be derived using the 4-step procedure which is described in the following.

Step 1: Determination of raw K values for the reference conditions

Input and output speech material of the 12 reference conditions of Table 1 is processed by the instrumental model, producing a MOS estimate for each speech file pair (see clause 6). Mean MOS values are then calculated over all speech files processed with one specific condition as described in Table 1, for each of the 12 reference circuits. The mean MOS estimations are first transformed to the non-extended, narrow-band R_{NB} -scale (range [0;100], subscript NB), using the relationship between MOS and R_{NB} given in the E-model:

$$\begin{aligned} \text{for } MOS = 1.0: & \quad R_{NB} = 0 \\ \text{for } 1.0 < MOS < 4.5: & \quad MOS = 1 + 0.035 \cdot R_{NB} + R_{NB} \cdot (R_{NB} - 60) \cdot (100 - R_{NB}) \cdot 7 \cdot 10^{-6} \\ \text{for } MOS \geq 4.5: & \quad R_{NB} = 100 \end{aligned} \quad (1)$$

These R_{NB} values still reflect the narrow-band use of the MOS scale assumed by the E-model, and not a wideband use scenario which would be encountered in a subjective test with wideband connections. In order to reflect the superior quality of wideband compared to narrow-band transmission, the R_{NB} values have to be transformed to R_{WB} values (range [0;129]), using the following relationship taken from [b-Möller]:

$$R_{WB} = 1.29 \cdot R_{NB} \quad (2)$$

Taking the R_{WB} value for the "clean" condition (No. 1 of Table 1) as the reference for $K = I_{e,wb} = 0$, raw estimates for wideband equipment impairment factors (K) can be calculated with:

$$K = R_{WB}(\text{clean}) - R_{WB}(\text{test condition}) \quad (3)$$

Step 2: Calculation of interpolation line parameters

From the raw K values and the respective defined $I_{e,wb,def}$ values (see Appendix I to [ITU-T G.113]) of the 12 reference conditions of Table 1, an interpolation line is calculated in the $I_{e,wb}$ space, using a straight line in the scatter plot of [K ; $I_{e,wb,def}$] pairs:

$$K = a \cdot I_{e,wb,def} + b \quad (4)$$

The coefficients a and b are determined numerically, approximating all the reference $K - I_{e,wb,def}$ pairs in a least-squares sense. Alternatively, but with less precision, the approximation can also be made graphically on the scatter plot.

Step 3: Determination of a stable $I_{e,wb}$ value for the codec under test

Starting from this interpolation line, an instrumentally derived $I_{e,wb}$ value for the new codec can be determined using the speech material from Annex A, which has been processed through the codec under investigation. Input and output speech material are evaluated by means of the instrumental model, producing MOS estimations for each speech file pair (see clause 6). A mean estimated MOS value is then calculated for the new codec. The mean estimated MOS is transformed into a K value,

using equations 1 to 3. The K value is then transformed into a raw estimate of $I_{e,wb}$ using the parameters a and b of the interpolation line:

$$I_{e,wb} = \frac{K - b}{a} \quad (5)$$

Equation 5, or its graphical representation, leads to a wideband equipment impairment factor value for the codec under test which can be regarded as stable. This I_e value will normally fit into the framework of wideband equipment impairment factors the interpolation line has been derived from, namely for the codecs included in reference conditions Nos 1 to 12. However, it does not necessarily satisfy the additivity property underlying the impairment factor principle.

In rare cases, the linear transformation may result in a negative $I_{e,wb}$ value for the codec under investigation. This might occur if the related instrumental MOS estimates are close to or better than the one for the "clean" condition (No. 1 of Table 1). In this case, $I_{e,wb}$ should be set to zero instead.

Step 4: Additivity check

Additivity of the newly derived $I_{e,wb}$ value has to be checked for both tandems of the new codec alone, and mixed tandems with codecs for which $I_{e,wb}$ values have already been defined in Appendix IV to [ITU-T G.113]. For all the tandems of the new codec alone, as well as for all the reference conditions of Table 2, pairs of observed values K and expected values $I_{e,wb,def}$ are made available, using the instrumental model. $I_{e,wb,def}$ for tandems of the new codec alone and for reference conditions of Table 2 are computed using the $I_{e,wb}$ value derived in Step 3. These pairs can be represented in the same scatter plot of Step 2. All major deviations from the interpolation line should be noted and investigated, as they may question the applicability of the additivity property of impairment factors.

If more than 3 out of 14 tandem conditions (2 pure tandems of the codec under investigation and 12 reference tandem conditions Nos 13-24, see Table 2) show major deviations from the interpolation lines, the additivity property should not be regarded as being satisfied. In this case, the equipment impairment factor derived from the experiment will not properly represent the degradations occurring in tandem operations of the new codec.

8 Limitations of the instrumentally-derived wideband equipment impairment factor values

The methodology described in this Recommendation has not been tested for transmission error conditions, such as frame erasures or packet loss. The inclusion of such conditions into a future wideband E-model is for further study in ITU-T.

Annex A

Speech material

(This annex forms an integral part of this Recommendation)

The speech material consists of the files that can be found in ITU-T's Test Signal Database at <http://www.itu.int/net/ITU-T/sigdb/genaudio/Pseries.htm#P.834.1>². Table A.1 summarizes the contents of this disc, and Table A.2 describes the file name convention for each language sub-directory.

Table A.1 – Directory structure of the speech data

Directory		Language	# of Files	Total MBytes	
\data	\original	\fr	French	4	1.3
		\jp	Japanese	4	1.0
		\ae	American English	4	1.0
	\pre_proc	\fr	French	4	1.3
		\jp	Japanese	4	1.0
		\ae	American English	4	1.0
	\coded	\fr	French	48	15.6
		\jp	Japanese	48	11.8
		\ae	American English	48	11.9

Table A.2 – Correspondence list for individual speech files

	\fr, \jp and \ae, respectively		
	Source	Pre-processed	Processed
Clean	f1.src	f1.axp	f1.c01
	f2.src	f2.axp	f2.c01
	m1.src	m1.axp	m1.c01
	m2.src	m2.axp	m2.c01
G.722.2@23.05	f1.src	f1.axp	f1.c02
	f2.src	f2.axp	f2.c02
	m1.src	m1.axp	m1.c02
	m2.src	m2.axp	m2.c02
G.722.2@19.85	f1.src	f1.axp	f1.c03
	f2.src	f2.axp	f2.c03
	m1.src	m1.axp	m1.c03
	m2.src	m2.axp	m2.c03

² Speech material is also available on a CD-ROM attached to the paper version of this Recommendation.

Table A.2 – Correspondence list for individual speech files

	\fr, \jp and \ae, respectively		
	Source	Pre-processed	Processed
G.722.2@15.85	f1.src	f1.axp	f1.c04
	f2.src	f2.axp	f2.c04
	m1.src	m1.axp	m1.c04
	m2.src	m2.axp	m2.c04
G.722.2@14.25	f1.src	f1.axp	f1.c05
	f2.src	f2.axp	f2.c05
	m1.src	m1.axp	m1.c05
	m2.src	m2.axp	m2.c05
G.722@64	f1.src	f1.axp	f1.c06
	f2.src	f2.axp	f2.c06
	m1.src	m1.axp	m1.c06
	m2.src	m2.axp	m2.c06
G.722.1@32	f1.src	f1.axp	f1.c07
	f2.src	f2.axp	f2.c07
	m1.src	m1.axp	m1.c07
	m2.src	m2.axp	m2.c07
G.722.1@24	f1.src	f1.axp	f1.c08
	f2.src	f2.axp	f2.c08
	m1.src	m1.axp	m1.c08
	m2.src	m2.axp	m2.c08
G.722@56	f1.src	f1.axp	f1.c09
	f2.src	f2.axp	f2.c09
	m1.src	m1.axp	m1.c09
	m2.src	m2.axp	m2.c09
G.722.2@8.85	f1.src	f1.axp	f1.c10
	f2.src	f2.axp	f2.c10
	m1.src	m1.axp	m1.c10
	m2.src	m2.axp	m2.c10
G.722@48	f1.src	f1.axp	f1.c11
	f2.src	f2.axp	f2.c11
	m1.src	m1.axp	m1.c11
	m2.src	m2.axp	m2.c11
G.722.2@6.6	f1.src	f1.axp	f1.c12
	f2.src	f2.axp	f2.c12
	m1.src	m1.axp	m1.c12
	m2.src	m2.axp	m2.c12

Appendix I

Calculation of equipment impairment factors from scores provided by the instrumental model described in [ITU-T P.862.2]

(This appendix does not form an integral part of this Recommendation)

In the case that the instrumental model defined in [ITU-T P.862.2] is used for the derivation of $I_{e,wb}$ values, the following interpolation line results from the processing of the 12 reference conditions of Table 1:

$$K = a \cdot I_{e,wb,def} + b \tag{I-1}$$

with the values $a = 0.8720$ and $b = 19.9487$.

The resulting scatter plot is depicted in Figure I.1

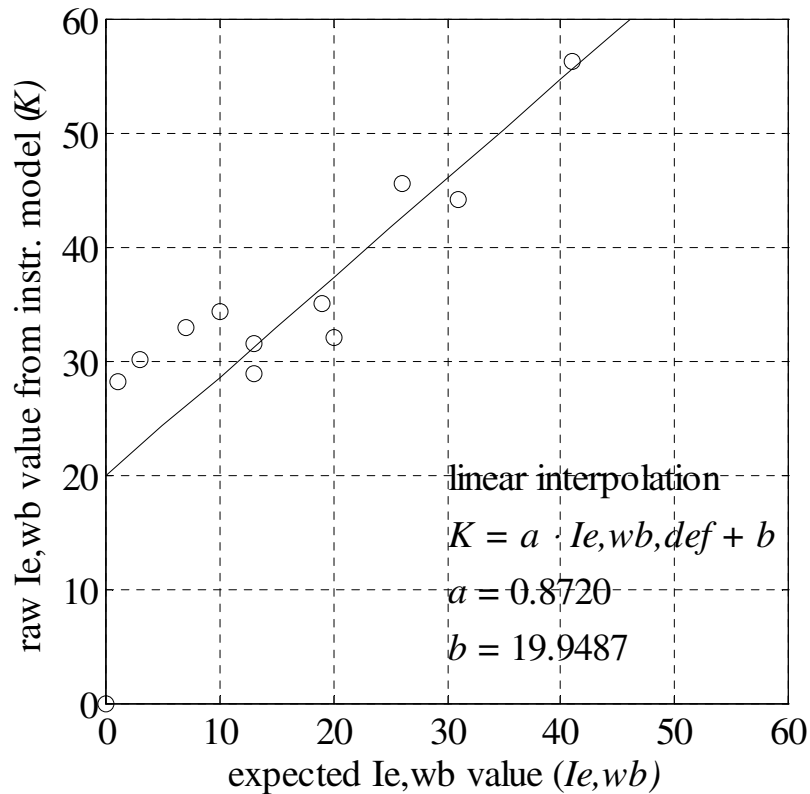


Figure I.1 – Linear interpolation line for the instrumental model according to [ITU-T P.862.2]

For each stimulus, an estimated MOS value is computed by [ITU-T P.862.2], v_i .

Mean MOS values are then calculated over all speech files processed with one specific condition, for each of the 12 reference circuits

$$MOS = \frac{1}{I} \sum_{i=1}^I v_i$$

I denotes the number of files per test condition.

The mean estimated MOS is transformed into a K value, using equations 1 to 3.

Then, the calculation of an $I_{e,wb}$ value for the new codec can be done as described in Steps 3 and 4, using the relation

$$I_{e,wb} = \frac{K - b}{a} \quad (\text{I-2})$$

with the values $a = 0.8720$ and $b = 19.9487$, and using the value:

$$R_{WB}(\text{clean}) = 129.0 \quad (\text{I-3})$$

Bibliography

- [b-Möller] Möller, S., Raake, A., Kitawaki, N., Takahashi, A., Wältermann, M. (2006). *Impairment factor framework for wideband speech codecs*, IEEE Transactions on Audio, Speech and Language Processing 14(6), pp. 1969-1976.

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