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International telephone connections and circuits – Transmission planning and the E-model

Wideband E-model

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PREPUBLISHED RECOMMENDATION

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Recommendation ITU-T G.107.1

Wideband E-model

Summary

Recommendation ITU-T G.107.1 gives the algorithm for the wideband version of the E-model as the common ITU-T transmission rating model for planning speech services that provide wideband (WB) speech transmission (50-7000 Hz). This computational model can be useful to transmission planners, to help ensure that users will be satisfied with end-to-end transmission performance. The primary output of the model is a scalar rating of transmission quality. A major feature of this model is the use of transmission impairment factors that reflect the effects of different types of degradations occurring on the entire transmission path, mouth-to-ear.

This WB-E-model is an adapted version of the narrowband (300-3400 Hz) E-model, typically referred to as "the E-model", which is described in Recommendation ITU-T G.107. It does not replace the narrowband (NB) E-model. Instead, it describes a separate WB version of the model that uses, within limits, similar concepts and input parameters as the NB E-model.

Recommendation ITU-T G.107.1

Wideband E-Model

1 Scope

This Recommendation describes the wideband version of a computational model, known as the E-model, that has proven useful as a transmission planning tool for assessing the combined effects of variations in several transmission parameters that affect conversational[1] quality. This computational model can be used, for example, by transmission planners to help ensure that users will be satisfied with end-to-end transmission performance whilst avoiding over-engineering of networks. It must be emphasized that the primary output from the model is the "rating factor" *R*, but this can be transformed to give estimates of customer opinion. Such estimates are only made for transmission planning purposes and not for actual customer opinion prediction (for which there is no agreed-upon model recommended by the ITU-T).

This version is an adapted version of the narrowband (300-3400 Hz) E-model, typically referred to as "the E-model", which is described in [ITU-T G.107]. The wideband (WB) version addresses scenarios which include wideband (50-7000 Hz) transmission. It does not replace the narrowband (NB) E-model. Instead, it describes a separate WB-version of the model that uses, within limits, similar concepts and input parameters as the NB E-model. The current version captures the effects of loudness loss, background noise at the sending side, circuit noise, talker echo, absolute delay, wideband speech coding, and voice-over-IP packet loss. Degradations which are covered but have not yet been studied in detail are the background noise at the receiving side and the listener echo. Degradations which are not yet covered are non-optimum sidetone levels and quantizing distortions.

For many parameter combinations of high importance to transmission planners, [ITU-T G.107.1] can be used with confidence (e.g., loudness loss, send-side noise, coding distortions), but for some parameter combinations of high importance (e.g., the effects of delay in conjunction with other impairments), wideband E-model predictions have been questioned and are currently under study.

Regarding the interpretation of the wideband E-model ratings, note that the current versions of [b-ITU-T G.108], [b-ITU-T G.108.1] and [b-ITU-T G.109] do not refer to the wideband version described here, but only to the narrowband version of the E-model described in [ITU-T G.107].

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 (2011), *The E-model: a computational model for use in transmission planning*.
<http://www.itu.int/rec/T-REC-G.107>

[1] Conversational quality in this context refers to transmission characteristics, e.g., long transmission times, effects of talker echoes, etc. However, the E-model, as described in this Recommendation, is not intended to model transmission impairments during double talk situations.

[ITU-T G.113] Recommendation ITU-T G.113 (2007), *Transmission impairments due to speech processing*.
<http://www.itu.int/rec/T-REC-G.113>

[ITU-T G.722] Recommendation ITU-T G.722 (1988), *7 kHz audio-coding within 64 kbit/s*.
<http://www.itu.int/rec/T-REC-G.722>

[ITU-T O.41] Recommendation ITU-T O.41 (1994), *Psophometer for use on telephone-type circuits*.
<http://www.itu.int/rec/T-REC-O.41>

[ITU-T P.800] Recommendation ITU-T P.800 (1996), *Methods for subjective determination of transmission quality*.
<http://www.itu.int/rec/T-REC-P.800>

[ITU-T P.833] Recommendation ITU-T P.833 (2001), *Methodology for derivation of equipment impairment factors from subjective listening-only tests*.
<http://www.itu.int/rec/T-REC-P.833>

[ITU-T P.833.1] Recommendation ITU-T P.833.1 (2009), *Methodology for the derivation of equipment impairment factors from subjective listening-only tests for wideband speech codecs*.
<http://www.itu.int/rec/T-REC-P.833.1>

[ITU-T P.834] Recommendation ITU-T P.834 (2002), *Methodology for the derivation of equipment impairment factors from instrumental models*.
<http://www.itu.int/rec/T-REC-P.834>

[ITU-T P.834.1] Recommendation ITU-T P.834.1 (2009), *Methodology for the derivation of equipment impairment factors from instrumental models for wideband speech codecs*.
<http://www.itu.int/rec/T-REC-P.834.1>

3 Definitions

This Recommendation does not define any new terms.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

LSTR Listener Sidetone Rating

MOS Mean Opinion Score

NB Narrow band

OLR Overall Loudness Rating

RLR Receive Loudness Rating

SLR Send Loudness Rating

STMR Sidetone Masking Rating

TELR Talker Echo Loudness Rating

WB Wide Band

WEPL Weighted Echo Path Loss

5 Conventions

None.

6 Wideband E-model

6.1 Introduction

The complexity of modern networks requires that, for transmission planning, the many transmission parameters be not only considered individually but also that their combined effects be taken into account. This can be done by "expert, informed guessing", but a more systematic approach is desirable, such as by using a computational model. The output from the model described here is a scalar transmission rating value, *R*, which varies directly with the overall conversational quality. [ITU-T G.113] gives guidance about specific impairments, including combined effects based upon a simplification of the model.

6.2 Transmission rating scale of the wideband E-model

For the narrow-band (NB) case described in [ITU-T G.107], the transmission rating scale ranges from $R = 0$ (lowest possible quality) to $R = 100$ (optimum quality). On this scale, a default NB transmission channel including logarithmic PCM coding and a noise floor (default parameter values according to Table 2 of [ITU-T G.107]) obtains a rating of $R = 93.2$. For a wideband speech transmission channel, the quality is generally judged better than that for a narrowband channel. Thus, this scale range was extended in order to be also applicable to wideband transmission scenarios. In the present wideband version, the E-model is defined for a wideband transmission channel of 50-7000 Hz, as it is defined in [ITU-T G.722].

Unfortunately, it is not possible to obtain direct human judgements on the *R*-scale, as this scale has additivity properties which are not reflected by ordinary rating scales. Instead, for NB conditions, ITU-T recommends collecting judgements on a 5-point absolute category rating scale (see [ITU-T P.800]). The mean rating, averaged over all test participants and stimuli reflecting the same circuit condition, is then called a mean opinion score (MOS).

It has been shown that MOS ratings differ between tests where only NB stimuli are presented, and tests where both NB/WB or purely WB stimuli are presented, as the use of the scale is largely influenced by the stimulus set. On the other hand, there is also experimental evidence that judgements for WB samples collected in a purely WB context do not differ significantly from those collected in a mixed NB/WB context (see [b-Barriac] and [b-Takahashi]). In addition to the stimulus bandwidth, test results are influenced by the test participant group, the language, the participants' native country, etc. [b-Möller-01]. For a NB context, an average S-shaped relationship is defined between the *R*-scale (range [0;100]) and MOS ratings (range [1;4.5]) collected from "average" test participants in an "average" experimental setting, see Annex B and Appendix I of [ITU-T G.107].

For a WB or a mixed NB/WB context, the *R*-scale was extended in a way which leaves the NB use of the scale unaffected, including the position of the reference connection (default parameter settings according to Table 2 of [ITU-T G.107]). Such an extension can be based on pairs of auditory tests in which the same (NB) test stimuli have been judged once in a purely NB and once in a mixed NB/WB context. The judgements on these common stimuli define a relationship between the use of the MOS-scale in a NB and in a mixed NB/WB context [b-Raake-01].

Two pairs of tests have been carried out and will be considered in the following. Details on parts of the tests can be found in [b-Möller-02]. The MOS results from these tests have been transformed to the *R*-scale using the NB transformation rule given in Annex B of [ITU G.107]. The resulting R_{NB} values (NB test) and $R_{NB/WB}$ values (mixed NB/WB test) for the conditions which were common in each pair are displayed in Figure 1.

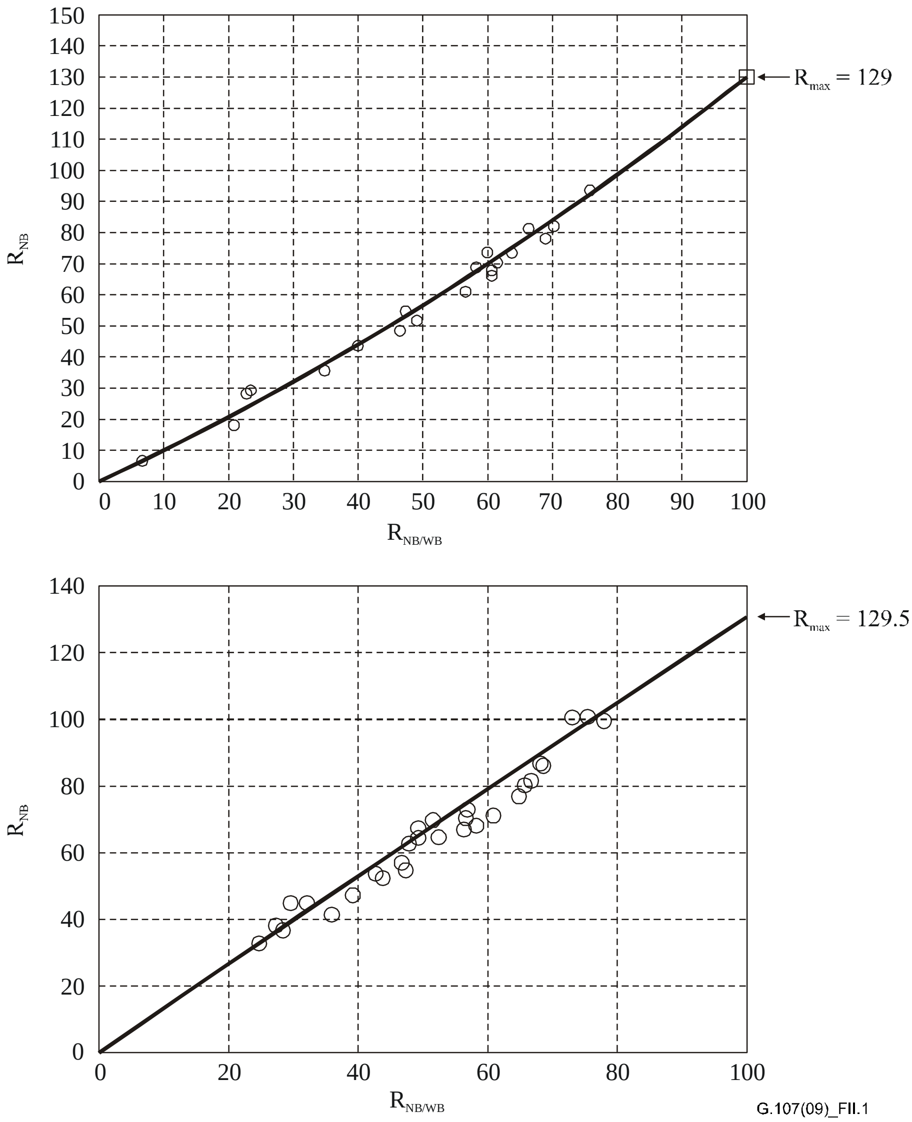

Figure 1 – Comparison between *R*-values derived in a NB and in a mixed NB/WB context

Due to the use of the NB relationship between MOS and *R* for deriving the $R_{NB/WB}$ values, the maximum $R_{NB/WB}$ value corresponding to MOS = 4.5 equals 100. The corresponding R_{NB} value of the panels in Figure 1 shows the amount by which the *R*-scale has to be extended in a NB/WB context. This maximum value is around R_{max} = 129. In other words, the NB transmission rating scale of the E-model has been extended by approximately 29% to reflect the quality improvement when migrating from NB to WB. This extended *R*-scale is a "universal" *R*-scale; it is applicable to both NB and WB transmission channels.

The primary output of the wideband E-model is the transmission rating *R*. However, the output can also give nominal estimates of user reactions, for instance in the form of MOS values, as described in Annex A.

7 The structure and basic algorithms of the wideband E-model

The wideband E-model is based on the equipment impairment factor method, following previous transmission rating models. The reference connection, as shown in Figure 2, is split into a send side and a receive side. The model estimates the conversational quality from mouth to ear as perceived by the user at the receive side, both as listener and talker.

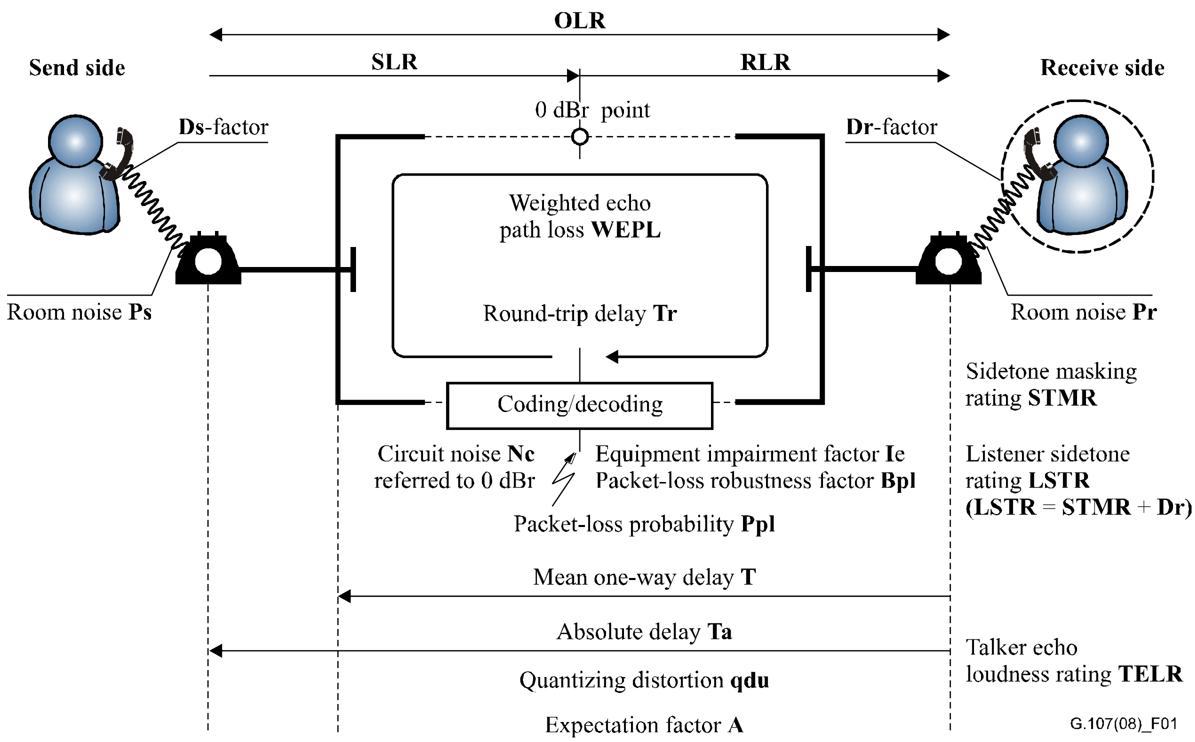

Figure 2 – Reference connection of the wideband E-model

The transmission parameters used as an input to the computation model are shown in Figure 2. Values for room noise and for the *D*-factors are handled separately in the algorithm for the send side and receive side and may be of different amounts. The parameters SLR, RLR and circuit noise Nc are referred to a defined 0 dBr point. All other input parameters are either considered as values for the overall connection, such as OLR (in any case, the sum of SLR and RLR), equipment impairment factors *Ie* and advantage factor *A*, or referred to only for the receive side, such as STMR, LSTR, WEPL (for calculation of listener echo) and TELR.

There are three different parameters associated with transmission time. The absolute delay *Ta* represents the total one-way delay between the send side and receive side and is used to estimate the impairment due to excessive delay. The parameter mean one-way delay *T* represents the delay between the receive side (in talking state) and the point in a connection where a signal coupling occurs as a source of echo. The round-trip delay *Tr* only represents the delay in a 4-wire loop, where the "double reflected" signal will cause impairments due to listener echo.

Not all parameters listed in Figure 2 are currently used in the WB E-model. However, they are displayed here in order to provide a full description of the transmission channel considering also degradations which might be included in an updated WB E-model at a later stage. The current version is based on [b-Raake-02] and further extensions for talker echo and delay presented in ITU-T.

7.1 Calculation of the transmission rating factor, *R*

For WB, the basic E-model formula (7-1 of [ITU-T G.107]) can be re-written as:

$$R = Ro{,}WB - Is{,}WB - Id{,}WB - Ie{,}eff{,}WB + A \qquad (7\text{-}1)$$

Ro,WB represents in principle the basic signal-to-noise ratio, including noise sources such as circuit noise and room noise. Factor *Is,WB* is a combination of all impairments which occur more or less simultaneously with the voice signal. Factor *Id,WB* represents the impairments caused by delay and the effective equipment impairment factor *Ie,eff,WB* represents impairments caused by low bit-rate codecs. It also includes impairment due to randomly distributed pack losses. The advantage factor *A* allows for compensation of impairment factors when the user benefits from other types of access. The term *Ro,WB* and the *Is,WB* and *Id,WB* values are subdivided into further specific impairment values. The following clauses give the equations used in the wideband E-model.

7.2 Basic signal-to-noise ratio, *Ro,WB*

The basic signal-to-noise ratio *Ro,WB* is defined by:

$$Ro,WB = 20 - 1.5 \cdot (No,WB + SLR) \qquad (7\text{-}2)$$

The term *No,WB* (in dBm0p) is the power addition of different noise sources:

$$No,WB = 10\log\left[10^{\frac{Nc}{10}} + 10^{\frac{Nos,WB}{10}} + 10^{\frac{Nor}{10}} + 10^{\frac{Nfo,WB}{10}}\right] \qquad (7\text{-}3)$$

Nc (in dBm0p) is the sum of all circuit noise powers, all referred to the 0 dBr point. The psophometric weighting according to [ITU-T O.41] is currently only defined up to 6 kHz. As a consequence, a linear extrapolation of the psophometric weighting curve up to 8 kHz can be used in order to correct the levels for the considered circuit noise.

Nos,WB (in dBm0p) is the equivalent circuit noise at the 0 dBr point, caused by the room noise *Ps* at the send side:

$$Nos,WB = Ps - SLR - Ds - 97 \qquad (7\text{-}4)$$

In the same way, the room noise *Pr* at the receive side is transferred into an equivalent circuit noise *Nor* (in dBm0p) at the 0 dBr point. This part of the E-model has not yet been checked for the wideband case, but it is assumed that it can serve as a rough estimation of the effect of room noise at the receiving side also in this case.

$$Nor = RLR - 121 + Pre + 0.008(Pre - 35)^2 \qquad (7\text{-}5)$$

The term *Pre* (in dBm0p) is the "effective room noise" caused by the enhancement of *Pr* by the listener's sidetone path:

$$Pre = Pr + 10\log\left[1 + 10^{\frac{(10-LSTR)}{10}}\right] \qquad (7\text{-}6)$$

Nfo (in dBm0p) represents the "noise floor" at the receive side,

$$Nfo,WB = Nfor,WB + RLR \qquad (7\text{-}7)$$

with *Nfor,WB* set to –96 dBmp.

7.3 Simultaneous impairment factor, *Is,WB*

The factor *Is,WB* is the sum of all impairments which may occur more or less simultaneously with the voice transmission. This aspect has not been analysed for the wideband case so far, thus it is set to

$$Is,WB = 0 \qquad (7\text{-}8)$$

7.4 Delay impairment factor, *Id,WB*

Id,WB, the impairment factor representing all impairments due to delay of voice signals, is further divided into the three factors *Idte,WB*, *Idle,WB* and *Idd*:

$$Id,WB = Idte,WB + Idle,WB + Idd \qquad (7\text{-}9)$$

The factor *Idte,WB* gives an estimate for the impairments due to talker echo:

$$Idte,WB = \left[\frac{Roe - Re,WB}{2} + \sqrt{\frac{(Roe - Re,WB)^2}{4} + 100} - 1 \right] \left(1 - e^{-T}\right) \quad (7\text{-}10)$$

where:

$$Roe = -1.5(No,WB - RLR) \quad (7\text{-}11)$$

$$Re,WB = 80 + 3(TERV,WB - 14) \quad (7\text{-}12)$$

$$TERV,WB = TELR + K - 40 \log \frac{1 + \frac{T}{10}}{1 + \frac{T}{150}} + 6e^{-0.3T^2} \quad (7\text{-}13)$$

For $T < 100$ ms:

$$K = 0.08 \cdot T + 10 \quad (7\text{-}14)$$

For $T \geq 100$ ms:

$$K = 18 \quad (7\text{-}15)$$

For the wideband case, we currently do not assume any mutual influence between talker echo and sidetone.

The factor *Idle,WB* represents impairments due to listener echo. This impairment has not been specifically studied for the WB case, but it is assumed that the degradations will be similar to those of the NB case, so the formulae are congruent with the ones of the NB E-model:

$$Idle,WB = \frac{Ro,WB - Rle}{2} + \sqrt{\frac{(Ro,WB - Rle)^2}{4} + 169} \quad (7\text{-}16)$$

where:

$$Rle = 10.5(WEPL + 7)(Tr + 1)^{-0.25} \quad (7\text{-}17)$$

The factor *Idd* represents the impairment caused by too-long absolute delay *Ta*, which occurs even with perfect echo cancelling.

For $Ta \leq 100$ ms:

$$Idd = 0$$

For $Ta > 100$ ms:

$$Idd = 25\left\{ \left(1 + X^6\right)^{\frac{1}{6}} - 3\left(1 + \left[\frac{X}{3}\right]^6\right)^{\frac{1}{6}} + 2 \right\} \quad (7\text{-}18)$$

with:

$$X = \frac{\log\left(\frac{Ta}{100}\right)}{\log 2} \quad (7\text{-}19)$$

7.5 Equipment impairment factor, *Ie,WB*

The values for the equipment impairment factor *Ie,WB* of elements using low bit-rate codecs are not related to other input parameters. They depend on subjective mean opinion score test results as well as on network experience. Refer to Appendix IV of [ITU-T G.113] for the currently recommended values of *Ie,WB*.

In case of packet loss, the packet-loss dependent effective equipment impairment factor *Ie,eff,WB* is derived using the codec-specific value for the equipment impairment factor at zero packet-loss *Ie,WB* and the packet-loss robustness factor *Bpl*. With the packet-loss probability *Ppl*, *Ie,eff,WB* is calculated using the equation:

$$Ie,effWB = IeWB + (95 - Ie,WB) \cdot \frac{Ppl}{Ppl + Bpl} \qquad (7\text{-}20)$$

As can be seen from Equation 7-20, the effective equipment impairment factor in case of *Ppl* = 0 (no packet-loss) is equal to the *Ie,WB* value defined in Appendix IV of [ITU-T G.113].

Corresponding values for *Bpl,wb* can be found in Appendix IV of [ITU-T G.113].

One should derive *Ie-effWB* by using the *Ie,wb* and *Bpl* values if they are provided in [ITU-T G.113]. If, for practical reasons, it is difficult to observe the packet-loss rate (*Ppl*), one can use the [ITU-T P.834.1] approach to directly derive *Ie-effWB*.

If *Ie,wb* is derived directly by using the instrumental method recommended in [ITU-T P.834.1], it already reflects the effect of packet loss introduced in the preparation of speech materials under test. Therefore, one should not use the eq. (7-20). Rather, one should use the *Ie,wb* value derived by [ITU-T P.834.1] in *Ie-effWB* in eq. (7-1).

7.6 Advantage factor, *A*

Background information on the advantage factor *A* can be found in Appendix II to [ITU-T G.113]. As this effect has not yet been studied for the wideband case, it is recommended to set:

$$A = 0 \qquad (7\text{-}21)$$

7.7 Default values

For all input parameters used in the algorithm of the E-model, the default values are listed in Table 1. It is strongly recommended to use these default values for all parameters which are not varied during planning calculation.

Table 1 – Default values and permitted ranges for the parameters

Parameter	Abbr.	Unit	Default value	Permitted range	Remark
Send loudness rating	SLR	dB	+8	0 ... +18	(Note 1)
Receive loudness rating	RLR	dB	+2	–5 ... +14	(Note 1)
Sidetone masking rating	STMR	dB	15	10 ... 20	(Note 2)
Listener sidetone rating	LSTR	dB	18	13 ... 23	(Note 2)
D-Value of telephone, send side	Ds	–	3	–3 ... +3	(Note 2)
D-Value of telephone, receive side	Dr	–	3	–3 ... +3	(Note 2)
Talker echo loudness rating	TELR	dB	65	5 ... 65	
Weighted echo path loss	WEPL	dB	110	5 ... 110	
Mean one-way delay of the echo path	T	ms	0	0 ... 500	

Table 1 – Default values and permitted ranges for the parameters

Parameter	Abbr.	Unit	Default value	Permitted range	Remark
Round-trip delay in a 4-wire loop	Tr	ms	0	0 ... 1000	
Absolute delay in echo-free connections	Ta	ms	0	0 ... 500	
Equipment impairment factor	Ie,WB	–	0	0 ... 56	(Note 4)
Packet-loss robustness factor	Bpl	–	4.3	4.3 ... 7.3	(Notes 3, 4)
Random packet-loss probability	Ppl	%	0	0 ... 20	(Notes 3, 4)
Circuit noise referred to 0 dBr-point	Nc	dBm0p	–70	–80 ... –40	
Noise floor at the receive side	Nfor	dBmp	–96	–	(Note 3)
Room noise at the send side	Ps	dB(A)	35	35 ... 85	
Room noise at the receive side	Pr	dB(A)	35	35 ... 85	
Advantage factor	A	–	0	0 ... 20	
NOTE 1 – Total values between microphone or receiver and 0 dBr-point. NOTE 2 – Fixed relation: LSTR = STMR + D. NOTE 3 – Currently under study. NOTE 4 – If Ppl > 0%, then the Bpl must match the codec, packet size, and PLC assumed.					

Annex A

MOS values derived from the transmission rating factor *R*

(This annex forms an integral part of this Recommendation.)

The transmission rating factor *R* can be in the range from 0 to 129, where $R = 0$ represents an extremely bad quality and $R = 129$ represents a very high quality in the wideband case. An estimated mean opinion score (MOS_{CQEW}) for the conversational situation on the scale 1-5 can be obtained from the *R*-factor by using the equations:

$$Rx = \frac{R}{1.29} \qquad \text{(A-1)}$$

For $Rx < 0$: $\quad MOS_{CQEW} = 1$

For $0 < Rx < 100$: $\quad MOS_{CQEW} = 1 + 0.035Rx + Rx(Rx - 60)(100 - Rx)7 \cdot 10^{-6}$ (A-2)

For $Rx > 100$: $\quad MOS_{CQEW} = 4.5$

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