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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

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

Fullband E-model

Recommendation ITU-T G.107.2

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
Transmission planning and the E-model	**G.100–G.109**
General Recommendations on the transmission quality for an entire international telephone connection	G.110–G.119
General characteristics of national systems forming part of international connections	G.120–G.129
General characteristics of the 4-wire chain formed by the international circuits and national extension circuits	G.130–G.139
General characteristics of the 4-wire chain of international circuits; international transit	G.140–G.149
General characteristics of international telephone circuits and national extension circuits	G.150–G.159
Apparatus associated with long-distance telephone circuits	G.160–G.169
Transmission plan aspects of special circuits and connections using the international telephone connection network	G.170–G.179
Protection and restoration of transmission systems	G.180–G.189
Software tools for transmission systems	G.190–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS	G.600–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T G.107.2

Fullband E-model

Summary

Recommendation ITU-T G.107.2 gives the algorithm for the fullband (FB) version of the E-model as the common ITU-T transmission rating model for planning speech services that provide FB speech transmission (20-20000 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 FB-E-model is an adapted version of the narrowband (NB) (300-3400 Hz) and wideband (WB) (50-7000 Hz) E-models, which are described in Recommendations ITU-T G.107 (NB) and ITU-T G.107.1 (WB). It does not replace the NB or the WB E-model. Instead, it describes a separate FB version of the model that uses, within limits, similar concepts and input parameters as the NB and WB E-models.

History

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1.0	ITU-T G.107.2	2019-06-29	12	11.1002/1000/13926

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E-model, fullband, speech quality, transmission planning.

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FOREWORD

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Table of Contents

Recommendation ITU-T G.107.2

Fullband E-model

1 Scope

This Recommendation describes the FB 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 NB (300-3400 Hz) and WB (50-7000 Hz) E-models, which are described in [ITU-T G.107] and [ITU-T G.107.1]. The FB version addresses scenarios which include FB (20-20000 Hz) transmission. It does not replace the NB or WB E-model. Instead, it describes a separate FB-version of the model that uses, within limits, similar concepts and input parameters as the NB and WB E-models. The current version only captures the effects of FB speech coding, voice-over-IP packet loss, and pure delay. Other degradations such as loudness loss, background noise at the sending side or receiving side, circuit noise, talker echo, listener echo, non-optimum sidetone levels and quantizing distortions have not yet been covered by the model.

Regarding the interpretation of the FB 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 FB version described here, but only to the NB 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 (2015), *The E-model: a computational model for use in transmission planning*.
<http://www.itu.int/rec/T-REC-G.107>

[ITU-T G.107.1] Recommendation ITU-T G.107.1 (2015), *Wideband E-model*.
<https://www.itu.int/rec/T-REC-G.107.1/en>

[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>

[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, has not yet been developed to an extent which would cover those characteristics in a. realistic way; most of its formulae, except the ones of Section 7.4, have been developed on the basis of subjective listening-only experiments. The model is also not intended to model transmission impairments during double talk situations. These effects are for further study within ITU-T Study Group 12.

[ITU-T G.722]	Recommendation ITU-T G.722 (2012), *7 kHz audio-coding within 64 kbit/s*. <http://www.itu.int/rec/T-REC-G.722>
[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>

3 Definitions

3.1 Terms defined elsewhere

None.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ACR	Absolute Category Rating
MOS	Mean Opinion Score
NB	Narrowband
SWB	Super-wideband
WB	Wideband

5 Conventions

None.

6 Fullband 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 FB E-model

For the narrowband (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 WB speech transmission channel, the quality is generally judged better than that for a NB channel. Thus, this scale range was extended in [ITU-T G.107.1] to a maximum value of $R = 129$ for a clean wideband (50-7000 Hz) channel, as it is defined in [ITU-T G.722]. In the present version, this scale was further extended to reflect the even higher quality of the fullband (20-20000 Hz) channel.

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 (ACR) 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]. 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]). The extension was 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].

The same principle was applied for extending the *R*-scale beyond the wideband case. First, mixed bandwidth databases that contain a direct super-wideband (SWB) (20-16000 Hz) condition, as well as NB/WB codecs for which the WB equipment impairment factor (*Ie,WB*) is known, have been identified. The subjective MOS values of the mixed-band conditions have been transformed to the R-scale with the transformations given in [ITU-T G.107] and [ITU-T G.107.1] which are valid for the NB and WB case. $R_{\mathrm{WB/SWB}}$ then presents the *R* values of the NB/WB/SWB mixed bandwidth database compressed onto the WB *R*-scale of [ITU-T G.107.1] (which is limited to 129), whereas R_{WB} presents their uncompressed R values. A simple linear regression was used to map the compressed $R_{\mathrm{WB/SWB}}$ values (derived from the subjective MOS) onto R_{WB} (derived from the equipment impairment factors). The linear regression was calculated without intercept term and therefore the estimation model goes through the origin. The R_{WB} value which corresponds to $R_{\mathrm{WB/SWB}}$ = 129 then corresponds to the maximum value *Rmax* of the R-scale in the SWB case. Figure 1 shows an exemplary extrapolation for one database.

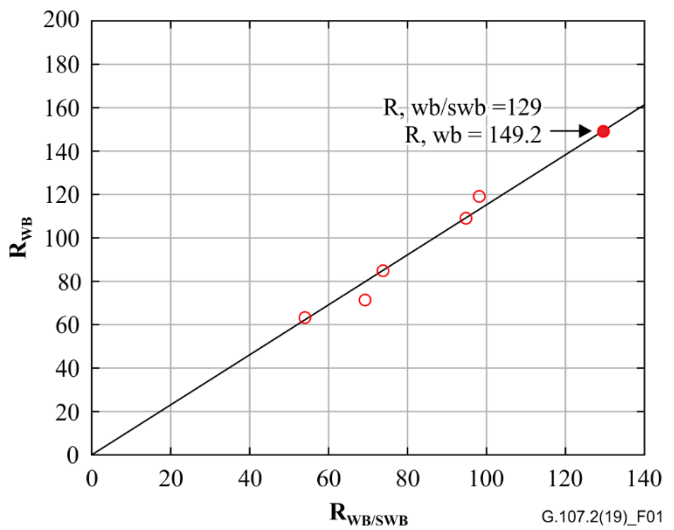

Figure 1 – Comparison between *R*-values derived in a NB/WB and in a mixed NB/WB/SWB context

Comparing the maximum *Rmax* values obtained with different databases, it was decided that a value of *Rmax* = 148 should be used as the maximum for a super-wideband case. As experimental evidence suggests that SWB and FB conditions are perceptually equivalent when being evaluated on a 5-point ACR scale according to [ITU-T P.800], it was decided to also use a value of *Rmax* = 148 in the fullband case.

It should be noted that the primary output of the FB 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 fullband E-model

The FB E-model is based on the equipment impairment factor method, following previous transmission rating models. The model estimates the conversational quality from mouth-to-ear as perceived by the user at the receive side, both as listener and talker.

The current version of the FB E-model only considers the effects of coding-decoding (codec) degradations, the effects of packet loss and discard in voice-over-IP telephony, as well as the effects of pure delay. It assumes that headsets with diotic listening are used at both sides of the connection.

7.1 Calculation of the transmission rating factor, *R*

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

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

Ro,FB represents in principle the basic signal-to-noise ratio. The factor *Is,FB* is a combination of all impairments which occur more or less simultaneously with the voice signal. The factor *Id,FB* represents the impairments occurring delayed with respect to the speech signal. The effective equipment impairment factor *Ie,eff,FB* represents impairments caused by low bit-rate codecs. It also includes impairment due to randomly distributed or bursty pack losses. The advantage factor *A* allows for compensation of impairment factors when the user benefits from other types of access. The following clauses give the equations used in the FB E-model.

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

The current version of the FB E-model does not yet consider noise sources, such as circuit noise, or background noise at the sending or receiving side. Thus, this value is only limited by the maximum value of the clean FB channel on the transmission rating scale:

$$Ro,FB = 148 \quad (7\text{-}2)$$

The integration of different noise sources into *Ro,FB* is an object for further study.

7.3 Simultaneous impairment factor, *Is,FB*

The factor *Is,FB* 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 FB case so far, thus it is set to:

$$Is,FB = 0 \quad (7\text{-}3)$$

7.4 Delay impairment factor, *Id,FB*

The factor *Id,FB*, represents all impairments due to delay of voice signals.

So far, only the contribution of pure delay, i.e., without echo, is addressed by the FB E-model. The contribution for pure delay is calculated from the overall one-way delay *Ta* as follows:

For $Ta \leq 100$ ms:

$$Idd = 0 \quad (7\text{-}4a)$$

For *Ta* > 100 ms:

$$Idd = 1.48 \cdot 25\left\{(1+X^6)^{\frac{1}{6}} - 3\left(1+\left[\frac{X}{3}\right]^6\right)^{\frac{1}{6}} + 2\right\} \qquad (7\text{-}4b)$$

with:

$$X = \frac{\log\left(\frac{Ta}{100}\right)}{\log 2} \qquad (7\text{-}5)$$

7.5 Effective equipment impairment factor, *Ie,eff,FB*

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

$$Ie,eff,FB = Ie,FB + (132 - Ie,FB) \cdot \frac{Ppl}{Ppl+Bpl} \qquad (7\text{-}6)$$

As can be seen from Equation 7-6, the effective equipment impairment factor in case of *Ppl* = 0 (no packet-loss) is equal to the *Ie,FB* value.

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

7.6 Advantage factor, *A*

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

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

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
Equipment impairment factor	*Ie,FB*	–	0	0 ... 120	(Note 2)
Packet-loss robustness factor	*Bpl*	–	4.3	7.4 ... 18	(Notes 1, 2)
Random packet-loss probability	*Ppl*	%	0	0 ... 20	(Notes 1, 2)
Overall one-way delay	*Ta*	ms	0	0 … 1700	
Advantage factor	A	–	0	0 ... 20	
NOTE 1 – Currently under study. NOTE 2 – 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 148, where *R* = 0 represents an extremely bad quality and *R* = 148 represents a very high quality in the FB case. An estimated mean opinion score (MOS_{CQEF}) for the conversational situation on the scale 1-5 can be obtained from the *R*-factor by using the equations:

$$Rx = \frac{R}{1.48} \quad \text{(A-1)}$$

For $Rx < 0$: $MOS_{CQEF} = 1$

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

For $Rx > 100$: $MOS_{CQEF} = 4.5$

Bibliography

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