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**GENERAL CHARACTERISTICS OF INTERNATIONAL TELEPHONE CONNECTIONS AND INTERNATIONAL TELEPHONE CIRCUITS**

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# PLANNING OF MIXED ANALOGUE – DIGITAL CIRCUITS (CHAINS, CONNECTIONS)

**Supplement 29 to**
**ITU-T Series G Recommendations**

(Previously "CCITT Recommendations")

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# FOREWORD

The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of the International Telecommunication Union. The ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Conference (WTSC), which meets every four years, established the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

Supplement 29 to ITU-T Series G Recommendations was revised by the ITU-T Study Group XII (1988-1993) and was approved by the WTSC (Helsinki, March 1-12, 1993).

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NOTES

1 As a consequence of a reform process within the International Telecommunication Union (ITU), the CCITT ceased to exist as of 28 February 1993. In its place, the ITU Telecommunication Standardization Sector (ITU-T) was created as of 1 March 1993. Similarly, in this reform process, the CCIR and the IFRB have been replaced by the Radiocommunication Sector.

In order not to delay publication of this Recommendation, no change has been made in the text to references containing the acronyms "CCITT, CCIR or IFRB" or their associated entities such as Plenary Assembly, Secretariat, etc. Future editions of this Recommendation will contain the proper terminology related to the new ITU structure.

2 In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

# CONTENTS


| | | Page |
|---|---|---|
| 1 | General | 1 |
| 2 | Planning principles | 1 |
| 3 | Objectives for the mixed analogue/digital chain of 4-wire circuits | 2 |
| | 3.4 Attenuation/frequency distortion | 2 |
| | 3.5 Group delay distortions | 3 |
| | 3.6 Non-linear distortions | 3 |
| | 3.7 Noise (total distortion) | 4 |
| | 3.8 Impulse noise | 7 |
| | 3.9 Short-time interruptions, phase jitter, amplitude and phase hits | 7 |
| | 3.10 Error performance | 7 |
| References | | 11 |
| Annex A – Definitions | | 11 |
| Appendix I – Influence of errors in digital 2048 kbit/s streams on the noise in voice-frequency mixed circuits | | 14 |
| | I.1 Introduction | 14 |
| | I.2 Noise power in a PCM voice-frequency circuit due to digital errors | 15 |
| | I.3 Conclusion | 18 |
| References (to Appendix I) | | 19 |
| Appendix II – Calculation method of MOS equivalent to noise due to quantization distortion | | 19 |
| Appendix III – The effect of errors in 2048 kbit/s digital streams on appearance of impulse noise in mixed voice-frequency circuits | | 20 |

# PLANNING OF MIXED ANALOGUE-DIGITAL CIRCUITS (CHAINS, CONNECTIONS)

*(Melbourne, 1988; amended at Helsinki, 1993)*

(referred to in Series G Recommendations)

## 1 General

In the period of transition from a fully analogue to a fully digital network, mixed analogue-digital circuits, chains and connections will take place on international and national networks for a fairly prolonged time.

The definition of notions of "mixed circuits, chains and connections" and examples of their possible structures are given in Annex A.

Structure of mixed circuits and moreover that of connections and chains, may be highly complex in comparison with circuits, chains and connections composed of transmission systems of one type (analogue or digital), that is, of homogeneous structure. The most favourable from the point of view of minimization of analogue-digital conversions is "overlay" strategy. Distortions and noise in mixed circuits to a great extent differ from those in circuits of the homogeneous structure, because in the case of mixed circuits distortions and noise typical for both analogue and digital transmission systems are combined taking into account the influence made on them by analogue-digital conversions. Measuring methods for distortions and noise in mixed circuits are of specific character as well. Factors mentioned above make the maintenance and operation of mixed circuits more complicated. Thus the task of developing planning rules for mixed circuits (chains, connections) becomes actual as well as studying the addition laws for distortions and noise.

## 2 Planning principles

Taking into account the above-mentioned, one should be guided by the following principles while planning mixed circuits:

– The number of analogue-digital conversions in mixed circuits, chains and connections should be as minimal as possible.

  For the purposes of minimization of analogue-digital conversions in mixed circuits, chains, connections, "overlay" strategy serves in the best way in the period of transition to a digital network.

– Quality of transmission on mixed circuits (chains, connections) should not deteriorate as compared to quality adopted by CCITT for analogue circuits. The objectives recommended for analogue circuits as a rule are observed.

  With this end in view when providing the mixed circuits (chains, connections), it is necessary to try to use the equipment of analogue and digital transmission systems, the distortion characteristics of which have some margin in relation to those ones which had been recommended by CCITT when designing this equipment based on the conditions of its application only in circuits of homogeneous structures. This primarily applies to such distortions as amplitude/frequency distortion, quantizing noise, non-linear distortions.

– For transmission planning to use the rating "Total distortion (noise)" which allows to define the permissible number of analogue-digital conversions at the specified length of an analogue portion of a mixed circuit or on the contrary, at the specified number of analogue-digital conversions to define the permissible length of an analogue portion of a mixed circuit.

  The procedure of using the rating "Total distortions (noise)" for planning the mixed circuits as well as the objectives for different parameters of mixed circuits are given below in clause 3.

## 3 Objectives for the mixed analogue/digital chain of 4-wire circuits

**3.1** Objectives for some mixed circuit parameters are contained in a number of G-, Q-, and M-Series Recommendations. However, these objectives do not take due account of the addition laws for distortions based on the multitude of mixed circuit structures and specific features of the measuring methods involved.

Considering the importance of retaining the transmission quality during the transition period and attaching great importance to the standardization of mixed analogue/digital circuits the multitudinous types of which emerge while using various kinds of analogue-to-digital conversions, it is worthwhile to have objectives for mixed analogue/digital circuits and 4-wire chains including both analogue and digital circuits.

The present objectives related to mixed 4-wire chain of circuits and the analogue/digital mixed connections arc those with analogue telephone sets at both ends.

It is based on the existing Recommendations for FDM channel equipment G.232, for PCM channel equipment G.712, for analogue switching centres Q.45, Q.45 *bis*, for digital switching centres Q.551 to Q.554, and takes account of other existing Recommendations of G- and M-Series.

Later on in accordance with the study results the present objectives will have to be supplemented by objectives for mixed chain of circuits formed with the help of various methods of analogue-to-digital conversion such as transmultiplexers (see Recommendations G.793, G.794), modems (see Recommendations G.941, V.37), transcoders (see Recommendation G.761), group codecs (see Recommendation G.795), DCME, as well as connections with a digital telephone at one end and an analogue telephone at the other end.

**3.2** Objectives for the nominal value of the input/output impedance return loss, unbalance loss in respect of earth, nominal re levels can be found in Recommendations for switching equipment (see Q.45, Q.45 *bis*, Q.553), for FDM channel equipment (see G.232) and for PCM channel equipment (see G.712).

**3.3** Objective for variations of transmission loss with time, single tone interference, products of unwanted modulation, intelligible crosstalk can be found in Recommendation G.151.

NOTES

1 For mixed chains the stability conditions improve on the one hand because of the existence of digital sections which have a higher stability than analogue ones, but on the other hand in the mixed circuits there is no possibility of a transit automatic regulation of analogue sections which deteriorates the overall stability.

2 Measurement of signal-to-crosstalk ratio between circuits can be performed without feeding an auxiliary signal into a channel affected by crosstalk (unlike that provided for in the Recommendation G.712). This can be explained by the fact that in a mixed circuits, as a rule, an analogue circuit noise will be presented at the input of analogue/digital converters.

3 The level of the interference at the sampling frequency should not exceed the value of $-50 + 10 \log n_2$ where $n_2$ is the number of analogue/digital converters.

### 3.4 Attenuation/frequency distortion

Attenuation/frequency distortion for the whole 4-wire chain should not exceed the values given in Figure 1/G.132.

For mixed chains (without consideration or switching centre distortions) the accumulation law of attenuation/frequency distortions is expressed by the following formula:

$$\Delta a = n_1 \, \overline{a}_{\mathrm{FDM}} + \sum_{i=1}^{n_2} a_{i\mathrm{PCM}} \pm \mathrm{K} \sqrt{\sigma^2 \mathrm{FDM} \cdot n_1} \qquad (3\text{-}1)$$

where

$n_1$ number of analogue sections;

$n_2$ number or analogue/digital conversions;

$\overline{a}_{\mathrm{FDM}}$ average value (determined component) of attenuation/frequency distortions of the analogue sections;

$\sigma_{FDM}$ r.m.s. deviation of attenuation/frequency distortions of analogue sections;

$a_{PCM}$ attenuation/frequency characteristics of analogue/digital equipment;

K = 1, 2 or 3 factor defining the probability or maximum/minimum value or attenuation/frequency distortions.

"K" is usually taken as equal to 3. The justification or the choice for K = 3 depending on a given probability can be found in [1, 2].

NOTES

1 Attenuation/frequency characteristics or analogue/digital equipment or the same type are similar. That is why, if in a mixed/chain of circuits analogue/digital equipment or the same type is used, the sum formula [2, 3]

$$\sum_{i=1}^{n_2} a_{iPCM}$$

can be replaced by a product $n_2\ a_{PCM}$.

2 The analogue-digital equipment distortion limits recommended in 1/G.712 and Figure 1/G.712 and the FDM-channel equipment distortion limits recommended in 1/G.232 and Figure 1/G.232 meet the limits indicated in Recommendation G.132 for mixed circuits in which the number of sections does not exceed 4.

When composing mixed chains with 2 greater number of sections, it is advisable to utilize modern channel equipment the attenuation/frequency distortions of which are considerably lower than those indicated in Recommendations G.232 and G.712.

3 Attenuation/frequency distortions are measured relative to a reference frequency of 1020 (1000) Hz.

4 See 3.4/Q.45 and Recommendation Q.553 to take account of the switching equipment distortions. Some additional information is to be found also in [4].

### 3.5 Group delay distortions

Group delay distortions should not exceed the values indicated in Recommendation G.133 for the 4-wire chain.

The law of imposition of group delay distortions is expressed by the following formula:

$$\Delta_\tau = n_1\ \tau_{FDM} + \sum_{i=1}^{n_2} \tau_{iPCM} \qquad (3\text{-}2)$$

where

$n_1$ the number of analogue sections;

$n_2$ the number of analogue/digital conversions.

NOTES

1 If, in a mixed chain, analogue/digital equipment of the same type is used, then the sum

$$\sum_{i=1}^{n_2} \tau_{iPCM}$$

is substituted by a product $n_2 \cdot \tau_{PCM}$

2 It is expected that the group delay distortion in mixed chains will be less than that of a fully analogue link of any combination of analogue and digital sections. But nevertheless the characteristics of distortion (symmetry) can change considerably. This should be taken into account when transmitting data on mixed circuits containing group delay equalizers.

3 Group delay distortions art measured with reference – to a frequency situated at the lower band end of the analogue channel, i.e. 190-200 Hz.

4 Switching centre distortions are negligible and can be ignored.

### 3.6 Non-linear distortions

The existing Recommendations for analogue circuits (see 2.11/M.1020), for switching equipment (see 6.1/Q.45) and Recommendation G.712 for analogue/digital equipment contain different specifications for non-linear distortions, the methods of their measurement differ too. The Recommendations for digital centres (Q.551 to Q.554) do not contain specifications for non-linear distortions.

At present it is not possible to recommend permissible values of non-linear distortions and a method for measuring mixed chains of circuits. This question needs to be studied.

### 3.7 Noise (total distortion)

The notion of noise in mixed circuits due to analogue-to-digital conversions producing quantization distortions which accompany the signal has lost its initial meaning and therefore instead of the term "noise" applicable to mixed circuits the term "total distortions" is very often used. This is stipulated by the fact that the measurement of quantization distortions (Recommendation Q.132) includes part of non-linear distortions and single-frequency interferences.

Total distortions in mixed circuits include analogue section noise which depends on the length of the sections in case of terrestrial transmission systems and the quantization distortions which are determined by the number and type of analogue-to-digital conversions and noise due to digital errors in the digital section which depends on the average bit error ratio.

The addition law of total distortions is expressed by the following formula:

$$P_{\Sigma} = 10 \lg (10^{-9} W_{FDH} + W_q \cdot m + W_e) \text{ (dBm0p)}$$

where:

$W_{FDM}$ is the psophometric noise power of analogue sections (pW0p);

$W_{FDM} = W_0 L$; $W_0$ is expressed at $\frac{pW0p}{km}$, L in km.

$W_q$ is the psophometric quantization distortion power of one 8 bit analogue-to-digital conversion (mW0p) when total distortion is measured with test signal:

$$W_q = 10^{0.1} [S - (S/N)] \text{ (mW0p)}$$

S is the test signal level of the frequency 1000 Hz (dBm0). To eliminate non-linear distortion the value of S should be no more than –10 dbm0 (S/N) signal-to-quantization distortion ratio.

When distortions are measured without test signal that:

$W_q$ is the unloaded codec noise power (idle circuit noise) according to Recommendation G.712;

m total number of Quantization Distortion Units (qdu's) according to Recommendation G.113;

$W_e$ psophometric noise power due to digital errors in the 2048 kbit/s stream with frame structure according to Recommendation G.732 (mW0p):

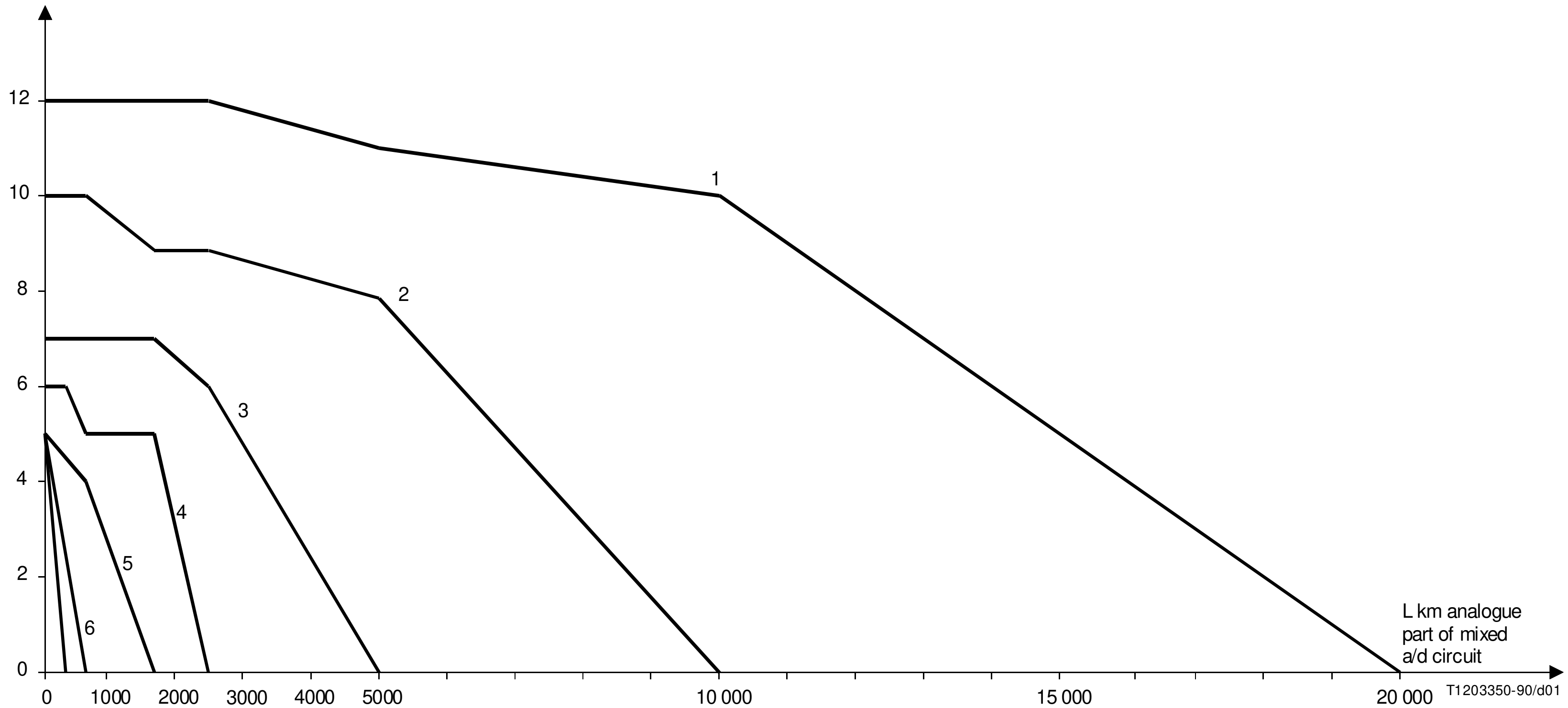
$$W_e = 10^{0.1 P_e}$$

$P_e$ noise power level due to digital errors is determined in Appendix I.

The permissible value of $P_{\Sigma}$ is determined from the necessity of providing the same transmission quality over mixed analogue/digital circuits as over the FDM circuits. This means that in case of the equal lengths of a Mixed analogue/digital circuit and an FDM circuit the permissible level of total distortions $P_{\Sigma}$ should not exceed the noise level in the FDM circuit. And in addition to these effects of influence of quantization distortion, caused by codecs, on the transmitted signal should be taken into account. Table II.1 gives the dependence of speech level-to-white noise level ratio on the number of codecs obtained on the basis of MOS-equivalent method. Based on this dependence, the Table 1 shows level values of total distortion $P_{\Sigma}$ in a mixed circuit for various numbers of codecs and various lengths of the analogue part. Taking the value of $P_{\Sigma}$ as being equal to the value of noise in the FDM circuit which corresponds to the length of a mixed analogue/digital circuit one can determine the permissible number of codecs in a mixed circuit in case of the specified length of the analogue part, or vice-versa, in case of the specified number of codecs one can determine the permissible length of the analogue part. The equivalent noise curves which are built based on the data from Table are given in Figure 1. It follows from this Figure for instance that if the total length of a mixed circuit is 20 000 km (curve 1) and length of the analogue part is 5000 km, then not more than 11 analogue/digital conversion of 8 bit PCM (11 qdu) are permissible.

TABLE 1

| | qdu | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L km | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 0 | 0 | –76.8 | –66.6 | –61.0 | –56.7 | –53.6 | –50.8 | –48.5 | –46.5 | –44.8 | –43.4 | –42.0 | –40.9 | –39.7 | –38.6 |
| 320 | –55 | –55 | –54.7 | –54 | –52.8 | –51.2 | –49.4 | –47.6 | –45.9 | –44.4 | –43.2 | –41.8 | –40.8 | –39.6 | –38.6 |
| 321<br>640 | –53 | –53 | –52.8 | –52.3 | –51.5 | –50.3 | –48.7 | –47.2 | –45.6 | –44.2 | –43 | –41.7 | –40.7 | –39.5 | –38.5 |
| 641<br>1600 | –51 | –51 | –50.9 | –50.6 | –50 | –49.1 | –47.9 | –46.5 | –45.1 | –43.9 | –42.8 | –41.5 | –40.5 | –39.4 | –38.4 |
| 1601<br>2500 | –49 | –49 | –48.9 | –48.7 | –48.3 | –47.7 | –46.8 | –45.7 | –44.6 | –43.4 | –42.4 | –41.2 | –40.3 | –39.2 | –38.1 |
| 2501<br>5000 | –46 | –46 | –46 | –45.9 | –45.6 | –45.3 | –44.8 | –44.1 | –43.2 | –42.3 | –41.5 | –40.6 | –39.7 | –38.8 | –37.9 |
| 5001<br>10 000 | –43 | –43 | –43 | –43 | –42.9 | –42.6 | –42.3 | –41.9 | –41.4 | –40.8 | –40.2 | –39.5 | –38.9 | –38.1 | –37.2 |
| 10 001<br>20 000 | –40 | –40 | –40 | –40 | –39.9 | –39.8 | –39.7 | –39.4 | –39.1 | –38.7 | –38.4 | –37.9 | –37.4 | –36.8 | –36.9 |




1 – all length of mixed a/d circuit = 20 000 km
2 – all length of mixed a/d circuit = 10 000 km
3 – all length of mixed a/d circuit = 5 000 km
4 – all length of mixed a/d circuit = 2 500 km
5 – all length of mixed a/d circuit = 1 600 km
6 – all length of mixed a/d circuit = 640 km
7 – all length of mixed a/d circuit = < 320 km

FIGURE 1

The value of total distortion for non speech transmission for various length analogue part, various numbers of qdu's and various numbers of BER are available in Tables 2, 3, 4.

If BER at each digital part is better than $10^{-6}$ (with the bit rate of 2048 kbit/s) the component $W_e$ can be omitted.

NOTES

1 For a satellite part the terrestrial lengths is taken to be equal to 2500 km.

2 In determining total distortions additional noise should be taken into consideration which can be caused by deviation in transmission level and impedance from nominal values. The limit values are given in [5].

### 3.8 Impulse noise

The impulse noise is specified for analogue circuits used for data transmission (see Recommendations M.1020, M.1025) and for switching equipment (see 5.2/Q.45 and Recommendation Q.553). For voice-frequency PCM transmission system, the impulse noise is not specified because it is supposed that it should not be there at all.

In practice it has been noticed however that with accumulation of errors in digital streams the impulse noise can appear in a voice-frequency circuit which leads to interference in data transmission.

Table III-1 shows the dependence of the number of impulse noise having duration of more than 30 ms in a PCM voice-frequency circuit with the analysis threshold of –21 dBm0 during 15 minute measuring intervals on an average bit error rate and the number of packetized errors in a 2048 kbit/s stream.

It could be seen, that in the case if an average bit error rate at each digital section is less than $10^{-6}$ the objective of Recommendations M.1020 and M.1025 is not exceeded, and thus the influence of a digital section within a voice-frequency mixed chain of circuits could be neglected.

Additional information can be found in [6].

### 3.9 Short-time interruptions, phase jitter, amplitude and phase hits

These parameters strongly influence data transmission. For analogue circuits they are specified in Recommendations M.1020, M.1060 and M.910. For voice-frequency circuits set up on PCM systems. objectives are not available. It can be tentatively presumed that in mixed chains of circuits the presence of digital sections does not have a considerable effect. However, the question needs to be studied.

### 3.10 Error performance

Further study.

TABLE 2

**Total distortion level in mixed circuit with test signal (dBm0p) –**
**Test signal: 1000 Hz; –10 dBm0**

| qdu | <320 km | | | | 321 to 640 km | | | | 641 to 1600 km | | | | 1601 to 2500 km | | | | 2501 to 5000 km | | | | 5001 to 10 000 km | | | | 10 001 to 20 000 km | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ |
| 0 | –55 | | | | –53 | | | | –51 | | | | –49 | | | | –46 | | | | –43 | | | | –40 | | | |
| 0.5 | –45 | –44 | –40 | –32 | –45 | –44 | –40 | –32 | –44 | –43 | –40 | –32 | –44 | –43 | –40 | –32 | –43 | –42.5 | –40 | –32 | –41 | –41 | –39 | –32 | –39 | –38 | –37 | –32 |
| 1 | –43 | –42.5 | –40 | –32 | –43 | –42.5 | –40 | –32 | –42 | –42 | –40 | –32 | –42 | –42 | –39 | –32 | –41 | –41 | –39 | –40 | –40 | –40 | –38 | –32 | –32 | –38 | –37 | –31 |
| 2 | –40 | –40 | –38 | –32 | –40 | –40 | –38 | –32 | –40 | –40 | –38 | –32 | –39 | –39 | –37 | –32 | –39 | –38 | –37 | –31.5 | –38 | –38 | –37 | –31 | –37 | –37 | –36 | –31 |
| 3 | –38 | –38 | –37 | –31 | –38 | –38 | –37 | –31 | –38 | –38 | –37 | –31 | –38 | –38 | –37 | –31 | –38 | –38 | –37 | –31 | –37 | –37 | –36 | –31 | –36 | –36 | –35 | –31 |
| 3.5 | –37 | –37 | –36 | –31 | –37 | –37 | –36 | –31 | –37 | –37 | –36 | –31 | –37 | –37 | –36 | –31 | –37 | –37 | –36 | –31 | –36 | –36 | –35 | –31 | –36 | –36 | –35 | –31 |
| 4 | –37 | –37 | –36 | –31 | –37 | –37 | –36 | –31 | –37 | –37 | –36 | –31 | –37 | –37 | –36 | –31 | –36 | –36 | –35 | –31 | –36 | –36 | –35 | –31 | –35 | –35 | –34 | –30.5 |

TABLE 3

**Total distortion level in mixed circuit with test signal (dBm0p) –**
**Test signal: 1000 Hz; –25 dBm**

| qdu | <320 km | | | | 321 to 640 km | | | | 641 to 1600 km | | | | 1601 to 2500 km | | | | 2501 to 5000 km | | | | 5001 to 10 000 km | | | | 10 001 to 20 000 km | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ |
| 0 | –55 | | | | –53 | | | | –51 | | | | –49 | | | | –46 | | | | –43 | | | | –40 | | | |
| 0.5 | –54 | –52 | –45.5 | –33 | –52 | –49.5 | –45 | –33 | –51 | –50 | –48 | –33 | –49 | –48 | –44 | –33 | –46 | –46 | –43 | –33 | –43 | –43 | –41 | –33 | –40 | –40 | –39 | –32 |
| 1 | –53 | –51 | –45 | –33 | –52 | –49.5 | –45 | –33 | –50 | –49 | –44.5 | –33 | –48 | –47 | –44 | –33 | –46 | –46 | –43 | –33 | –43 | –43 | –41 | –33 | –40 | –40 | –39 | –32 |
| 2 | –52 | –49.5 | –45 | –33 | –51 | –50 | –45 | –33 | –50 | –49 | –44.5 | –33 | –48 | –47 | –44 | –33 | –45 | –45 | –42.5 | –33 | –43 | –43 | –41 | –33 | –40 | –40 | –39 | –32 |
| 3 | –51 | –50 | –45 | –33 | –50 | –49 | –44.5 | –33 | –49 | –48 | –44 | –33 | –48 | –47 | –44 | –33 | –45 | –45 | –42.5 | –33 | –43 | –43 | –41 | –33 | –40 | –40 | –39 | –32 |
| 3.5 | –51 | –50 | –45 | –33 | –50 | –49 | –44.5 | –33 | –49 | –48 | –44 | –33 | –47 | –46.5 | –43.5 | –33 | –45 | –45 | –42.5 | –33 | –43 | –43 | –41 | –33 | –40 | –40 | –39 | –32 |
| 4 | –50 | –49 | –44.5 | –33 | –49 | –48 | –44 | –33 | –48 | –47 | –44 | –33 | –47 | –46.5 | –43.5 | –33 | –45 | –45 | –42.5 | –33 | –42 | –42 | –40.5 | –33 | –40 | –40 | –39 | –32 |

TABLE 4

**Total distortion level in mixed idle circuits (dBm0p)**

| qdu | <320 km | | | | 321 to 640 km | | | | 641 to 1600 km | | | | 1601 to 2500 km | | | | 2501 to 5000 km | | | | 5001 to 10 000 km | | | | 10 001 to 20 000 km | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ | BER = $10^{-\infty}$ | BER = $10^{-5}$ | BER = $10^{-4}$ | BER = $10^{-3}$ |
| 0 | –55 | | | | –53 | | | | –51 | | | | –49 | | | | –46 | | | | –43 | | | | –40 | | | |
| 0.5 | –55 | –51 | –46 | –32 | –53 | –50 | –46 | –32 | –51 | –49 | –45 | –32 | –49 | –47 | –45 | –32 | –46 | –45 | –43 | –32 | –43 | –43 | –41 | –32 | –40 | –40 | –39 | –32 |
| 1 | –55 | –51 | –46 | –32 | –53 | –50 | –46 | –32 | –51 | –49 | –45 | –32 | –49 | –47 | –45 | –32 | –46 | –45 | –43 | –32 | –43 | –43 | –41 | –32 | –40 | –40 | –39 | –32 |
| 2 | –55 | –51 | –46 | –32 | –53 | –50 | –46 | –32 | –51 | –49 | –45 | –32 | –49 | –47 | –45 | –32 | –46 | –45 | –43 | –32 | –43 | –43 | –41 | –32 | –40 | –40 | –39 | –32 |
| 3 | –55 | –51 | –46 | –32 | –53 | –50 | –46 | –32 | –51 | –49 | –45 | –32 | –49 | –47 | –45 | –32 | –46 | –45 | –43 | –32 | –43 | –43 | –41 | –32 | –40 | –40 | –39 | –32 |
| 3.5 | –55 | –51 | –46 | –32 | –53 | –50 | –46 | –32 | –51 | –49 | –45 | –32 | –49 | –47 | –45 | –32 | –46 | –45 | –43 | –32 | –43 | –43 | –41 | –32 | –40 | –40 | –39 | –32 |
| 4 | –54 | –50 | –46 | –32 | –52 | –49 | –45 | –32 | –51 | –49 | –45 | –32 | –49 | –47 | –45 | –32 | –46 | –45 | –43 | –32 | –43 | –43 | –41 | –32 | –40 | –40 | –39 | –32 |

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[1] GAS 9 *Economic and technical aspects of the transition from analogue to digital telecommunication networks*, 1984

[2] MOSKVITIN (V. D.): Opredelenije trebovanij k chastotnym kharakteristikam zvenjev sostavnykh kanalov i traktov. (Specification of requirements for attenuation frequency distortions in sections of composite circuits and links). *Elektroviaz*, No. 11, 1969.

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[4] COM XII-19 *USSR Attenuation/frequency distortions and delay distortions or mixed audiofrequency analogue/digital circuits*, 1985-1988.

[5] CCITT Delayed Contribution D.25 Noise and total distortion in Recommendation G.712, G.713, G.714, G.715, Q.551, Q.552 and Q.553, FRG, 1990.

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## Annex A

(to Supplement 29)

## Definitions

The definition of notions: “channel”, “circuit”, “section”, “chain”, “connection” and “mixed analogue-digital channel (circuit)”, “mixed analogue-digital chain”, “mixed analogue-digital connection”.

**Channel** – IEC vocabulary (701.02.01)

**(transmission) channel:** A means of transmission signals in one direction between two points.

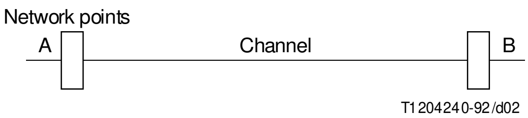


FIGURE A.1

**Circuit** – IEC vocabulary (701.02.03)

**(telecommunication) circuit:** A combination of two transmission channels permitting transmission in both directions between two points.

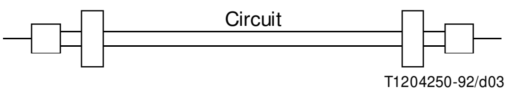


FIGURE A.2

**section:** Channel (circuit) portion between two adjacent points where signal (time or frequence) conversion is performed.

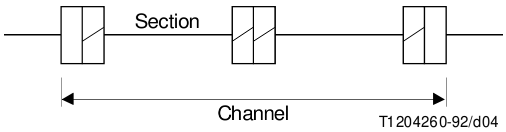


FIGURE A.3

**chain:** Several channels (circuits) connected with each other in sequence.


FIGURE A.4

**connection:** Recommendation P.10 definition 21.02, IEC vocabulary 701.03.01)

A temporary association of transmission channels or telecommunication circuits, switching and other functional units set up to provide the means of a transfer of information between two or more points in a telecommunication network.

NOTE – A connection is the result of a switching operation.

For the purpose of this Supplement, one should consider as a connection the connection between users' terminals. According to IEC vocabulary such connection is called "complete connection" (IEC dictionary 701.03.02). Connection is a chain between two users' terminals.

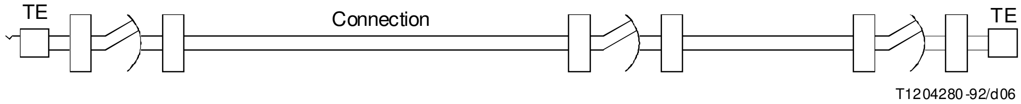


FIGURE A.5

**mixed analogue-digital channel (circuit):** A channel (circuit) comprising analogue-digital (digital-analogue) conversion. If one-type transmission channel is provided (only digital or only analogue) then analogue-digital (digital-analogue) conversion is possible only at the ends of the channel (channel translation equipment in accordance with Recommendation G.712, transmultiplexor in accordance with Recommendations G.793 and G.794). If the channel is made of separate sections of analogue and digital transmission systems then analogue-digital (digital-analogue) conversion is possible in its separate sections (group modems are in accordance with Recommendation G.941, V.37, transcoders are in accordance with Recommendation G.761, group codecs are in accordance with Recommendation G.795).

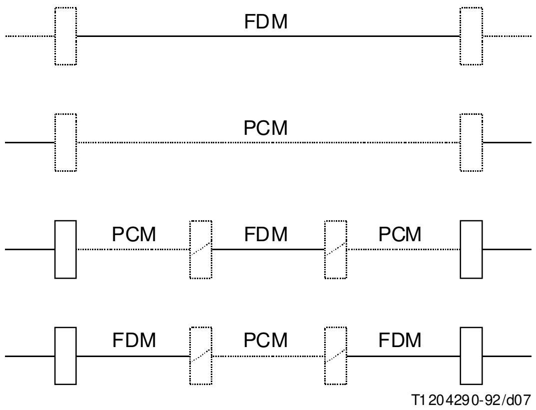


FIGURE A.6

**Examples of mixed analogue-digital channels (circuits)**

**mixed analogue-digital chain:** Several channels (circuits), all or part of which are mixed channels (circuits), connected with each other in sequence.

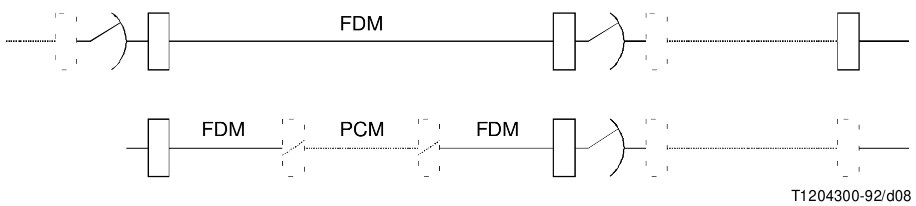


FIGURE A.7

**Examples of mixed analogue-digital chains**

**mixed analogue-digital connection:** Mixed analogue-digital chain between two user's terminals.

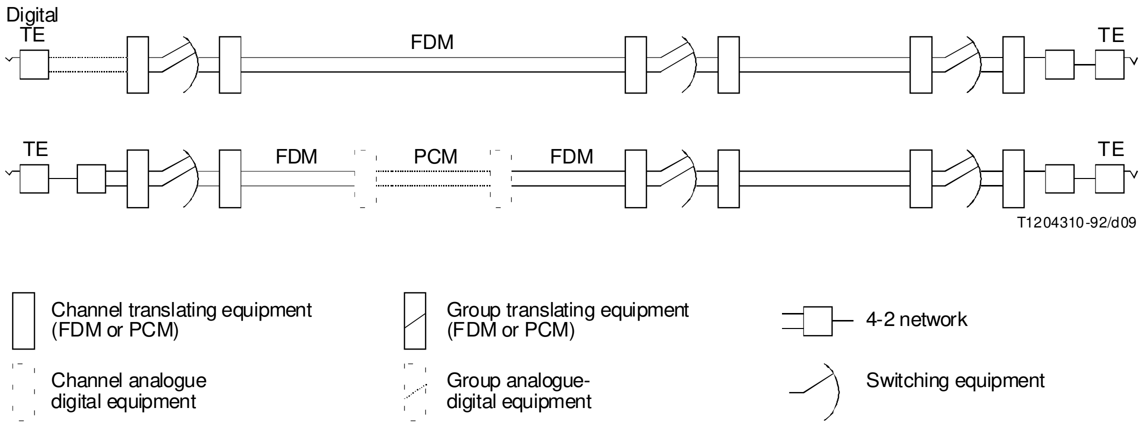


FIGURE A.8

**Examples of mixed analogue-digital connections**

## Appendix I

(to Supplement 29)

SOURCE: USSR TELECOMMUNICATIONS ADMINISTRATION

TITLE: INFLUENCE OF ERRORS IN DIGITAL 2048 kbit/s STREAMS ON THE NOISE IN VOICE-FREQUENCY MIXED CIRCUITS

### I.1 Introduction

The quality of PCM circuits is influenced by digital errors appearing in the digital streams. The digital errors influence many parameters of a voice-frequency circuit, including noise.

This appendix considers the effects of digital errors on the noise in a voice-frequency circuit of a PCM system in case of sending a sinusoidal signal of 1000 Hz with various levels and on the noise in an idle PCM circuit.

## I.2 Noise power in a PCM voice-frequency circuit due to digital errors

### I.2.1 Noise power due to digital errors in case of sending test signal

The evaluation of the noise power due to digital errors was made with the help of the formula obtained in [1]:

$$W = \sum_{e=1}^{255} P_e \sum_{i=0}^{255} f(V_i)\, a(V_i) \qquad \text{(I-1)}$$

where

$P_e$ is probability of an error combination;

$f(V_i)$ is probability distribution density of the input signal levels;

$V_i$ is the *i*th value of the voltage of the quantized input signal (*V*);

$V_{i,e}$ is an error value of the voltage at the codec output corresponding to (an error combination (*V*).)

$a(V_i) = \dfrac{10^{12}\,(V_i - V_{i,e})^2}{600}$ instantaneous power of the noise because of digital errors (pW0).

The probability of an error combination $P_e$ was determined based on computer-simulation of errors in a 2048 kbit/s stream with the frame structure corresponding to G.732 on the assumption that for 2048 kbit/s transmission systems these errors get combined into packets and have a distribution very near to the Neuman distribution, but for the transmission systems with a line speed of more than 2048 kbit/s the errors in the 2048 kbit/s stream are independent and they are distributed in accordance with the binomial law.

The probability of the number ($K$) of independent errors distributed in accordance with binomial law within the time $T_0$ was determined with the help of Poisson formula:

$$P(K) = e^{-M}\,\frac{M^K}{K!} \qquad \text{(I-2)}$$

The probability of the number ($K$) of packet errors distributed according to the Neuman law within the time $T_0$ was determined with the help of formula [2]:

$$P(k) = e^{-m_1}\,\frac{(m_2)^k}{k!} \sum_{u=1}^{\infty} \frac{(m_1 e^{-m_2})^u}{u!}\, u^k \qquad \text{(I-3)}$$

In formulae (I-2) and (I-3):

$m_1$ is the average number of error packets within the time $T_{0i}$.

$m_2$ is the average number of error bits in a packet.

$M$ is the average number of errors within the time $T_{0i}$:

$$M = M_1 \times m_2 = n \times \overline{\text{BER}}$$

$n$ is the number of bits transmitted within the time $T_0$.

$\overline{\text{BER}}$ is the average long-time bit error rate.

$u$ is the number of packets within the time $T_{0i}$.

$k$ is the number of errors within the time $T_{0i}$.

For simulation purposes the following parameters have been used as input parameters:

- $T_0$ is the duration of one cycle, $T_0 = 24 \times 3600[S]$,
- $T$ is the total time of the process, $T = 30 \times 24 \times 3600[S]$,
- $\overline{\text{BER}}$ is long-time bit error rate $10^{-3}$, $10^{-4}$, $10^{-5}$, $10^{-6}$, $10^{-7}$, $10^{-8}$.
- $m_2$ is the average number of error bits in one packet = [5, 10, 20, 50, 100, 200, 500, 1000].

The probability of error combinations in a channel interval was determined for each frame. The value obtained in each frame was then averaged for the total time of the process.

The instantaneous power of the noise $a(V_i)$ due to digital errors was determined on the output of decoder for the A-law of companding for each of 8 discretes of sinusoidal signal with a frequency of 1000 Hz within the range of levels $S$ from –45 up to 0 dBm0. Then the level of psophometric noise power was determined $P$ (dBm0p).

The calculation results are given in Figures I.1, I.2 and I.3. Figures I.1 and I.2 show the change of the psophometric power level $P$ due to the packet errors, the average number of errors in a packet being equal to $m_2 = 5$ (Figure I.1), and $m_2 = 200$ (Figure I.2).

The calculation results have shown that the worst case average number of error bits in a packet is approximately equal to 5 – 10. With this value of $m_2$ the psophometric power level makes –25 ÷ –35 dBm0p when the average long-time BER is $10^{-3}$, and –48 ÷ –52 dBm0p when the average long-time BER is $10^{-5}$. The lowest noise level corresponds to the input signal level of $S = -10$ dBm0. The value of psophometric noise power level with $m_2 = 200$ is by 10 – 15 dB lower than the values of the noise level corresponding to $m_2 = 5$ in case of the same average long-time bit error rates. The minimum value of the noise level corresponds to the input signal level of $S = -25$ dBm0.

The results of the noise level calculation in case of independent errors (Figure 3) show that the higher the level of the input signal the greater the noise level.

With changes of the input signal level from –45 to 0 dBm0 the noise power level gets increased by approximately 20 dB.

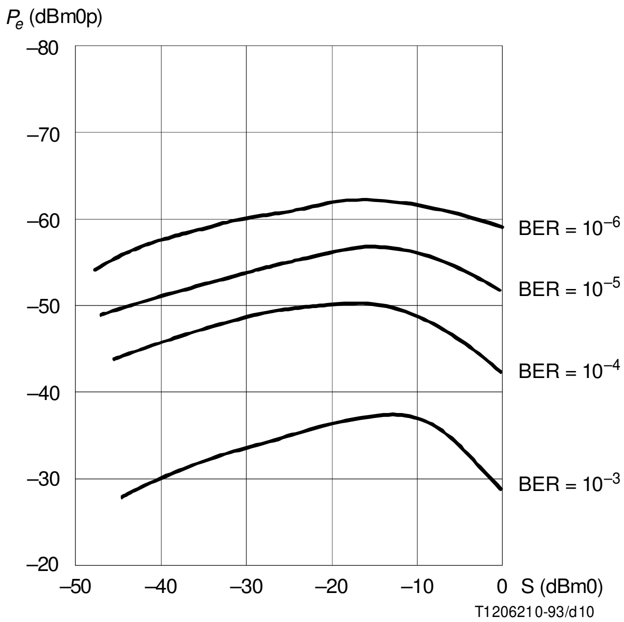


FIGURE I.1

**Neuman distribution, average number of errors in the packets equals 5**

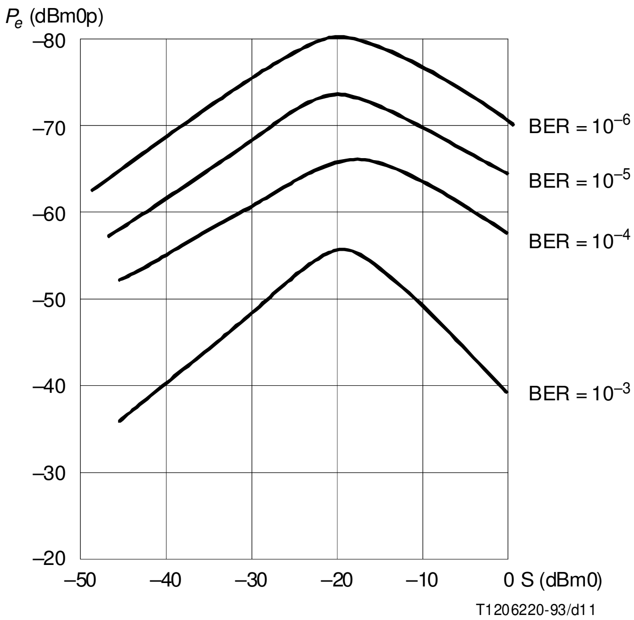


FIGURE I.2

**Neuman distribution, average number of errors in the packets equals 200**

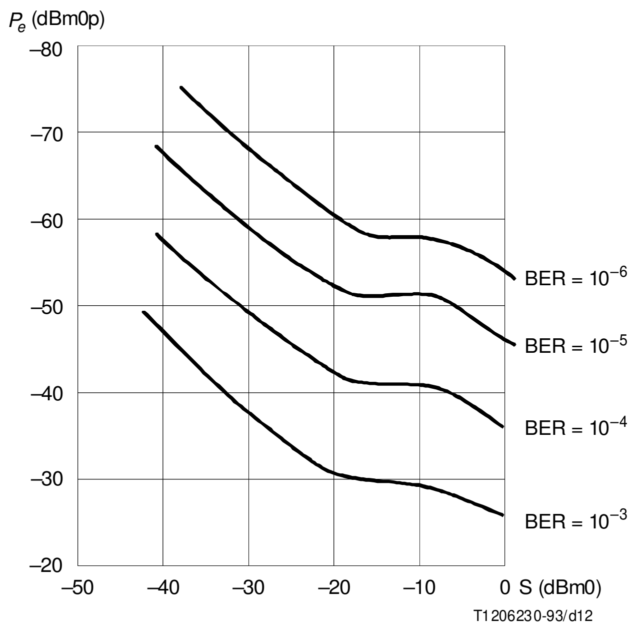


FIGURE I.3

**Binomial distribution**

#### I.2.2 Noise power caused by digital errors in an idle channel

The evaluation of the noise power due to digital errors was made with the formula:

$$W = \sum_{e=1}^{255} P_e \, a(V_0) \qquad \text{(I-4)}$$

where

$$a(V_0) = \frac{10^{12} \, (V_0 - V_{i,e})}{600}$$ is instantaneous noise power due to digital errors in an idle channel

$P_e$ – the same as in (I-1).

The calculation results of the noise power level due to errors in the 2048 kbit/s stream for various average long-term bit error rates are given in Figure I.4. The most unfavourable influence on the noise in an idle channel is caused by packet errors, and as to independent errors in the 2048 kbit/s stream they should be taken into account only when $\overline{\text{BER}} \geq 10^{-4}$.

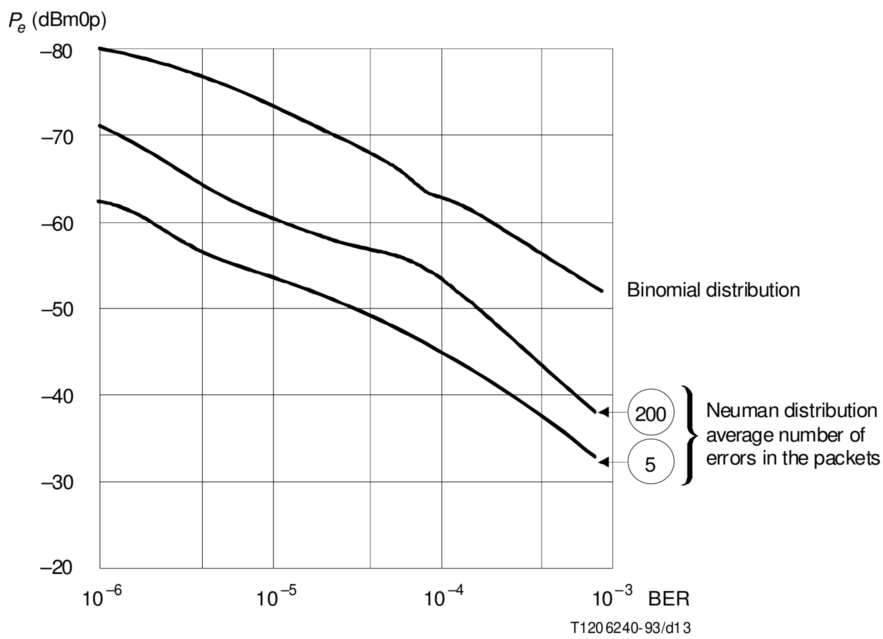


FIGURE I.4

## I.3 Conclusion

This calculation of the noise power level in a PCM voice-frequency circuit due to errors in a 2048 kbit/s stream has shown that this level depends on three factors: the error distribution law, the average bit error rate and the test signal level. Besides that the packet errors contribute more to the noise of an idle circuit, and independent errors to the noise in the circuit when a test signal is fed.

The worst packeting coefficient is equal to 5 – 10. In case of independent errors the noise level in the circuit with a test signal will grow with the increase of the test signal level. For packet errors, depending on the packeting coefficient, there is a certain test signal level associated with the lowest noise level in the circuit.

**References** (to Appendix I)


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# Appendix II

(to Supplement 29)

SOURCE: NTT (JAPAN)

TITLE: CALCULATION METHOD OF MOS EQUIVALENT TO NOISE DUE TO QUANTIZATION DISTORTION

MOS equivalent to noise due to quantization distortions of m-tandem PCM 8-bit codecs is shown by the following formula:

$$10^{0.1\,[S\ -\ S/No]} \qquad [mW0p]$$

where:

S/No: Signal to opinion white noise equivalence ratio is shown in Table II.1 in terms of qdu numbers (m); and

S: Speech level, equal to –17 dBm0;

No: White noise level [dBm0p].

TABLE II-1

**qdu number (m) and signal-to-opinion white noise equivalence ratio**

| m (qdu) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S/No (dB) | 59.8 | 49.6 | 44.0 | 39.7 | 36.6 | 33.8 | 31.5 | 29.5 | 27.8 | 26.4 | 25.0 | 23.9 | 22.7 | 21.6 | 20.5 |
| NOTE – This table is obtained on the basis of a laboratory opinion test which was a connection composed of 8-bit PCM codec (see Recommendation G.712) a white noise generator, 600-telephone set and so on. | | | | | | | | | | | | | | | |

## Appendix III

(to Supplement 29)

SOURCE: USSR TELECOMMUNICATION ADMINISTRATION

TITLE: THE EFFECT OF ERRORS IN 2048 kbit/s DIGITAL STREAMS ON APPEARANCE OF IMPULSE NOISE IN MIXED VOICE-FREQUENCY CIRCUITS

The preliminary results of the studies on impulse noise in PCM circuits are dealt with in Contribution COM XII-188 (study period 1985-1988).

Further investigations were conducted. The results of determining the number of impulse noise in PCM circuits due to computer-simulated error in a 2048 kbit/s stream were achieved. The assumption was made that their distribution follows the Neuman law (packet errors) or the binomial law (single errors).

The methodology of determining the probability of the number of packet and independent (single) errors as well as the input data for simulation correspond to the data presented in Appendix I.

The impulse noise threshold for the purpose of analysis has been taken as equal to –21 dBm0, the impulse noise registration duration was more than 30 ms, the dead time was 125 ms (see Recommendations M.1020 and O.71). The impulse response of the real filter of the PCM channel equipment is given in Figure III.1 and corresponds to that of Contribution COM XII-188 (study period 1985-1988).

The study results are summarized in Table III.1. The analysis of these results shows that packetized errors lead to a much greater number of impulse noise in comparison with the binomial distribution of errors.

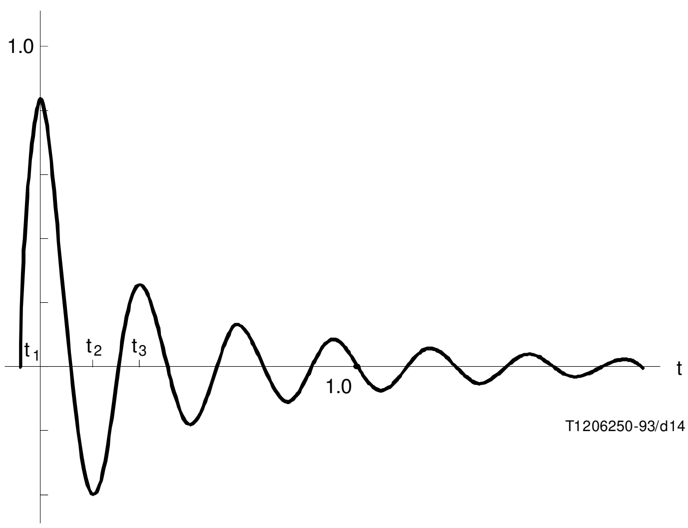


FIGURE III.1

TABLE III-1

| Error Distribution | Average bit error rate | | | | |
|---|---|---|---|---|---|
| | $10^{-7}$ | $10^{-6}$ | $10^{-5}$ | $10^{-4}$ | $10^{-3}$ |
| | Average number of impulse noise exceeding –21 dBm0 threshold during 15 minutes | | | | |
| Neuman law: | | | | | |
| Average number of errors in the packets 5-10 | – | 6 | 60 | 480 | 1880 |
| Average number of errors in packets 200 | – | 1 | 8 | 40 | 520 |
| Binomial law | – | – | – | 8 | 172 |

In case of packetized errors the greatest number of impulse noise corresponds to an average number of errors in packets equal to 5-10.

Exceeding of the objective established in Recommendation M.1020 (18 events during 15 minutes) is observed in the case where the average BER is worse than $10^{-6}$.