INTERNATIONAL TELECOMMUNICATION UNION

CCITT

THE INTERNATIONAL
TELEGRAPH AND TELEPHONE
CONSULTATIVE COMMITTEE

Series G

Supplement 29
(11/1988)

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

OBJECTIVE FOR THE MIXED ANALOGUE/ DIGITAL CHAIN OF 4-WIRE CIRCUITS

Reedition of CCITT G Series Recommendation Supplement 29 published in the Blue Book, Fascicle III.1 (1988)

NOTES

1 CCITT G-series Recommendation Supplement 29 was published in Fascicle III.1 of the *Blue Book*. This file is an extract from the *Blue Book*. While the presentation and layout of the text might be slightly different from the *Blue Book* version, the contents of the file are identical to the *Blue Book* version and copyright conditions remain unchanged (see below).

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

Supplement No. 29

OBJECTIVE FOR THE MIXED ANALOGUE/DIGITAL CHAIN OF 4-WIRE CIRCUITS

Draft Recommendation G.136

(This Supplement is proposed for further study during the present study period with the aim to convert the supplement into a Recommendation.)

1 General

In the period of transition from a fully analogue to a fully digital network, there will be, on international and national networks, mixed type chain of 4-wire telephone circuits (see Recommendation G.101, § 4.2), some sections of which can be made with analogue or digital transmission systems.

Considering the fact that the transition period may last for a fairly prolonged time, and also considering the need for guaranteeing a certain quality of transmission on mixed chain of circuits, the CCITT recommends observance of some principles for the composition of mixed chain of circuits as set forth below and some objectives for their parameters.

The main principle in the standardization of mixed circuits lies in the retaining of the standards adopted for the FDM circuits. This would have resulted in retaining the transmission quality over the 4-wire chain formed by the international circuits and national extension circuits.

For some parameters this can be achieved, but as far as some other parameters are concerned due to analogue/digital conversions and errors in digital sections there are some considerable differences in standards and measuring methods.

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, CCITT thinks it worth while to have a specific Recommendation on objectives for mixed analogue/digital circuits and 4-wire chains including both analogue and digital circuits.

The present Recommendation related to mixed 4-wire chain of circuits and the analogue/digital mixed connections dealt with in this Recommendation are 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 of Question 26/XII the present Recommendation will have to be supplimented by objectives for mixed chain of circuits formed with the help of various methods of analogue-to-digital conversion such as transmultiplexers (Recommendations G.793, G.794), modems (Recommendations G.941, V.37), transcoders (Recommendation G.761), group codecs (Recommendation G.795), DCME, as well as connections with a digital telephone at one end and an analogue telephone at the other end.

2 Structure of a mixed analogue/digital voice frequence chain of 4-wire circuit

The parameters of a mixed 4-wire chain are essentially dependent on the number of analogue sections and on the number of analogue/digital conversions in the chain.

According to Recommendation G.103 the total number of 4-wire circuits in a 4-wire chain of the maximum length is 12 in exceptional cases (Table 2/G.101) so that it may be assumed that the number of circuits will not exceed 12. The worst cases in terms of distortions occur when:

– all switching centres are digital, and the circuit sections from and to the centres are set up on analogue transmission systems. The number of analogue/digital conversions is then 11, the number of analogue sections is 12;

– all switching centres are analogue, and the circuit sections from and to the centres are set up on digital systems. The number of analogue/digital conversions is 12 in this case, the number of digital sections is 12.

Such cases are very rare. More representative is considered to be a case where the number of analogue/digital conversions makes one half of the maximum number (Recommendation G.103, Annex B), that is 6, and digital islands are available. The structure of such a 4-wire chain is presented in Figure 1. The number of analogue sections is 6, the number of digital sections is also 6. Other structures of mixed 4-wire chain come into the picture when connection of the sections is realized without a switching equipment. These structures are considered in Recommendation M.562 (§ 3.2). The worst case for a circuit of 12 sections without switching centres occurs when digital and analogue sections alternate (see Figure 2), the number of analogue-digital conversions being equal to 6, the number of digital sections to 6, and the number of analogue sections also to 6.

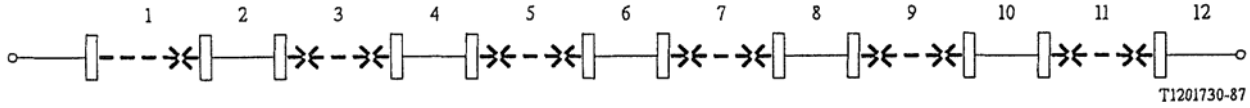

FIGURE 1

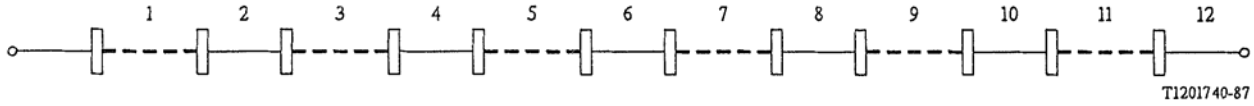

FIGURE 2

Thus, the examination of various structures of mixed analogue/digital voice-frequency chain of circuits shows that for a 4-wire chain of maximum length having 12 sections, it is advisable to establish objectives of distortions based on 6 analogue/digital conversions, 6 analogue and 6 digital sections.

Intermediate variants for combinations of analogue, digital sections and analogue-to-digital conversions will be:

11 analogue sections + 1 a/d conversion
(1 digital section) = 12

. . . . . .

6 analogue sections + 6 a/d conversions
(6 digital sections) = 12

It should be borne in mind that the chains may most frequently consist of less than 12 sections. The contribution of switching centres to distortion is negligible, if they do not contain analogue/digital conversions.

3 Objectives for parameters of mixed analogue/digital circuits

3.1 The nominal value of the input/output impedance of the analogue and digital sections and of a switching equipment should be 600 ohms.

3.2 Return loss of the input/output impedance referred to the nominal value of the analogue and digital sections and of a switching equipment should preferably be not less than 20 dB in the 300-3400 Hz band.

Note – For a switching centre and channel FDM equipment, the value of 15 dB is permissible in the 300-600 Hz band (see Recommendation Q.45, § 6.3 and Recommendation G.232, § 7).

3.3 *Unbalance loss in respect to earth*

The existing Recommendations for switching centres (Q.45, Q.553) and channel FDM equipment (G.712) standardize the unbalance loss in respect to the earth in different ways. There are differences in the measuring methods as well. The Recommendation for the FDM-channel equipment (G.232), does not specify this parameter. The question of standardization and methods of measuring this parameter for mixed circuits channels is under study.

Pending the establishment of unified objectives and measuring methods, Recommendation K.10 on the unbalance loss of communication equipment should be referred to in general guidelines in the case of mixed chain of 4-wire circuits.

3.4 *Nominal relative level*

The nominal relative level on the transmit side of each section (analogue and digital) is -14 (-16) dBr. The nominal relative level on the receive side of each section (analogue and digital) is +4 (+7) dBr (see Recommendations G.232, § 11, G.712, § 14, Q.45, § 3 and Q.553 § 2.2)

The nominal relative level at the virtual analogue switching point is

– sending: –3.5 dBr

– receiving: –4.0 dBr for analogue
–3.5 dBr for digital

(See Recommendation G.101, § 5.2.)

The nominal relative value in a mixed circuit is defined for a frequency which is not a subharmonic of the sampling frequency. The recommended tentative value for the frequency is 1020 Hz.

3.5 *Variations of transmission loss with time*

The standard deviation of the transmission loss should not exceed 1 dB.

The difference between mean and nominal value of the transmission loss should not exceed 0.5 dB.

Note – The indicated values are defined in Recommendation G.151, § 3 for a fully analogue circuit under the condition that the channels are part of a single group equipped with automatic regulation.

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. That is why the indicated values should be considered as tentative and are to be confirmed.

3.6 *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 of switching centre distortions) the accumulation law of attenuation/frequency distortions is expressed by the following formula:

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

with

n_1 : number of analogue sections;

n_2 : number of analogue/digital conversions;

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

σ_{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 of maximum/minimum value of attenuation/frequency distortions.

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

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Note 1 – Attenuation/frequency characteristics of analogue/digital equipment of the same type are similar. That is why, if in a mixed/chain of circuits analogue/digital equipment of the same type is used, in the sum formula (1)

$$\sum_{i=1}^{n_2} a_{i\,\mathrm{PCM}}$$

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

Note 2 – The analogue-digital equipment distortion limits recommended in Recommendation G.712 (§ 1, Figure 1) and the FDM-channel equipment distortion limits recommended in Recommendation G.232 (§ 1, Figure 1) 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 a 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.

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

Note 4 – See Recommendation Q.45 (§ 3.4 and Q.553) to take account of the switching equipment distortions.

3.7 *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:

$$\Delta\tau = n_1\, \tau_{\mathrm{FDM}} + \sum_{i=1}^{n_2} \tau_{i\,\mathrm{PCM}} \qquad (2)$$

where

n_1 the number of analogue sections,

n_2 the number of analogue/digital conversions.

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

$$\sum_{i=1}^{n_2} \tau_{i\,\mathrm{PCM}}$$

is substituted by a product $n_2 \,.\, \tau_{\mathrm{PCM}}$.

Note 2 – It is expected that the group delay distortion in mixed chains will be less than that of a fully analogue link for 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.

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

Note 4 – Switching centre distortions are negligible and can be ignored.

3.8 *Intelligible crosstalk*

Near-end and far-end signal-to-intelligible crosstalk ratios between circuits and between send and receive directions should satisfy Recommendation G.151 (§ 4).

Note 1 – It is expected that the values indicated in Recommendation G.151, will be maintained and even better for mixed chains for any combination of analogue and digital sections, due to higher values achieved in the analogue/digital conversion equipment.

Note 2 – Measurement of the 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 note to point 11 of Recommendation G.712). This can be explained by the fact that in a mixed circuit, as a rule, and in an analogue circuit noise will be present at the input of analogue/digital converters in a mixed chain.

3.9 *Non-linear distortions*

The existing Recommendations for analogue circuits (M.1020, § 2.11), for switching equipment (Q.45, § 6.1) 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.

3.10 *Noise (total distortions)*

The notion of noise in mixed chains of 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 chain of circuits the term "total distortions" is used very often. 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.

From this view point the total distortions in mixed chains include analogue section noise which depends on the length of the sections in case of terrestrial transmission systems and on the quantization distortion which are determined by the number and type of analogue-to-digital conversions.

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

$$P = 10 \log_{10} \left\{ 10^{-9} \cdot W_{FDM} + 10^{0.1\left[S - \left((S/N) - 10 \log \eta_2 \text{ qdu}\right)\right]} \right\} \quad (3)$$

where

– W_{FDM} noise power of analogue sections (pWp0)

– $W_{FDM} = W_o \frac{\text{pWp0}}{\text{km}} \text{ L km}$

(for a section provided by a satellite the terrestrial length is taken to be equal to 2500 km).

– S/N signal-to-quantization distortion ratio of one analogue-to-digital conversion.

– η_2 qdu total number of quantization distortion units of analogue-to-digital conversions.

To determine S/N and the total number of qdu's one should refer to Recommendation G.113.

– S signal level at which general distortions are measured.

To eliminate any effect of non-linear distortion the value of S should be no more than –10 dBm0.

The permissible value of P is to be determined in the studies in Study Group XII.

The value of –36 dBm0 (with S = –10 dBm0), i.e. signal-to-total distortions ratio 26 dB, can be indicated as a premilinary value.

The noise in an idle channel should comply with Recommendations G.123 and G.153, § 1.

Note 1 – Total distortions also include a component determined by errors in digital sections. It is assumed that if BER at each digital section is 10^{-6} (with the bit rate of 64 kbit/s) the respective component can be omitted.

Note 2 – The values of total distortions for various length of analogue sections and various numbers of qdu's mixed chains are available in Tables 5/M.580 and 6/M.580 of Annex A to this Recommendation.

3.11 *Single tone interference*

The level of any single tone signal should not exceed –73 dBm0 (see Recommendation G.151, § 8). The indicated value does not relate to the interfering signal at the sampling frequency.

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 conversions in a mixed circuit. The indicated value is tentative and needs to be confirmed by study results in Study Group XII.

3.12 *Products of unwanted modulation*

Product levels of unwanted modulation caused by power sources should not exceed –45 dB (see Recommendation G.151, § 7).

3.13 *Impulse noise*

Impulse noise is specified for analogue circuits used for data transmission (Recommendations M.1020 and M.1025) and for switching equipment (Recommendation Q.45, § 5.2 and Q.553). For voice-frequency circuits in PCM transmission systems the impulsive 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, impulse noise can appear in a voice-frequency circuit which leads to interference in the transmisison of data signals. (Preliminary results on the effect of digital link errors on impulse noise in idle PCM voice-frequency channels is given in [4].)

The effect of impulsive noise appearing in digital sections on the overall value of interference in a mixed 4-wire chain is subject of study.

3.14 *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.

3.15 *Error performance*

Further study.

References

[1] 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”, 1969, No. 11.

[2] Moskvitin (V. D.): Nozmirovanije chastotnykh kharakteristik ostatochnogo zatuhanija kanalov. (Frequency distortion objectives for transmission loss.) “Elektrosviaz, 1970, No. 1.

[3] COM XII-19 (period 1985-1988), USSR Attenuation/frequency distortions and delay distortions of mixed audiofrequency analogue/digital circuits.

[4] COM XII-188 (period 1985-1988), USSR Interrelation between errors of a digital line and impulse noise in voice-frequency channels of the PCM System.

ANNEX A

(to draft Recommendation G.136)

TABLE 5/M.580

Signal-to-total distortion ratio for public telephone circuit maintenance using a test frequency level of -10 dBm0

Type of circuit	Number of QDUs (Note 1)	Unit	Distance in analogue transmission (Note 3) (km)						
			< 320	321 to 640	641 to 1600	1601 to 2500	2501 to 5000	5001 to 10000	10 001 to 20 000
Analogue	0 (Note 2)	dB	45	43	41	39	36	33	30
Composite circuit	0.5	dB	35	35	34	34	33	31	29
	1	dB	33	33	32	32	31	30	28
	2	dB	30	30	30	29	29	28	27
	3	dB	28	28	28	28	28	27	26
	3.5	dB	27	27	27	27	27	26	26
	4	dB	27	27	27	27	26	26	25

Note 1 – The number of QDUs contributed by various processes are given in Table 1/G.113 [8].

Note 2 – The values are idle noise terminated with a nominal impedance of 600 Ω.

Note 3 – The section of the circuit provided by satellite (between earth stations), employing FDM techniques, contributes approximately 10 000 pWp (–50 dBm0p) of noise. Therefore, for the purpose of determining the total distortion limits for international public telephony circuits, the length of this section may be considered, from Table 4/M.580, to be equivalent to 2500 km.

TABLE 6/M.580

Signal-to-total distortion ratio for public telephone circuit maintenance using a test frequency level of –25 dBm0

Type of circuit	Number of QDUs (Note 1)	Unit	Distance in analogue transmission (Note 3) (km)						
			< 320	321 to 640	641 to 1600	1601 to 2500	2501 to 5000	5001 to 10000	10 001 to 20 000
Analogue	0 (Note 2)	dB	30	28	26	24	21	18	15
Composite circuit	0.5	dB	29	27	26	24	21	18	15
	1	dB	28	27	25	23	21	18	15
	2	dB	27	26	25	23	20	18	15
	3	dB	26	25	24	23	20	18	15
	3.5	dB	26	25	24	22	20	18	15
	4	dB	25	24	23	22	20	17	15

Note 1 – The number of QDUs contributed by various processes are given in Table 1/G.113 [8].

Note 2 – The values are idle noise terminated with a nominal impedance of 600 Ω.

Note 3 – The section of the circuit provided by satellite (between earth stations), employing FDM techniques, contributes approximately 10 000 pWp (-50 dBm0p) of noise. Therefore, for the purpose of determining the total distortion limits for international public telephony circuits, the length of this section may be considered, from Table 4/M.580, to be equivalent to 2500 km.

ANNEX B

(to draft Recommendation G.136)

SOURCE: THE URSS TELECOMMUNICATION ADMINISTRATION

TITLE: INTERRELATION BETWEEN ERRORS IN A DIGITAL CIRCUIT AND IMPULSE NOISE IN VOICE-FREQUENCY CHANNELS OF THE PCM SYSTEM

B.1 *Introduction*

Voice-frequency channels of PCM as well as FDM systems should be fit for transmitting various types of signals. It is well known that the transmission quality of discrete signals in voice-frequency channels is affected by impulse noise. At present, Recommendation G.712 has no requirements to voice-frequency PCM-channels regarding impulse noise. However, under real-life conditions in a voice-frequency PCM channel impulse noise contributes to the error-rate of digital links. The present contribution gives the investigation results of impulse noise in voice-frequency PCM-channels.

B.2 *Influence of digital circuit errors on impulse noise in an idle voice-frequency PCM channel*

Evaluation of error influence on digital links on the value of impulse noise in voice-frequency channels was conducted experimentally on a channel equipment (satisfying Recommendation G.712) of a PCM transmission system (2048 kbit/s). With the help of an error simulator errors had been introduced into one or several bits corresponding to a chosen idle voice-frequency channel of a digital link (Figure 1). In the voice-frequency channel impulse noise could be observed with the help of an oscillograph. The shape of the pulse response in the voice-frequency channel is presented in Figure B-2.

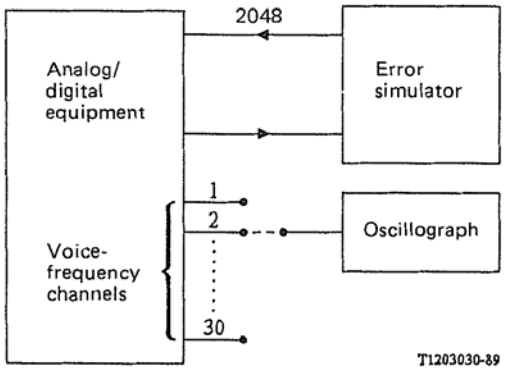

FIGURE B-1

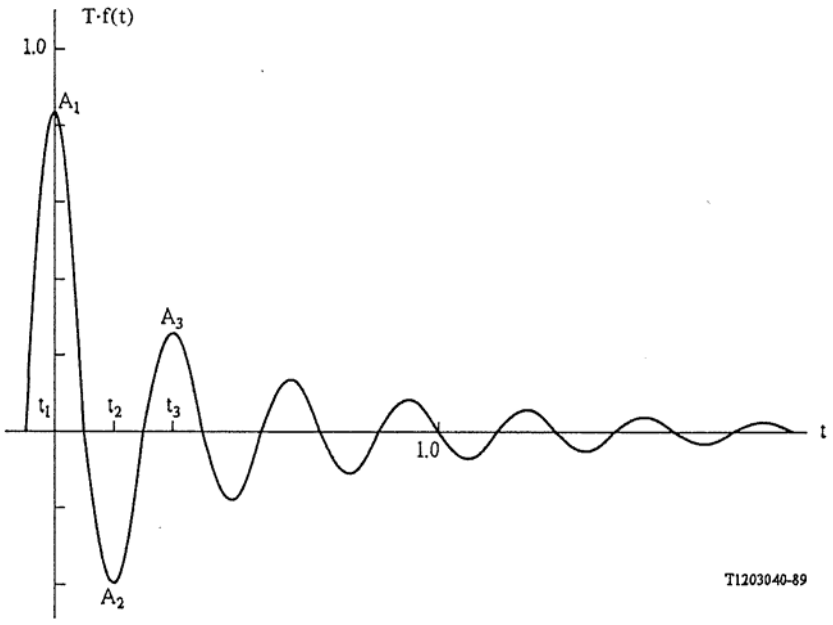

FIGURE B-2

The parameters of pulse response are given in Table 1 (the values are chosen for the point of the relative zero level at a resistance of 600 ohms). These data allow us to formulate the following conclusions:

- The pulse amplitude of the response depends on the bit number which contains the error; the errors in the more significant bits cause a greater amplitude of the response.
- With single errors the maximum value of the pulse peak A_1 (in case of an error in the second bit) is -22.1 dBm0.
- With burst-building and with an increase in the number of errored bits in the code word of the prime digital path (2048 kbit/s) the response amplitude values A_1, A_2, A_3, . . . grow, but their duration, as determined by the response of the channel's low frequency receiving filter, remains unchanged. This applies to the cases where in a prime digital path, the error bursts affect the digital stream for not more than one discretization period, i.e. the number of the errors in a burst does not exceed 256. With errors in code words occurring every 125 μs the superposition of responses takes place as a result of the receiving filter reaction on the error pulses in each following discretization period.

TABLE B-1

Errored bits in a frame of primary multiplex	Amplitude of pulse response			Duration of pulse response		
	A_1	A_2	A_3	t_1	t_2	t_3
	dBm0	dBm0	dBm0	μs	μs	μs
2	–22.1	–28.2	–33.8	320	160	130
3	–34.1	–40.2	–45.8	320	160	130
2 and 3	–10.1	–16.2	–21.8	320	160	130
2 and 3 and 4 from 2 to 8,	–4.1	–10.2	–15.8	320	160	130
2 discretization periods from 2 to 8,	–4.3	–6.7	–14.8	440	180	100
3 discretization periods from 2 to 8,	–4.3	–4.9	–14.8	600	200	100
4 discretization periods from 2 to 8,	–4.3	–4.7	–14.8	680	180	120
5 discretization periods from 2 to 8,	–4.3	–6.7	–14.8	840	200	120
6 discretization periods from 2 to 8,	–3.8	–4.3	–14.8	930	200	100
7 discretization periods	–5.25	–8.7	–14.8	1100	180	140

Thus, when errors, on a 2048 kbit/s digital path grow into burst of 2 errors and more there is a certain probability that the value of the impulse noise in a PCM voice-frequency channel exceeds –21 dBm0 given in Recommendation M.1020, § 2.6.

With error bursts of 256 and more bits the above-mentioned impulse noise will always be present.

The quantitative relationship between the number of bursts, the number of errors in them within a definite time interval and the number of impulse noise interferences and the BER in a voice-frequency channel is under study at present.

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Printed in Switzerland

Geneva, 2007