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ASSUMPTIONS FOR THE CALCULATION OF NOISE ON HYPOTHETICAL REFERENCE CIRCUITS FOR TELEPHONY

ITU-T Recommendation G.223

(Extract from the *Blue Book*)

NOTES

1 ITU-T Recommendation G.223 was published in Fascicle III.2 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.

Recommendation G.223

ASSUMPTIONS FOR THE CALCULATION OF NOISE ON HYPOTHETICAL REFERENCE CIRCUITS FOR TELEPHONY

(Remark of Recommendation G.222, Volume III of the Red Book, amended at Geneva, 1964; further amended)

1 Nominal mean power during the busy hour

To simplify calculations when designing carrier systems on cables or radio links, the CCITT has adopted a *conventional* value to represent the *mean absolute power level* (at a zero relative level point) of the speech plus signalling currents, etc., transmitted over a telephone channel in one direction of transmission during the busy hour.

The value adopted for this mean absolute power level corrected to a zero relative level point is -15 dBm0 (mean power = 31.6 microwatts); this is the mean with time and the mean for a large batch of circuits.

Note 1 - This conventional value was adopted by the CCIF in 1956 after a series of measurements and calculations had been carried out by various Administrations between 1953 and 1955. The documentation assembled at the time is indicated. in [1]. The adopted value of about 32 microwatts was based on the following assumptions:

i) mean power of 10 microwatts for all signalling and tones (Recommendation Q.15 [2], gives information concerning the apportionment on an energy basis of signals and tones);

ii) mean power of 22 microwatts for other currents, namely:

- speech currents, including echoes, assuming a mean activity factor of 0.25 for one telephone channel in one direction of transmission;
- carrier leaks (see Recommendations G.232, § 5; G.233, § 11; G.235, § 5); and the Recommendations cited in [3] and [4];
- telegraph signals, assuming that few telephone channels are used for VF telegraphy systems (output signal power 135 microwatts (the Recommendation cited in [5])) or phototelegraphy (amplitude modulated signal with a maximum signal power of about 1 milliwatt (the Recommendation cited in [6])).

On the other hand, the power of pilots in the load of modern carrier systems has been treated as negligible.

The reference to "the busy hour" in § 1 is to indicate that the limit (of -15 dBm0) applies when transmission systems and telephone exchanges are at their busiest so that the various factors concerning occupancy and activity of the various services and signals are to be those appropriate to such busy conditions.

It is not intended to suggest that an integrating period of one hour may be used in the specification of the signals emitted by individual devices connected to transmission systems. This could lead to insupportably high short-term power levels being permitted which give rise to interference for durations of significance to telephony and other services.

Note 2 - The question of reconsidering the assumptions leading to this conventional value arose in 1968 for the following reasons:

- changes in the r.m.s. power of speech signals, due to the use of more modern telephone sets, to a different transmission plan, and perhaps also to some change in subscriber habits;
- change in the mean activity factor of a telephone channel due, *inter alia,* to different operating methods;
- increase in the number of VF telegraphy bearer circuits and sound-programme circuits;
- introduction of circuits used for data transmission, and rapid increase in their number.

During several Study Periods these points have been under study and various Administrations carried out measurements of speech signal power and loading of carrier systems. The results are shown in Supplement No. 5. These results indicate that there is no sufficiently firm information to justify an alteration to the conventional mean value of -15 dBm0 (32 μW0) for the long-term mean power level per channel.

Indeed, the steps envisaged by Administrations to control and reduce the levels of non-speech signals indicate a tendency to limit the effect of the increase in the non-speech services.

As regards the subdivision of the 32 μW into 10 μW signalling and tones and 22 μW speech and echo, carrier leaks, and telegraphy, again there is no evidence which would justify proposals to alter this subdivision.

As a general principle, it should always be the objective of Administrations to ensure that the *actual* load carried by transmission systems does not significantly differ from the *conventional* value assumed in the design of such systems.

Note 3 - The CCITT has agreed to the following rules concerning the maximum permissible number of VF telegraph bearer circuits:

1) For a *12-channel system,* both the load capacity and the intermodulation requirements are determined by the statistics of speech; hence there is no reason to limit the number of channels in a 12-channel system which may be used as VF telegraphy bearer channels.

2) For a *60-channel system,* the load capacity is determined by the statistics of speech but the intermodulation requirements for a mixed VF telegraph and speech loading become controlling when the VF telegraph bearers exceed about 30% of the total. Hence it is possible, without change of specifications, to allow up to 20 channels in this system to be used for VF telegraphy.

3) For a *120-channel system,* about 12% of the total could be allowed for VF telegraph bearers. The number of reserve circuits for VF telegraphy is excluded from these limits for both 60- and 120-channel systems. The number of channels for these systems should be distributed more or less uniformly throughout the line-frequency band.

4) For *systems with 300 or more channels,* the CCITT is not yet able to define any specific limit, owing to the many complicated factors such as mean power, peak power, overload capacity, intermodulation, noise-performance and pre-emphasis, which have to be taken into consideration.

5) For *groups and supergroups* no conclusion could be obtained. From information available, it would be unwise, without special consideration, to exceed two VF telegraph systems per supergroup in a wideband system.

6) *For transmission systems not exceeding 1000 km* the permissible number of telegraph systems may be increased if the power per telegraph channel is reduced according to Table 1/G.223.

   A similar table in respect of transmission systems longer than 1000 km cannot be drawn up at this time. There is evidence to suggest that for systems considerably longer than 1000 km a reduction in telegraph signal power gives rise to unacceptable levels of telegraph distortion and character error rates.

TABLE 1/G.223

Total number of circuits provided by the transmission system (N)	Approximate number of circuits that may be used for 24-channel FM voice frequency telegraph systems with the indicated power level/TG channel (dBm0)			
	-22.5	-22.5	-27.0	-28.5
12	12	12	12	12
60	20	60	60	60
120	14	42	84	120
300 or more	N/30	N/10	N/5	N

2 Loading for calculation of intermodulation noise

2.1 It will be assumed for the calculation of intermodulation noise below the overload point that the multiplex signal during the busy hour can be represented by a uniform spectrum random noise signal, the mean absolute power level of which, at a zero relative flat level point, is given by the following formulae:

$$10 \log_{10} \overline{P}(n) = (-15 + 10 \log_{10} n) \text{ dBm0 for } n \geqslant 240$$

and

$$10 \log_{10} \overline{P}(n) = (-1 + 4 \log_{10} n) \text{ dBm0 for } 12 \leqslant n < 240,$$

n being the total number of telephone channels in the system and $\overline{P}(n)$ the power of the random noise signal in milliwatts.

Examples are shown in Table 2/G.223 of the results given by these formulae for some typical values of n.

TABLE 2/G.223

n	$10 \log_{10} \overline{P}(n)$ (dBm0)	n	$10 \log_{10} \overline{P}(n)$ (dBm0)
12	3.3	240	8.8
24	4.5	300	9.8
36	5.2	600	12.8
48	5.7	960	14.8
60	6.1	1 800	17.6
120	7.3	2 700	19.3
		10 800	25.3

These results apply only to systems without pre-emphasis and using independent amplifiers for the two directions of transmission.

2.2 For 2-wire systems having common amplifiers for the two directions of transmission ($n + n$ systems), it is necessary to assume a different conventional loading. When the relative levels are the same for both directions of transmission the conventional load is given by the following formulae:

$$10 \log_{10} \overline{P}(n) = (-15 + 10 \log_{10} 2n) \text{ dBm0 for } n \geqslant 120$$

and

$$10 \log_{10} \overline{P}(n) = (-1 + 4 \log_{10} 2n) \text{ dBm0 for } 12 \leqslant n < 120,$$

where

$\overline{P}(n)$ is defined in § 2.1 above and n is the number of channels in each direction of transmission.

2.3 When use is made of a call concentrator having the effect of multiplying the number of circuits established on a system by a coefficient *a*, for the determination of the conventional load, the number of channels should be multiplied by *a* and the activity coefficient should remain unchanged (see also Note 5 below). The following formulae then replace those given in § 2.2 above:

$$10 \log_{10} \overline{P}(n) = (-15 + 10 \log_{10} an) \text{ dBm0 for } an \geqslant 240$$

and

$$10 \log_{10} \overline{P}(n) = (-1 + 4 \log_{10} an) \text{ dBm0 for } 12 \leqslant an < 240,$$

n being the total number of telephone channels in the system and $\overline{P}(n)$ the power of the random noise signal in milliwatts.

Note 1 - The mean absolute power level of a uniform-spectrum random noise test signal deduced from these formulae may be used in calculating the intermodulation noise on a hypothetical reference circuit, when there is no overloading. It is considered that these formulae give a good approximation in calculating intermodulation noise when $n \geq 60$. For small numbers of channels, however, tests with uniform-spectrum random noise are less realistic owing to the wide difference in the nature of actual and test signals.

Note 2 - In view of the conventional character of these calculations, it was not considered useful to take into account the power transmitted for programme transmissions over carrier systems. Moreover, the mean value of 0.25 was assumed for the activity factor of a telephone channel and it was not deemed useful to study any deviations from this mean.

Note 3 - Care must be taken in interpreting the results of tests with uniform-spectrum random noise loading, especially in systems in which the dominant noise contribution in certain channels arises from a particular kind of intermodulation product (e.g. A-B). In such cases, the weighting factor used in relating the performance of the channel to that under real traffic conditions must be carefully determined. The curve given by the transfer function of the network used to define the conventional telephone signal (see Recommendation G.227) may be used in this case to determine the weighting factor for the wideband signal.

Note 4 - The formulae in § 2.2 above for *(n + n)* type 12-channel systems are the same as those given in § 2.1 above (4-wire systems), assuming that the number of channels is doubled but that there is no correlation between the channel activities in each direction of transmission. For the purposes of this assumption, the fact that in an (*n* + *n*) system the two directions of transmission of a telephone circuit are not active at the same moment is ignored. Calculations have shown that the resultant error is negligible and in any case is on the safe side.

Note 5 - The formulae in § 2.3 above are only valid in the case when all channels are equipped with call concentrators. They are not applicable when only some of the channels are equipped with call concentrators, because the distribution of these channels generally will not be uniform over the band of the multiplex signal.

3 Component characteristics and levels

The values of the characteristics of circuit components and the levels to be used in calculations will be the nominal values.

Note - When specifying equipments, a reasonable margin should be allowed for the ageing of components and for tolerances on levels, supply voltages temperature, etc.

4 Psophometric weights and weighting factor

For calculating psophometric power, use should be made of the *Table of psophometer weighting for commercial telephone circuits* which is given in Table 4/G.223.

If uniform-spectrum random noise is measured in a 3.1-kHz band with a flat attenuation/frequency characteristic, the noise level must be reduced by 2.5 dB to obtain the psophometric power level. For another bandwidth, *B*, the weighting factor will be equal to:

$$\left(2.5 + 10 \log_{10} \frac{B}{3.1 \text{ kHz}} \right) \text{dB}$$

When *B* = 4 kHz, for example, this formula gives a weighting factor of 3.6 dB.

5 Calculating noise in modulating (translating) equipments

(See also Recommendation G.230.)

5.1 For group, supergroup, etc., *modulating equipments,* in calculating *intermodulation noise* (below the overload point), the following conventional values, already accepted, will be assumed for the load at a zero relative level point:

- for 12-channel group modulators: 3.3 dBm0;
- for 60-channel supergroup modulators: 6.1 dBm0;
- for 300-channel mastergroup modulators: 9.8 dBm0.

5.2 The mean noise power in channel translating equipments due to interference from channels adjacent to the disturbed channel will be calculated as follows. In all the terminal equipment of the hypothetical reference circuit there are six exposures to adjacent-channel disturbance. Five of these disturbing channels will be assumed to carry speech-like loading signals each having a mean power of 32 µW, i.e. an absolute power level of - 15 dBm0 per channel at a zero relative level point, while the sixth disturbing channel will be assumed to carry telegraphy, phototelegraphy or data transmission with a conventional loading of 135 µW applied at the zero relative level point, i.e. an absolute power of -8.7 dBm0 uniformly distributed over the frequency range 380 to 3220 Hz.

The conventional telephony signal defined in Recommendation G.227 may be used to simulate the speech signals transmitted on the disturbing channels.

Note - Limitation of crosstalk caused by channels adjacent to the disturbed channel is governed by an additional clause in the channel equipment specification (see Recommendation G.232, § 9.2). In addition, the power of signalling pulses is restricted by Recommendation G.224.

5.3 In all cases allowance should, of course, be made for thermal noise.

6 Overload point of amplifiers, the equivalent r.m.s. power of the peak of the multiplex signal and the margin against saturation

6.1 **overload point**

The overload point or overload level of an amplifier is at that value of absolute power level at the output at which the absolute power level of the third harmonic increases by 20 dB when the input signal to the amplifier is increased by 1 dB.

This first definition does not apply when the test frequency is so high that the third harmonic frequency falls outside the useful bandwidth of the amplifier. The following definition may then be used:

Second definition - The overload point or overload level of an amplifier is 6 dB higher than the absolute power level in dBm, at the output of the amplifier, of each of two sinusoidal signals of equal amplitude and of frequencies A and B respectively, when these absolute power levels. are so adjusted that an increase of 1 dB in both of their separate levels at the input of the amplifier causes an increase, at the output of the amplifier, of 20 dB in the intermodulation product of frequency 2A - B.

6.2 **equivalent r.m.s. sine wave power of the peak of a multiplex telephone signal**

This is the power of a sinusoidal signal whose amplitude is that of the peak voltage of the multiplex signal. Figure 1/G.223 shows the equivalent peak power level in terms of the number of channels. Up to 1000 channels, it is derived from Curve B, Figure 7 of Reference [7] taking into account the conventional value *(*-15 dBm0) allowed by the CCITT for the mean power per channel instead of -16 dBm0, i.e. an increase of 1 dB. Numerical values are given in Table 3/G.223.

TABLE 3/G.223

Number of channels, *n*	12	24	36	48	60	120	300	600	960
Equivalent peak power level (dBm0)	19	19.5	20	20.5	20.8	21.2	23	25	27

For systems having a capacity higher than 1000 channels, the equivalent peak power level may be derived from the following formula:

$$10 \log_{10} P_{eq} = \left[-5 + 10 \log_{10} n + 10 \log_{10} \left(1 + \frac{15}{\sqrt{n}} \right) \right] \text{ dBm0}$$

where

P_{eq} is the equivalent r.m.s. sine wave power in milliwatts and

n the number of channels.

Table 3a/G.223 gives corresponding numerical values for a few typical numbers of channels.

The curve in Figure 1/G.223 and the formula for numbers of channels exceeding 1000 are for use when there is no amplitude limiter at the channel input and when there is no pre-emphasis in the overall band of the multiplex signal; other cases are being studied.

Note - Mathematical models which enable calculations of the equivalent peak power level of multiplex telephone speech signals are described in Supplement No. 22 at the end of present fascicle.

6.3 **Margin against saturation**

In planning, a margin of a few decibels should be maintained between the absolute level of the equivalent power of the peak of the multiplex signal and the amplifier saturation point, to allow for level variations, ageing, etc. A national practice to estimate the signal load margin of systems and equipments is shown in Supplement No. 26.

Multiplex signals different from telephony - It is stressed that § 6.2 above relates to systems designed for telephony only, i.e. for, a channel loading as described in § 1 above. It should be realized that when the characteristics of the multiplex signal differ significantly from those assumed in § 1 above, additional margins against saturation may be required.

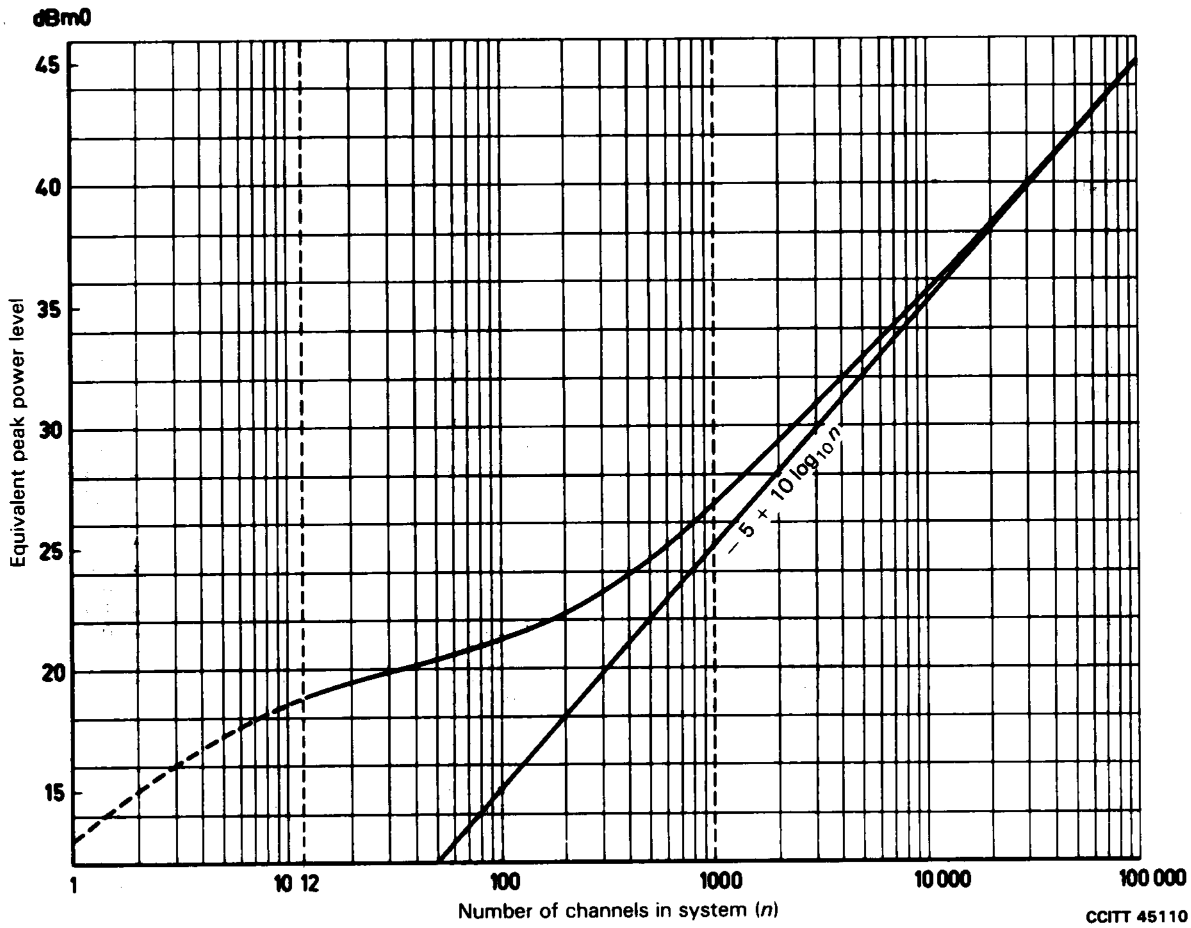

FIGURE 1/G.223

Equivalent r.m.s. sine wave power level of the peak of a multiplex signal at a zero relative level point, as a function of the number of telephony channels in a system, without pre-emphasis or peak limiting assuming a mean power level per channel of - 15 dBm0, with a standard deviation of 5.8 dB

TABLE 3a/G.223

Number of channel, *n*	1260	1800	2700	3600	10 800
Equivalent peak power level (dBm0)	27.5	29	30.5	31.5	36

TABLE 4/G.223

Table of commercial telephone circuit psophometer weighting coefficients

Frequency Hz	Weight		
	Numerical value	Numerical values squared	Value in decibels
16.66	0.056	0.003136	-85.0
50	0.71	0.5041	-63.0
100	8.91	79.3881	-41.0
150		1 260.25	-29.0
200	35.5	7 938.81	-21.0
250	89.1	31 684	-15.0
300	178	87 025	-10.6
350	295	141 376	- 8.5
400	376	234 256	- 6.3
	484		
450		338 724	- 4.7
500	582	436 921	- 3.6
550	661	537 289	- 2.7
600	733	630 436	- 2.0
650	794	724 201	- 1.4
700	851	813 604	- 0.9
750	902	912 025	- 0.4
800	955	1 000 000	0.0
	1 000		
850		1 071 225	+ 0.3
900	1 035	1 149 184	+ 0.6
950	1 072	1 229 881	+ 0.9
1 000	1 109	1 258 884	+ 1.0
1 050	1 122	1 229 881	+ 0.9
1 100	1 109	1 149 184	+ 0.6
1 150	1 072	1 071 225	+ 0.3
1 200	1 035	1 000 000	0.0
	1 000		
1 250		954 529	-0.20
1 300	977	912 025	-0.40
1 350	955	861 184	-0.65
1 400	928	819 025	-0.87
1 450	905	776 161	-1.10
1 500	881	741 321	-1.30
1 550	861	708 964	-1.49
1 600	842	678 976	-1.68
	824		
1 650		651 249	-1.86
1 700	807	625 681	-2.04
1 750	791	600 625	-2.22
1 800	775	577 600	-2.39
1 850	760	555 025	-2.56
1 900	745	535 824	-2.71
1 950	732	518 400	-2.86
2 000	720	501 264	-3.00
	708		
2 050		487 204	-3.12
2 100	698	474 721	-3.24
2 150	689	461 041	-3.36
2 200	679	448 900	-3.48
2 250	670	436 921	-3.60
2 300	661	425 104	-3.72
2 350	652	413 449	-3.84
	643		
2 400		401 956	-3.96
2 450	634	390 625	-4.08
2 500	626	380 689	-4.20
2 550	617	368 449	-4.33
2 600	607	357 604	-4.46
2 650	598	348 100	-4.59
2 700	590	336 400	-4.73
2 750	580	326 041	-4.87
2 800	571	315 844	-5.01
	562		

TABLE 4/G.223 *(concluded)*

Table of commercial telephone circuit psophometer weighting coefficients

Frequency Hz	Weight		
	Numerical value	Numerical value squared	Value in decibels
2 850	553	305 809	-5.15
2 900	543	294 849	-5.30
2 950	534	285 156	-5.45
3 000	525	275 625	-5.60
3 100	501	251 001	-6.00
3 200	473	223 729	-6.50
3 300	444	197 136	-7.05
3 400	412	169 744	-7.70
3 500	376	141 376	-8.5
3 600	335	112 225	-9.5
3 700	292	85 264	-10.7
3 800	251	63 001	-12.0
3 900	214	45 796	-13.4
4 000	178	31 684	-15.0
4 100	144.5	20 880.25	-16.8
4 200	116.0	13 456	-18.7
4 300	92.3	8 519.29	-20.7
4 400	72.4	5 241.76	-22.8
4 500	56.2	3 158.44	-25.0
4 600	43.7	1 909.69	-27.2
4 700	33.9	1 149.21	-29.4
4 800	26.3	691.69	-31.6
4 900	20.4	416.16	-33.8
5 000	15.9	252.81	-36.0
>5 000	<15.9	<252.81	< -36.0

Note - If, for the planning of certain telephone transmission systems, calculations are made on a basis of the psophometric weighting values and if appears useful to adopt, for frequencies above 5000 Hz, more precise values than those given above, the following values may be used:

5 000 to 6 000	< 15.9	< 252.81	< -36.0
>6 000	< 7.1	< 50.41	< -43.0

References

[1] *CCITT collected documents on the volume and power of speech currents transmitted over international telephone circuits*, Blue Book, Vol. III, Part 4, Annex 6, ITU, Geneva, 1965.

[2] CCITT Recommendation *Nominal mean power during the busy hour*, Vol. VI, Rec. Q.15.

[3] CCITT Recommendation *Characteristics of group links for the transmission of wide-spectrum signals*, Vol. III, Rec. H.14, § 2.3.

[4] CCITT Recommendation *Characteristics of supergroup links for the transmission of wide-spectrum signals*, Vol. III, Rec. H.15, § 2.3.

[5] CCITT Recommendation *Basic characteristics of telegraph equipments used in international voice-frequency telegraph systems*, Vol. III, Rec. H.23, § 1.2.

[6] CCITT Recommendation *Phototelegraph transmissions on telephone-type circuits*, Vol. III, Rec. H.41, § 2.3.

[7] HOLBROOK (B. D.) and DIXON (J. T.): Load Rating Theory for Multichannel Amplifiers, *Bell System Technical Journal*, **18**, No. 4, pp. 624-644, October 1939.