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TRANSMISSION CHARACTERISTICS AT 4-WIRE ANALOGUE INTERFACES OF A DIGITAL EXCHANGE

1 General

This Recommendation provides characteristics for:

— 4-wire analogue interfaces (Type $C_{1\backslash d1}$, $C_{1\backslash d2}$ and $C_{1\backslash d3}$),

— input and output connections with 4-wire analogue interfaces, and

— half connections with 4-wire analogue interfaces,

in digital transit and combined local and transit exchanges in accordance with the definitions given in Recommendation Q.551, particularly in Figures 1/Q.551 and 2/Q.551.

The characteristics of the input and output connections of a given interface are not necessarily the same. The characteristics of half connections are not necessarily identical for different types of interfaces.

This Recommendation is intended for switched connections that may be part of an international long-distance connection via 4-wire line circuits interconnected by 4-wire exchanges. Since 4-wire analogue interfaces of digital exchanges may connect with circuits which are used for both international and national traffic, the same values recommended for international connections may also be used for connections entirely within the national network.

Recommendation Q.553

2 Characteristics of interfaces

2.1 *Characteristics common to all 4-wire analogue interfaces*

2.1.1 *Exchange impedance*

2.1.1.1 *Nominal value*

The nominal impedance at the 4-wire input and output interfaces should be 600 ohms, balanced.

2.1.1.2 *Return loss*

The return loss, measured against the nominal impedance, should not be less than 20 dB over the frequency range 300 Hz to 3400 Hz.

Note — For output measurement, the exchange test point T_i must be driven by a PCM signal corresponding to the decoder output value number 0 for the μ-law or decoder output value number 1 for the A-law. (See Recommendation Q.551, § 1.2.3.1.)

2.1.2 *Impedance unbalance about earth*

The value for the Longitudinal Conversion Loss (LCL) defined in Recommendation G.117, § 4.1.3, with the circuit under test in the normal talking state, should exceed the minimum values of Figure 1/Q.553, in accordance with Recommendations Q.45 **|** fIbis and K.10.

Figure 1/Q.553, p.

Note 1 — An Administration may adopt other values and in some cases a wider bandwidth, depending upon actual conditions in its telephone network.

Note 2 — A limit may also be required for the Transverse Conversion Loss (TCL) as defined in Recommendation G.117, § 4.1.2, if the exchange termination is not reciprocal with respect to the transverse and longitudinal connections. A suitable limit would be 40 dB to ensure an adequate near-end crosstalk attenuation between interfaces.

Test method

LCL should be measured in accordance with the principles given in Recommendation O.9, §§ 2.1 and 3. Figure 2/Q.553 shows the basic measuring arrangement.

Measurements of the longitudinal and transverse voltages should be performed by means of a frequency-selective level meter.

Figure 2/Q.553, p.

2.1.3 *Relative levels*

In assigning the relative levels to the interfaces, the limiting of ‘‘difference in transmission loss between the two directions of transmission’’ in Recommendation G.121, Annex A has been taken into account. For the national extension this is the value ‘‘loss (t-b)-loss(a-t)’’. (See the text in the cited Recommendation for guidance.) This difference is limited to ± | dB. However, to allow for additional asymmetry of loss in the rest of the national network, only part of this difference can be used by the digital exchange.

2.1.3.1 *Nominal levels*

The nominal relative levels at the 4-wire analogue input and output interfaces of the digital exchange depend on the type of equipment which is connected to the exchange. (See Figure 1/Q.551.)

In practice it may be necessary to compensate for the loss between the output interfaces of the digital exchange and the input ports of the connected equipment to fulfill transmission plan conditions. The definition of adjustable steps for and the location of this compensation (digital exchange or connected equipment) is within national competence.

Nominal values of relative levels are given in §§ 2.2.1, 2.3.1 and 2.4.1 for the different types of half connections.

2.1.3.2 *Tolerances of relative levels*

The difference between the actual relative level and the nominal relative level should lie within the following ranges:

— input relative level: —0.3 to +0.7 dB;

— output relative level: —0.7 to +0.3 dB.

These differences may arise, for example, from design tolerances, cabling (between analogue equipment ports and the DF) and adjustment increments.

Note — Adjustment of the relative level should be made in accordance with Recommendation G.712, § 15.

2.2 *Characteristics of interface* $C_{1\backslash d1}$

According to Figure 1/Q.551, the interface $C_{1\backslash d1}$ of a digital exchange is intended to interwork with the channel translating equipment of an FDM system.

2.2.1 *Values of nominal levels*

The nominal values of relative levels at the channel translating equipment are specified in Table 2/G.232 for the two recommended cases. With the pads in the channel translating equipment set to zero, these values are:

H.T. [T1.553]

	Case 1	Case 2
R	+4.0 dBr	+7.0 dBr
S	—14.0 dBr	—16.0 dBr

Table [T1.553], p.

The nominal values of relative levels at the digital exchange must be adjusted to compensate for the total loss between the interface of the digital exchange and the channel translating equipment. Therefore:

$$L_i = R - A_R$$

$$L_o = S + A_S$$

where

A_R = total loss in the receive path

A_S = total loss in the send path

2.3 *Characteristics of interface $C_{1\backslash d2}$*

According to Figure 1/Q.551, the interface $C_{1\backslash d2}$ of a digital exchange is intended to interwork with the incoming and outgoing relay set of an analogue 4-wire exchange. (See Figure 1/Q.45 | fIbis .)

2.3.1 *Values of nominal levels*

The nominal values of relative levels at the relay set of an analogue exchange are consistent with Table 2/G.232 for the two recommended cases. These values are:

H.T. [T2.553]

	Case 1	Case 2
R	—14.0 dBr	—16.0 dBr
S	+4.0 dBr	+7.0 dBr

Table [T2.553], p.

The nominal values of relative levels at the digital exchange must be adjusted to compensate for the total loss between the interface of the digital exchange and the relay sets of the analogue exchange. Therefore:

$$L_i = R - A_R$$

$$L_o = S + A_S$$

where

A_R = total loss in the receive path

A_S = total loss in the send path

2.4 *Characteristics of interface $C_{1\d3}$*

According to Figure 1/Q.551 the interface $C_{1\d3}$ of a digital exchange is intended to connect to a 4-wire analogue switching stage. (See Figure 1/G.142, case 5.)

2.4.1 *Values of nominal levels*

The nominal values of relative levels are determined by the relative levels of the analogue 4-wire switching stages in the national transmission plans. For example, if these relative levels are identical with the virtual analogue switching point of —3.5 dBr in both directions of transmission, the nominal input and output levels of a $C_{1\d3}$ interface are:

$$L_i = L_o = —3.5 \text{ dBr}$$

Different levels at the switching stages and transmission loss between interface $C_{1\d3}$ and the switching stages can require adjusting these levels.

3 Characteristics of half connections

3.1 *Characteristics common to all 4-wire analogue interfaces*

3.1.1 *Transmission loss*

3.1.1.1 *Nominal value*

The nominal transmission loss, according to Recommendation Q.551 § 1.2.4.1, is defined for input and output connections of a half connection with 4-wire analogue interface in §§ 3.2.1, 3.3.1 and 3.4.1.

3.1.1.2 *Tolerances of transmission loss*

The difference between the actual transmission loss and the nominal transmission loss of an input or output connection of the same half connection according to § 2.1.3.2 should lie within the following values:

—0.3 to +0.7 dB.

These differences may arise for example, from design tolerances, cabling (between analogue equipment ports and the DF) or adjustment increments.

3.1.1.3 *Short-term variation of loss with time*

When a sine-wave test signal at the reference frequency of 1020 Hz and at a level of —10 dBm0 (if preferred, the value 0 dBm0 may be used) is applied to a 4-wire analogue interface of any input connection, or a digitally simulated sine-wave signal of the same characteristic is applied to the exchange test point T_i of any output connection, the level at the corresponding exchange test point T_o and the 4-wire analogue interface respectively, should not vary by more than ± | .2 dB during any 10-minute interval of typical operation under the steady state condition permitted variations in the power supply voltage and temperature.

3.1.1.4 *Variation of gain with input level*

With a sine-wave test signal at the reference frequency of 1020 Hz and at a level between —55 dBm0 and +3 dBm0 applied to the 4-wire analogue interface of any input connection, or with a digitally simulated sine-wave signal of the same characteristic applied to the exchange test point T_i of any output connection, the gain variation of that connection, relative to the gain at the input level of —10 dBm0, should lie within the limits given in Figure 3/Q.553.

The measurement should be made with a frequency selective meter to reduce the effect of the exchange noise. This requires a sinusoidal test signal.

Figure 3/Q.553, p.

3.1.1.5 *Loss distortion with frequency*

According to Recommendation Q.551, § 1.2.5, the loss distortion with frequency of any input or output connection should lie within the limits shown in the mask of Figures 4/Q.553, a) and b), respectively. The preferred input level is —10 dBm0.

3.1.2 *Group delay*

‘‘Group delay’’ is defined in the Blue Book, Fascicle I.3.

3.1.2.1 *Absolute group delay*

See Recommendation Q.551, § 3.3.1.

3.1.2.2 *Group delay distortion with frequency*

Taking the minimum group delay, in the frequency range between 500 Hz and 2500 Hz, of the input or output connection as the reference, the group delay distortion of that connection should lie within the limits shown in the template of Figure 5/Q.553. Group delay distortion is measured in accordance with Recommendation O.81.

3.1.3 *Noise*

3.1.3.1 *Weighted noise*

Two components of noise must be considered: noise arising from the coding process and noise from the exchange power supply and other analogue sources transmitted through signalling circuits. The first component is limited by Recommendation G.714, §§ 9 and 10 to —66 dBm0p for an input connection; and to —75 dBm0p for an output connection. The other component is limited by Recommendation G.123, § 3 to —(67+3) dBm0p = —70 dBm0p for one 4-wire analogue interface.

Figure 4/Q.553, p. 6

Figure 5/Q.553, p. 7

This leads to the following maximum values for the overall weighted noise at the output interfaces of a half connection of a digital exchange:

— Input connection: —64.5 dBm0p for equipment with signalling on the speech wires;

—66.0 dBm0p for equipment with signalling on separate wires.

— Output connection: —68.8 dBm0p for equipment with signalling on the speech wires;

—75.0 dBm0p for equipment with signalling on separate wires.

3.1.3.2 *Unweighted noise*

This noise will be more dependent on the noise on the power supply and on the rejection ratio.

Note — The need for and value of this parameter are both under study. Recommendations Q.45*bis* , § 2.5.2 and G.123, § 3 must also be considered.

3.1.3.3 *Impulsive noise*

Limits should be placed on impulsive noise arising from sources within the exchange; these limits are under study. Pending the results of this study, Recommendation Q.45 | fIbis , § 2.5.3 may give some guidance on the subject of controlling impulsive noise with low frequency content.

Note 1 — The sources of impulsive noise are often associated with signalling functions (or in some cases the power supply) and may produce either transverse or longitudinal voltage at 4-wire interfaces.

Note 2 — The disturbances to be considered are those to speech or modem data at audio frequencies, and also those causing bit errors on parallel digital lines carried in the same cable. This latter case, involving impulsive noise with high frequency content, is not presently covered by the measurement procedure of Recommendation Q.45 | fIbis .

3.1.3.4 *Single frequency noise*

The level of any single frequency (in particular the sampling frequency and its multiples), measured selectively at the interface of an output connection should not exceed —50 dBm0.

Note — See Recommendation Q.551, § 1.2.3.1.

3.1.4 *Crosstalk*

For crosstalk measurements auxiliary signals are injected as indicated in Figures 6 to 9/Q.553. These signals are:

— the quiet code (see Recommendation Q.551, § 1.2.3.1);

— a low level activating signal. Suitable activating signals are, for example, a band limited noise signal (see Recommendation O.131), at a level in the range —50 to —60 dBm0 or a sine-wave signal at a level in the range from —33 to —40 dBm0. Care must be taken in the choice of frequency and the filtering characteristics of the measuring apparatus in order that the activating signal does not significantly affect the accuracy of the crosstalk measurement.

3.1.4.1 *Crosstalk measured with analogue test signal*

3.1.4.1.1 *Far-end and near-end crosstalk*

A sine-wave test signal at the reference frequency of 1020 Hz and at a level of 0 dBm0, applied to an analogue 4-wire input interface, should not produce a level at either output of any other half connection exceeding —73 dBm0 for a near-end crosstalk (NEXT) path and —70 dBm0 for a far-end crosstalk (FEXT) path. These paths are shown in Figure 6/Q.553.

Figure 6/Q.553, p.

3.1.4.1.2 *Go-to-return crosstalk*

A sine-wave test signal at any frequency in the range 300-3400 Hz and at a level of 0 dBm0, applied to the 4-wire interface of an input connection, should not produce a level exceeding —66 dBm0 at the analogue output of the same half connection. See Figure 7/Q.553.

Figure 7/Q.553, p.

3.1.4.2 *Crosstalk measured with digital test signal*

3.1.4.2.1 *Far-end and near-end crosstalk*

A digitally simulated sine-wave test signal at the reference frequency of 1020 Hz and at a level of 0 dBm0, applied to an exchange test point T_i, should not produce a level exceeding —70 dBm0 for near-end crosstalk (NEXT) or —73 dBm0 for far-end crosstalk (FEXT), at either output of any other half connection. (See Figure 8/Q.553.)

Figure 8/Q.553, p.

3.1.4.2.2 *Go-to-return crosstalk*

A digitally simulated sine-wave test signal, at any frequency in the range 300-3400 Hz and at a level of 0 dBm0, applied to an exchange test point T_i of an output connection, should not produce a crosstalk level exceeding —66 dBm0 at the exchange test point T_o of the corresponding input connection. See Figure 9/Q.553.

Figure 9/Q.553, p.

3.1.5 *Total distortion including quantizing distortion*

With a sine-wave test signal at the reference frequency of 1020 Hz (see Recommendation O.132) applied to the 4-wire interface of an input connection, or with a digitally simulated sine-wave signal of the same characteristic applied to the exchange test point T_i of an output connection, the signal-to-total distortion ratio, measured at the respective outputs of the half connection with a proper noise weighting (see Table 4/G.223) should lie above the limits shown in Figure 10/Q.553 for signalling on separate wires and in Figure 11/Q.553 for signalling on the speech wires.

Note — The sinusoidal test signal is chosen to obtain results independent of the spectral content of the exchange noise.

Figure 10/Q.553, p.

Figure 11/Q.553, p.

The values of Figure 11/Q.553 include the limits for the coding process given in Figure 5/G.714 and the allowance for the noise contributed via signalling circuits from the exchange power supply and other analogue sources which is limited to —(67+3) dBm0p = —70 dBm0p for one 4-wire analogue interface by Recommendation G.123, § 3.

3.1.6 *Discrimination against out-of-band signals applied to the input interface*

(Applicable only to input connections.)

3.1.6.1 *Input signals above 4.6 kHz*

With any sine-wave signal in the range from 4.6 kHz to 72 kHz applied to the 4-wire interface of a half connection at a level of —25 dBm0, the level of any image frequency produced in the time slot corresponding to the input connection should be at least 25 dB below the level of the test signal. This value may need to be more stringent to meet the overall requirement.

3.1.6.2 *Overall requirement*

Under the most adverse conditions encountered in a national network the half connection should not contribute more than 100 pW0p of additional noise in the band 10 Hz-4 kHz at the output of the input connection, as a result of the presence of out-of-band signals at the input port of the input connection.

3.1.7 *Spurious out-of-band signals received at the output interface*

(Applicable only to an output connection.)

3.1.7.1 *Level of individual components*

With a digitally simulated sine-wave test signal in the frequency range 300-3400 Hz and at a level of 0 dBm0 applied to the exchange test point T_i of a half connection, the level of spurious out-of-band image signals measured selectively at a 4-wire interface of the output connection should be lower than —25 dBm0. This value may need to be more stringent to meet the overall requirement.

3.1.7.2 *Overall requirement*

Spurious out-of-band signals should not give rise to unacceptable interference in the equipment connected to the digital exchange. In particular, the intelligible and unintelligible crosstalk in a connected FDM channel should not exceed a level of —65 dBm0 as a consequence of the spurious out-of-band signals at the half connection.

3.2 *Characteristics for interface* $C_{1\backslash d1}$

3.2.1 *Nominal value of transmission loss*

According to the relative levels defined in § 2.2.1, the nominal transmission losses of a half connection with a $C_{1\backslash d1}$ interface are:

— Input connection: $R — A_R$

— Output connection: $—S — A_S$

See § 2.2.1 for definitions for R , S , A_R and A_S.

3.3 *Characteristics for interface* $C_{1\backslash d2}$

3.3.1 *Nominal value of transmission loss*

According to the relative levels defined in § 2.3.1 the nominal transmission losses of a half connection with a $C_{1\backslash d2}$ interface are:

— Input connection: $R - A_R$

— Output connection: $-S - A_S$

See § 2.2.1 for definitions for R, S, A_R and A_S.

3.4 *Characteristics for interface* $C_{1\backslash d3}$

3.4.1 *Nominal value of transmission loss*

According to the relative levels defined in § 2.4.1 the nominal transmission losses of a half connection with a $C_{1\backslash d3}$ interface are:

— Input connection: —3.5 dB,

— Output connection: 3.5 dB.

Different levels at the switching stages and transmission loss between interface $C_{1\backslash d3}$ and the switching stages can require adjusting these losses.

TRANSMISSION CHARACTERISTICS AT DIGITAL INTERFACES

OF A DIGITAL EXCHANGE

1 General

The field of application of this Recommendation is found in Recommendation Q.500.

The signals taken into consideration are passed through the following interfaces as described in Recommendations Q.511 and Q.512 and Figure 1/Q.551.

— Interface A is for primary rate digital signals at 2048 kbit/s or 1544 kbit/s.

— Interface B is for secondary rate digital signals at 8448 kbit/s or 6312 kbit/s.

— Interface types V are for digital subscriber line access.

Interface types V may appear remote from the exchange through the use of digital transmission facilities. When this occurs, there should be no impact on transmission parameters other than delay.

Detailed transmission characteristics of the digital interface ports are given in § 2 of this Recommendation.

§ 3 covers the requirements for transmission characteristics of the half-connections between the digital interfaces and the exchange test points. The half-connection comprises an input connection (the one-way 64 kbit/s path from the interface to the test point) and an output connection (the one-way 64 kbit/s path from the test point to the interface) as defined in Recommendation Q.551. Requirements are given for the input connection and the output connection characteristics and the two are not necessarily identical.

The overall characteristics of a connection through the digital exchange involving two interfaces can be obtained by suitably combining the values for the characteristics of the two half-connections. For example, the overall characteristics of the connection between a Z interface and the A interface are obtained by combining the Z interface half-connection characteristics given in § 3.3 of Recommendation Q.552 with the A interface half-connection requirements given in § 3.1 of this Recommendation.

Where bit integrity is maintained on the digital half-connection and the error performance requirements are met, the digital half-connection will add no impairment to the voice-band performance of a complete connection through the switch (with the exception of delay). For this reason the digital half-connection requirements do not include the conventional voice band parameters.

(The cases where bit integrity is not maintained are for further study.)

The values given are to be considered as either ‘‘design’’ or ‘‘performance objectives’’ according to the explanation of the terms given in Recommendation G.102 (Transmission performance objectives and recommendations) and the particular context. These objectives should be met under the most adverse specified timing and synchronization conditions as given in Recommendation Q.541, § 3.

2 Characteristics of interfaces

This section covers requirements for interfaces A, B, V.

These interfaces must meet the requirements for timing and synchronization given in Recommendation Q.541, § 3.

2.1 *Interface characteristics common to digital interfaces*

The general characteristics of the interfaces A, B, V_2, V_3, V_4 are given in Recommendations G.703, G.704, G.705, G.706, Q.511 and Q.512.

2.2 *Interface characteristics at interface A*

The physical and electrical characteristics of interface A are given in §§ 2 and 6 of Recommendation G.703.

2.2.1 *Jitter and wander tolerance at the exchange input*

Jitter and wander tolerance is the ability of the exchange to accept phase deviations on incoming signals without introducing slips or errors.

The jitter/wander tolerance at input A should comply:

— with Recommendation G.824, § 3.1.1, for the A interface at 1544 kbit/s;

— with Recommendation G.823, § 3.1.1, for the A interface at 2048 kbit/s.

This specification may not be applicable to inputs used solely for synchronization purposes (i.e. for deriving the internal timing of the exchange).

2.3 *Interface characteristics at interface B*

The physical and electrical characteristics of interface B are given in §§ 3 and 7 of Recommendation G.703.

2.3.1 *Jitter and wander tolerance at the exchange input*

Jitter and wander tolerance is the ability of the exchange to accept phase deviations on incoming signals without introducing slips or errors.

The jitter/wander tolerance at input B should comply:

— with Recommendation G.824, § 4.2.2, for the B interface at 6312 kbit/s;

— with Recommendation G.823, § 3.1.1, for the B interface at 8448 kbit/s.

This specification may not be applicable to inputs used solely for synchronization purposes (i.e. for deriving the internal timing of the exchange).

2.4 *Interface characteristics at interface* V_1

The functional characteristics of the basic access digital section between the V_1 and T reference-point are defined in Recommendations Q.512 and I.AA. The characteristics and parameters of a digital transmission system which may form part of the digital section for the ISDN basic rate access are given in Recommendation I.AB.

2.5 *Interface characteristics at other V-type interfaces*

The other V-type interfaces will have transmission characteristics of the A and B interfaces as given in §§ 2.2 and 2.3 above.

3 Characteristics of 64 kbit/s half connections

This section covers the essential digital characteristics of 64 kbit/s half connections. Where these requirements are met, the digital half connection will add no impairment to the voice band performance of a complete connection through the exchange (with the exception of delay). The voice band performance of digital half connections may therefore be interpreted by assuming that ideal send and receive sides (see Recommendation G.714) are connected to the digital inputs and outputs respectively. The digital half connection requirements also ensure that any connection through the exchange using a pair of digital half connections will provide acceptable performance for non-voice 64 kbit/s digital services.

3.1 *Half connection characteristics common to all digital interfaces*

3.1.1 *Error performance*

The design objective long-term mean Bit Error Ratio (BER) for a single pass of a 64 kbit/s connection through an exchange between the digital transmissionB/Fswitching interfaces should be 1 in 10^9 or better. This corresponds to 99.5% error-free minutes assuming that the occurrence of errors has a Poisson distribution.

3.1.2 *Bit integrity*

Bit integrity will be maintained if called for to support 64 kbit/s non-telephony services.

Note — It is understood that to meet this requirement, digital processing devices such as μ/A law converters, echo suppressors and digital pads must be disabled for non-telephony calls requiring bit integrity. The means of disabling these devices has yet to be determined. (See Recommendation Q.551, § 1.2.6.1.)

3.1.3 *Bit sequence independence*

No limitation should be imposed by the exchange on the number of consecutive binary ones or zeros or any other binary pattern within the 64 kbit/s paths through the exchange.

3.1.4 *Absolute group dela* y

The requirements for absolute group delay are given in § 3.3.1 of Recommendation Q.551.

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PART II

SUPPLEMENTS TO THE Q.500 SERIES OF RECOMMENDATIONS

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Supplement No. 1

DEFINITION OF RELATIVE LEVELS, TRANSMISSION LOSS AND ATTENUATION/FREQUENCY DISTORTION FOR DIGITAL EXCHANGES

WITH COMPLEX IMPEDANCES AT Z INTERFACES

1 Introduction

During the studies of Study Group XI on transmission characteristics of exchanges it has been recognized that digital local exchanges may require complex impedances at the subscriber line interface (see Recommendation Q.552). These complex impedances result in difficulties with defining relative levels, transmission loss and attenuation/frequency distortion.

This Supplement gives the basis for coherent definitions which are in accordance with the principles outlined by Study Group XII in the G.100 series of Recommendations, Fascicle III.1.

2 Relative levels

There is a clear statement by Study Group XII that relative levels (*L*) — even at ports of complex impendance — relate to power (in general, apparent power) at a reference frequency of 1000 Hz. Accordingly, at a point of zero relative level (i.e. transmission reference point, cf. Recommendation G.101, item § 5.3.1) and at an impedance *Z* , the reference power of 1 mW (at 1000 Hz) corresponds to a voltage:

$$U_o = \sqrt{1\ mW \times |Z|} \qquad (1)$$

It follows that generally at a point of relative level *L* the voltage will be

$$U = 10^{L/20} \times \sqrt{1\ mW \times |Z|} \qquad (2)$$

and that consequently the level *L* can be expressed as

$$L = 20 \log \frac{|U|}{\sqrt{1\ mW \times |Z|}} \qquad (3)$$

This is the basis for a coherent definition of transmission loss, and subsequently of attenuation/frequency distortion, as derived below.

Note — In the future, measurements should be made at 1020 Hz.

3 nominal transmission loss

In the field of telecommunications, it is a well-established practice to define the nominal transmission loss (*NL*) between two points as the difference between the relative levels associated with these points. If, for instance, for a ‘‘connection through a digital exchange’’ the relative level at the input is L_i, and at the output, L_o, then the nominal loss is

$$NL = L_i - L_o$$

Watt is the unit of apparent power as well as of real power.

(4)

Figures 1 and 2, p.

Taking into account that according to the definition of the power reference circuit (Figure 1), $|E|$ is frequency-independent, one obtains from equations (3) and (4) the nominal loss.

$$NL = 20 \log \left| \frac{E}{U(1000 \text{ Hz})} \right| + 10 \log \left| \frac{Z_{02}(1000 \text{ Hz})}{Z_{01}(1000 \text{ Hz})} \right| \tag{5}$$

It may be noted that equation (5) represents the ‘‘composite loss’’ (ITU definition 05.20) at 1000 Hz. The composite loss is the only measure of attenuation that allows adding of the losses of ‘‘half-channels’’ (i.e. A-D and D-A) regardless of the specific impendances at the input and output ports.

4 attenuation/frequency distortion

‘‘Attenuation distortion’’ or ‘‘loss distortion’’ is the result of imperfect amplitude/frequency response and is generally specified in addition to the relative levels of a transmission section, from which the nominal transmission loss is derived. The definition of the attenuation/frequency distortion (*LD*) is well established: it is the difference between the actual response of voltage versus frequency $U(f)$ and the ideal (planned) response of voltage versus frequency $U^*(f)$, referred to the corresponding difference at 1000 Hz:

$$LD = \left[20 \log \left| \frac{E}{U(f)} \right| - 20 \log \left| \frac{E}{U^*(f)} \right| \right] - \left[20 \log \left| \frac{E}{U(1000 \text{ Hz})} \right| - 20 \log \left| \frac{E}{U^*(1000 \text{ Hz})} \right| \right] \tag{6}$$

Equation (6) can be rewritten as follows:

$$LD = 20 \log \left| \frac{U(1000 \text{ Hz})}{U(f)} \right| - 20 \log \left| \frac{U^*(1000 \text{ Hz})}{U^*(f)} \right| \tag{7}$$

For practical reasons the ideal response of voltage versus frequency, $U^*(f)$, is flat. Taking this into account, equation (7) reduces further to

$$LD = 20 \log \left| \frac{U(1000 \text{ Hz})}{U(f)} \right| \tag{8}$$

It should be noted that equation (8) is valid regardless of whether Z_{01} is equal to Z_{02} or not. However, impedance matching at input ($Z_{01}' = Z_{01}$) and output ($Z_{02}' = Z_{02}$) is assumed. A measurement in accordance with equation (8) is entirely in conformity with existing measuring techniques.

5 Conclusions

Nominal transmission loss and attenuation/frequency distortion are essential loss parameters. Their definitions in Sections 3 and 4 are based on the definition of relative (power) levels at 1000 Hz in accordance with Study Group XII which has stated the following advantages:

1) an illustrative indication of passband performance (especially with regard to band-edge distortion and extraneous ripples);

2) a loss definition in accordance with the relative level definition;

3) the loss values are relevant to singing margin evaluation;

4) the loudness insertion loss will be (almost) equal to the exchange loss;

5) additivity with a fair degree of accuracy;

6) the definition is also suitable for half exchange loss currently envisaged by Study Group XI.

Supplement No. 2

IMPEDANCE STRATEGY FOR TELEPHONE INSTRUMENTS AND DIGITAL LOCAL EXCHANGES IN THE BRITISH TELECOM NETWORK

1 Introduction

When planning the introduction of digital local exchanges it is essential to take into account the subjective performance offered to customers. This will, of course, include provision of overall loudness ratings within an acceptable range of values. Noise, distortion and other impairments also need to be adequately controlled. However, it is also important to consider those parameters largely influenced by the impedances associated with telephone instruments, local lines and exchanges. In particular acceptance values of sidetone and echo/stability losses need to be obtained. These parameters are influenced by the choice of:

i) Input and balance impedances of telephone instruments,

ii) Input and balance impedances of the digital exchange hybrid,

iii) Impedances of the 2-wire local lines.

This contribution outlines the impedance strategy adopted for telephone instruments and digital local exchanges in the British Telecom network. It is shown that there are major advantages in adopting complex impedances both for the exchange hybrid and for new telephone instruments. The contribution includes calculations of sidetone, echo and stability balance return losses based on a sample of 1800 local lines in the British Telecom network.

2 Impedance strategy for a digital local exchange

2.1 In order to adequately control echo and stability losses in the digital network the nominal hybrid balance impedance ZB for lines of up to 10 dB attenuation is based on a 3 element network. This network consists of a resistor in series with a parallel resistor/capacitor combination, i.e.:

Figure 1, p.

With appropriate component values it has been found that this network can give significantly improved echo and stability balance return losses compared with a resistive network.

2.2 The nominal exchange input impedance ZI is also based on a 3 element network of the same form as the balance impedance ZB. This network, with suitable component values, is required to give an acceptable sidetone performance on the lower loss lines. It has been found that a 600 Ω resistive input impedance gives unacceptable sidetone performance on these lower loss lines.

3 Impedance strategy for telephone instruments

It should be noted that the digital local exchange is designed to operate with a low feeding current (= 40 mA). The telephone instrument will therefore be operating as though it were connected to a long line on a conventional analogue exchange. In particular, any regulation function will be disabled.

The input impedance of present instruments is, under low current feeding conditions, substantially resistive. It has been found that there is a significant improvement in echo/stability balance return losses at the exchange hybrid if the telephone input impedance is also made complex. The preferred impedance is close to the design value for the exchange balance impedance ZB.

4 Background to calculated results

This section includes the results of calculating STMR values, echo and stability balance return losses for a range of local connections.

Four groups of exchange lines have been used where the groups have mean attenuations of 1 dB, 3 dB, 6 dB and 9 dB. Each group consists of at least 100 samples of local lines in the British Telecom network with attenuations within 1 dB of the mean value for the group.

Two telephone instruments have been used with identical characteristics except for input impedance. One instrument retains a conventional, substantially resistive impedance; the other instrument uses a complex capacitive input impedance. The sidetone balance impedance is, in both cases, designed to match long lengths of 0.5 mm Cu cable.

Two cases for the exchange hybrid impedances are considered. The strategy outlined in Section 2 is used i.e., complex input and balance impedance, and for comparison purposes, a conventional ‘‘transmission equipment’’ hybrid is assumed with nominal 600 Ω input and balance impedances.

Using a computer program, values of echo and stability balance return losses, and sidetone masking rating are calculated for the four exchange line groups with the two telephone instruments and two exchange line hybrids.

5 Results

5.1 *Sidetone values*

For this case the comparison is made between a 600 Ω exchange input impedance and a complex input impedance. (It should be noted that the STMR values have been calculated as in Recommendation P.79 of the Blue Book).

Note — The exchange input impedance has the following approximate values:

R_1 = 300 Ω, R_2 = 1000 Ω, C = 220 nF (see Figure 1).

The results are summarized in Table 1 below:

H.T. [T1.2]

TABLE 1

Calculated values of STMR

Exchange termination	Mean value of STMR (dB) {			
	1	3	6	9
600 Ω	2.6	5.2	8.1	12.4
Complex termination	13.9	14.8	12.7	13.0

Table 1 [T1. p.

It is clear from Table 1 that a 600 Ω termination gives far from satisfactory results with shorter local lines which will include at least 50% of local lines in the British Telecom network. Use of a complex input impedance improves these STMR values by approximately 10 dB and the values are closer to the recommended values given in Recommendation G.121.

These results show that a complex input impedance is essential for the case of sensitive telephone instruments directly connected to digital exchange hybrids. The performance with a resistive impedance is in fact worse than the performance on a conventional analogue exchange because of the low feeding current and impedance masking effect of the digital exchange.

5.2 *Echo and stability balance return losses*

As far as impedance is concerned the most important factor is the choice of the balance impedance for the exchange line hybrid as this determines the network echo and stability performance. Initially a comparison is made between a 600 Ω impedance and a complex impedance assuming existing telephone instruments. Having chosen a balance impedance it is then shown that a further improvement can be made by considering the telephone input impedance.

5.2.1 *Exchange balance impedance*

Table 2 below shows the summarized results for mean values of echo balance return loss (calculated according to Recommendation G.122, Volume III.1, of the Blue Book), and stability balance return loss.

Note — The complex balance impedance has approximate values R_1 = 370 Ω, R_2 = 620 Ω, C = 310 nF (see Figure 1).

H.T. [T2.2]

TABLE 2

Calculated values of mean echo (stability) balance return losses assuming existing telephone input impedance

Exchange balance impedance	{			
	{ 1	3	6	9
600 Ω	22.5 (13.9)	12.9 (7.5)	9.4 (6.2)	8.3 (6.0)
Complex impedance	10.2 (8.0)	13.8 (9.1)	15.2 (11.2)	17.1 (12.9)

Table 2 [T2.2], p.

In addition to calculating mean values for the distributions it is important to consider the edges of the distributions. This is especially true for echo and stability performance where it is the worst case values that are likely to cause network difficulties.

Table 3 shows the minimum values of calculated echo and stability balance return losses for the samples of lines considered. The values for stability balance return loss are those given in brackets.

H.T. [T3.2]

TABLE 3

Calculated values of minimum echo (stability)
balance return losses
assuming existing
telephone input impedance

Exchange balance impedance	{ 1	3	6	9
600 Ω	20 (13)	11 (5)	8 (4)	6 (3)
Complex impedance	9 (7)	11 (7)	12 (9)	11 (7)

Table 3 [T3.2], p.

With the exception of the 1 dB sample of lines it can be seen from Table 2 that the complex impedance results in mean values for the distributions which are higher than the corresponding values using a 600 Ω impedance. The improvement is particularly marked for the higher loss exchange lines. When the minimum values of the distributions are also taken into account (Table 3) there is a clear advantage in using the complex balance impedance. A similar advantage would also be obtained with non-speech devices such as data modems which have an impedance similar to that of the telephone instrument (assuming a low feeding current).

5.2.2 *Telephone input impedance*

Having chosen a suitable complex balance impedance for the exchange hybrid, the options for changing the telephone input impedance can be considered. Tables 4 and 5 present calculated results for the distributions of echo and stability balance return losses at the exchange hybrid, comparing the effect of complex and resistive telephone input impedances.

Note — The input impedance has nominal values R_1 = 370 Ω, R_2 = 620 Ω, C = 310 nF. (See Figure 1.)

H.T. [T4.2]

TABLE 4

Calculated value of mean echo (stability)
balance return losses
assuming complex
exchange balance impedance

Telephone input impedance	{ 1	3	6	9
Resistive	10.2 (8.0)	13.8 (9.1)	15.2 (11.2)	17.1 (12.9)
Complex	29.0 (23.6)	21.0 (13.9)	16.9 (12.8)	17.0 (11.8)

Table 4 [T4.2], p.

H.T. [T5.2]

TABLE 5

Calculated value of minimum echo (stability) balance return losses

assuming complex exchange balance impedance

Telephone input impedance	{ { 1	3	6	9
Resistive	9 (7)	11 (7)	12 (9)	11 (7)
Complex	24 (18)	15 (11)	13 (10)	10 (7)

Table 5 [T5.2], p.

The results in Tables 4 and 5 show a significant improvement in echo and stability balance return losses for the lower loss local lines. There is little difference for the higher loss lines as the balance return loss is primarily determined by the cable characteristics. It can be concluded that there is a clear advantage in designing future telephone instruments with a complex input impedance.

6 New telephone instruments in the existing analogue network

In § 5.2.2 the advantages of a complex telephone input impedance have been illustrated when used with digital exchanges. However, there are also advantages if these instruments are used on conventional analogue exchanges.

The sidetone balance impedance of instruments is generally optimised around the capacitive impedance of unloaded cable. If the telephone input impedance is also capacitive then the sidetone performance of instruments on own exchange calls can be improved. The improvement will be most marked when both instruments are on short lines hence the sidetone is largely determined by the input impedance of the other instrument. This situation is widely encountered on analogue PABXs where the majority of extensions are of low loss.

7 Application to other voiceband terminal equipment

The discussions in this paper have concentrated on telephone instruments. However the conclusions concerning telephone input impedance can equally be applied to other voiceband equipment, e.g., data modems. Work in Study Group XII has shown that higher speed modem services require signal to listener echo ratios approaching 25 dB for successful operation. If the data modem adopts a complex input impedance then the improvements in stability balance return losses (and hence signal to listener echo ratio) discussed in § 5.2.2 can be obtained.

8 Summary and conclusions

This paper has considered aspects of an impedance strategy for the local network with the introduction of digital local exchanges and new telephone instruments.

Calculations based on a large sample of local lines in the British Telecom network have shown that:

i) The input impedance of the digital exchange must take into account the sidetone performance of the telephone instruments. To provide acceptable sidetone performance it has been found necessary to provide a complex input impedance which more closely matches the sidetone balance impedance of the telephone instrument.

ii) Adopting a complex exchange balance impedance gives a significant improvement in echo and stability balance return losses. This improvement is considered necessary to provide adequate echo performance in the digital network without requiring extensive use of echo control devices.

iii) A further improvement in echo and stability losses is obtained by using a complex input impedance for new telephone instruments. This impedance also improves the sidetone performance of connections on analogue exchanges.

iv) The conclusions are also relevant to other voiceband apparatus. Signal to listener echo ratios on voiceband data connections can be improved if the modems use a complex input impedance.

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