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PRINCIPLES OF DETERMINING AN IMPEDANCE STRATEGY FOR THE LOCAL NETWORK

Supplement 31 to
ITU-T Series G Recommendations

(Previously "CCITT Recommendations")

FOREWORD

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

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

Supplement 31 to ITU-T Series G Recommendations was prepared by the ITU-T Study Group XII (1988-1993) and was approved by the WTSC (Helsinki, March 1-12, 1993).

NOTES

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 Similarly, in this reform process, the CCIR and the IFRB have been replaced by the Radiocommunication Sector.

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

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

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PRINCIPLES OF DETERMINING AN IMPEDANCE STRATEGY FOR THE LOCAL NETWORK

(Helsinki, 1993)

(referred to in Series G Recommendations)

1 Introduction

This Supplement gives the background and guidance required to support a consistent approach to impedance planning in the local network. It is clear that impedance issues are having an increasingly important influence on end-to-end performance as they can affect a significant number of transmission parameters. There is a need to bring together the important impedance issues relating to the local part of the overall connection.

Previous contributions to CCITT have indicated that it is highly unlikely that a single set of impedances will be suitable for all networks hence this Supplement does not set out to derive such a unified set of values. The aim is to identify the overall issues and provide sufficient guidance that the transmission planner can develop the optimum solution for his local situation whilst still meeting the CCITT objectives for overall performance.

For the purposes of this Supplement "local network" is taken to include all the customer equipment and network equipment required to provide the transmission path between the acoustic reference point at the customer's telephone instrument and the first 4-wire digital point in the national and international 4-wire chain of circuits. This, therefore, includes all the analogue portions of the connection where impedance can be an issue.

2 Structure

The Supplement is divided into three main clauses:

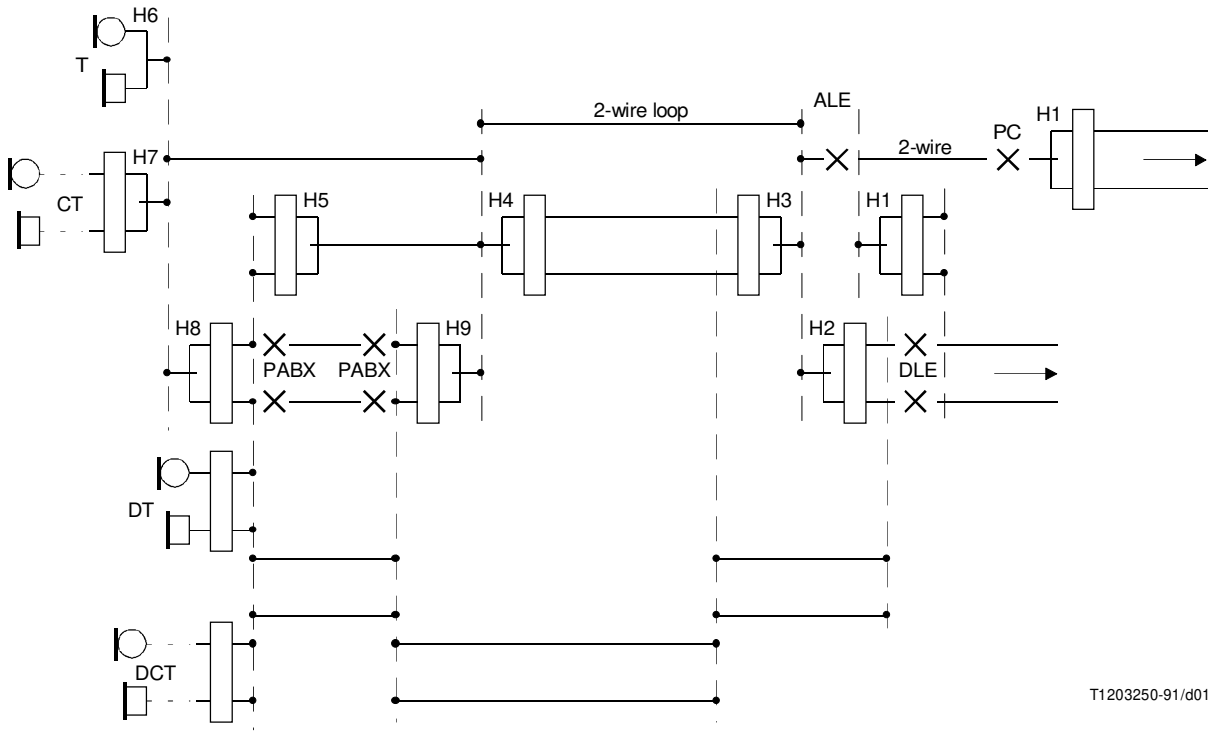
- an outline of the relevant network components (e.g. digital local exchange) and the associated important impedances (e.g. input and balance impedances);
- a guide to the influence of the impedances on the principal transmission planning parameters such as loudness rating, echo and stability. The clause quantifies the contribution of the specific impedances to these parameters and identifies any existing Recommendation covering specific performance objectives;
- an outline of a recommended procedure enabling development of a consistent set of impedances for a new local network situation or to reappraise an existing situation.

3 Relevant impedances

3.1 Customer and network equipment

There are clearly a very large number of combinations of customer and network equipment that could be used to access the national 4-wire chain of circuits. Customer equipment can include fixed or cordless telephones (analogue or digital), analogue or digital PABXs and the interconnecting leased lines. In addition, it is important that non-speech terminal equipment such as voice-band data modems is taken into account as echo can affect the performance of these devices. The network equipment will include the local loop (analogue or digital) and analogue or digital exchanges with their interconnecting junctions.

Whilst it is difficult to illustrate every combination of equipment it is possible to indicate the combinations most likely to influence the impedance arguments. Figure 1 shows typical customer and network equipment, including possible interconnection arrangements for access to the 4-wire chain for commonly occurring equipment. As an example it shows a 2-wire telephone connected to the national 4-wire chain via 2 PABXs, a 4-wire local line, an analogue local exchange and a PCM multiplexor. Figure 1 also identifies the 2-wire to 4-wire conversion units (also referred to as hybrids in the following text) which influence the impedance planning.



T	2-wire telephone connected to PABX or local loop
CT	Cordless digital telephone connected to PABX or local loop
DT	Digital telephone connected to PABX or digital local loop
DCT	Cordless telephone connected to PABX or digital local loop
H1→H9	2-wire to 4-wire converting units
PC	Primary centre
H1	PCM mux terminating 4-wire chain
H2	2-wire interface on Digital Local Exchange (DLE)
H3	Local line transmission mux (exchange end)
H4	Remote mux
H5	2-wire interface for DT and DCT
H6, H7	2-wire interface for T and CT
H8	PABX 2-wire extension interface
H9	PABX 2-wire local loop interface

FIGURE 1

Local network interconnections

3.2 Principal impedances

From Figure 1 the principal impedances are as follows:

- the input and balancing impedances of the various 2-wire to 4-wire conversion units denoted as H1 to H9;
- the impedances associated with the 2-wire cable sections (e.g. 2-wire local loop);
- the "impedance transparency" of the 2-wire switches (e.g. analogue local exchange);
- the impedance of 1 port customer terminal equipment (e.g. telephone instruments or data modems).

The above impedances all need to be taken into account when considering the principal transmission planning parameters.

4 Influence of impedances on principal transmission parameters

4.1 General

This subclause considers each impedance (or group of impedances) in turn and identifies its contribution to the principal transmission parameters. The parameters covered are:

- sidetone ratings (STMR, LSTR);
- talker echo;
- stability loss;
- listener echo;
- loss frequency distortion.

The aim is for the subclause to provide:

- a reference to identify the effect of any one impedance on overall performance;
- the basic data to enable clause 5 to propose a logical approach to impedance planning.

4.2 Sidetone ratings (STMR and LSTR)

Definitions and objectives for STMR and LSTR are found in Annex A/G.111. The assumption that STMR applies for round-trip delays of up to 3 ms will be used here; for longer delays the talker echo approach will be used. The contribution of impedance matching to achieving the objectives can best be illustrated by the expressions below taken from Annex A/G.111.

$$\text{STMR} = \text{SLR(set)} + \text{RLR(set)} + A_{\text{m}} - 1$$

where A_{m} is a function of the telephone input and sidetone balancing impedances and the impedance presented to the telephone set.

From Figure 1 the key impedances influencing the value of A_{m} and hence the sidetone performance are:

- balance impedances of telephone hybrids H5, H6 and H7;
- balance impedance of PBX hybrid H9;
- balance impedance of local transmission mux;
- input impedance of hybrids H1, H2, H4 and H8;
- image impedance of 2-wire cable sections.

From this list it may be concluded that:

a) balance impedances of hybrids part of the sidetone paths (H3, H5, H6, H7 and H9) will have similar effects on values of sidetone and should be considered together;

b) input impedances of hybrids H1, H2, H4 and H8, i.e. those having a significant influence on the impedance presented to the telephone set should be considered together;

c) optimum performance would be achieved if the impedances listed in a) had the similar values to the impedances listed in b).

It will be noted that there are both upper and lower limits for sidetone, not very far apart. To respect these limits for all lengths of line presents a problem for an impedance strategy, which is different according to whether regulated or non-regulated telephones are used. For non-regulated telephone sets, SLR and RLR remain constant in equation (1), so that A_{m} (and hence the impedance presented to the telephone set) must remain substantially constant, irrespective of line length. For regulated sets, SLR and RLR both increase for sort lines, so that A_{m} must correspondingly fall off, i.e. the exchange impedance can, and should, differ quite considerably from the image impedance of the line.

4.3 Talker echo

The factors governing talker echo and its effect on customer opinion are discussed in Supplement 2/G.131 – Talker echo on International Connections. This Supplement shows that the Overall Loudness Rating of the talker-echo path for connections with 2-wire points is strongly influenced by the echo balance return loss at the listener's end. Echo balance return loss is a weighted average of the individual balance return losses at frequencies in the range 300-3400 Hz. (See Recommendation G.122).

Echo balance return loss is a function of the various impedances of the connection which need to be considered in any echo strategy. Annex B/G.122 shows that for the case where the national extension includes a 2-wire section echo loss is a function of the balance impedances of the hybrid terminating the 4-wire national and international chain and the impedance presented to that hybrid, i.e. the combined effect of the local network impedances.

From Figure 1 the key impedances influencing talker-echo performance are:

- the balance impedance of hybrids that may terminate the 4-wire chain of circuits;
- the input impedance of hybrids connected to the 2-wire connection sections;
- the image impedance of 2-wire cable sections.

From this list it may be concluded that:

a) balance impedances of hybrids “facing” the echo path will have similar effects on the echo balance return loss sidetone path and should be considered together;

b) input impedances of relevant hybrids connected to the 2-wire section should be considered together;

c) optimum performance would be achieved if the impedances listed in a) had similar values to the impedances listed in b).

4.4 Stability

4.4.1 Call phases

The stability of connections involving 2-wire and 4-wire sections is of importance both during the call set-up (and clear-down) phase and the conversation phase. In both cases the value of interest is the lowest loss of the path a-t-b in the 0-4 kHz frequency range as shown in Figure 1/G.122. As outlined in Recommendation G.122 the balance return loss of the relevant hybrids are a key factor in determining the lowest loss of the path a-t-b; this is normally called the stability balance return loss – the lowest value in the 0-4 kHz frequency range.

However, the terminating conditions for the 2 phases are not equal hence they need to be treated separately as outlined in Recommendation G.122.

4.4.2 Stability balance return loss of an established connection

A comparison of 4.3 and 4.4 will show that echo balance return loss (EBRL) and stability balance return loss (SBRL) of an established connection are both calculated from the same data, i.e. balance return losses at frequencies in the range 0-4 Hz. The difference being that EBRL is a weighted average of balance return losses in the range 300-3400 Hz and SBRL is the lowest value of balance return loss in the range 0-4000 Hz.

The impedances that are significant in determining talker echo (and EBRL) are also the key impedances for determining SBRL of an established connection, hence the conclusions in 4.3 apply.

4.4.3 Stability balance return loss during set-up and clear-down

For the set-up and clear-down condition, customer terminal equipment and network equipment does not necessarily present the same impedances as under conversational conditions. Where these impedances are not known it is common practice to assume worst case terminating impedances, e.g. open circuit and short circuit, and evaluate SBRL. Under these conditions the input impedance of the relevant hybrids are also important as the mismatch factor can be a significant contributor to the balance return loss.

However, it should be recognized that SBRL is only one of the factors influencing stability and should not be treated in isolation. For example, it may be that a digital exchange will not connect both directions of transmission before the called subscriber answer signal is received, hence there will be no path for oscillations to build up. These aspects are discussed in Recommendation G.122.

4.5 Listener echo

Listener echo can be experienced by telephony customers where it results in a "hollow" quality which may be found disturbing. This can be encountered when 4-wire digital exchanges (including PBXs) are set up with a low transmission loss to interwork with existing 2-wire cabling.

Listener echo for telephony customers is determined by the balance return losses of the relevant hybrids in a similar manner to talker echo. The same impedances therefore determine the contribution to both talker echo and listener echo and similar impedance relationships exist as outlined in 4.3. In general, it is true that acceptable values of EBRL for voice will ensure acceptable listener echo performance for voice customers (see 4.1/G.126).

However, as outlined in Recommendation G.126, listener echo tends to have a more serious impact on voice-band data signals where the double reflected signals can increase the bit error ratios. The remainder of this subclause will therefore concentrate on listener echo as it affects voice-band data.

Voice-band data is in many cases carried over the same network as voice traffic with the identical network impedances. However, the data modem impedance may not be the same as the telephone instrument impedance, hence different values of balance return loss would be achieved. Recommendation G.126 also recommends that frequencies in the range 500-2500 Hz are of most importance to modem services and balance return losses should be calculated in that range.

The conclusions on the network impedances outlined in 4.3 also apply to listener echo where the modem is connected to the 2-wire local line via a hybrid, which replaces the telephone hybrid, e.g. H6.

4.6 Loss frequency distortion

The effect of loss frequency distortion (attenuation distortion) on voice performance is outlined in Annex B/P.11. Loss frequency distortion needs to be considered in an impedance strategy as impedance mismatch at voice band interfaces between equipment that can introduce additional distortion. From Figure 1 the key impedances will be:

- input impedance of all hybrids (H1-H9);
- image impedance of 2-wire cable sections.

5 Outline approach to determining values for key impedances

5.1 Scope

There are unlikely to be many cases where a transmission planner has a totally new network situation to consider where there are no existing equipment constraints.

The most likely application for an impedance strategy will be to review an existing situation, then make recommendations that will cover the longer term case of evolution to digital transmission and switching between 2-wire local cabling.

This subclause adopts the following staged approach:

- make proposals for customer and network impedances for the long term case of customer terminal equipment (excluding PBXs), analogue 2-wire loops with digital local exchanges;
- consider requirements for the case of digital local network transmission equipment;
- propose a solution to cover any interim analogue-digital interworking situations that will eventually disappear from many networks.

5.2 Analogue 2-wire cabling

It is assumed that the existing base of local loop plant is unlikely to change significantly in the medium term for economic reasons. There may be increased use of fibre access but the installed 2-wire base is likely to be the major influence on impedances.

A knowledge of the individual local network under study is required for any impedance analysis. Several countries have adopted the approach of taking a representative sample of local lines and determining the detailed cable make-up from record examination or measurements. The cable information needs to be in a form that can be used by a transmission calculation program that can derive values for balance return losses and the relevant loudness quantities. Supplement 3/P.11 gives examples of such programs.

The following stages are suggested for arriving at provisional impedance values.

NOTE – The impedances associated with each hybrid are shown using the following convention:

Z_{B6} represents the balance impedance of the telephone hybrid H6;

Z_{I2} represents the input impedance of the exchange hybrid H2.

Stage 1 – Determine values for Z_{B6}, Z_{I2} to meet STMR objectives

A value for Z_{B6} can be estimated by considering a sample of the longer lines from the local line data base. Z_{B6} should give a sufficient match against these lines to provide acceptable values of STMR and LSTR. For these longer lines the choice of Z_{I2} is less critical.

Using this provisional value for Z_{B6}, the STMR performance for shorter lines can be investigated. This will lead to a provisional value for Z_{I2}.

Due regard must be paid to the type of telephone set in use (regulated or non-regulated), as pointed out in 4.2 above.

Stage 2 – Determine values for Z_{I6}, Z_{B2} to meet echo and stability objectives

From clause 4 there are several criteria to meet for the echo and stability objectives. An iterative approach is likely to be required to find a solution that meets all the requirements. A suggested starting point is to derive a value for Z_{B2} that gives acceptable echo balance return losses for short, average and long local loops. However, it may be that a single value for Z_{B2} is not possible and the range of values for different categories of local loop need to be adopted. This will also depend on the starting value assumed for Z_{I6}, hence the need for an iterative approach.This iterative approach is generally amenable to computer analysis techniques.

Section 4 proposed that optimum echo performance could be achieved when Z_{I6} and Z_{B2} were equal. The echo losses should therefore be recalculated with this assumption and the results compared. If an improvement is seen, then the new value for Z_{I6} could be adopted.

Stage 3 – Impact of voice-band data equipment

Stages 1 and 2 have now produced provisional values for the input and balance impedances of the telephone instrument and digital local exchange that broadly meet the sidetone, echo and stability criteria. Further calculations should now be done to check the effect on stability and listener echo using appropriate modem impedances. It may also be necessary to review stages 1 and 2 if it proves difficult to meet the stability and listener echo objectives.

Stage 4 – Application of calculated values to other equipment

The above stages should result in a set of compromise impedances for telephone instruments, data modems and digital local exchanges that meet the objectives for the key network parameters identified in clause 4. However, the values are also appropriate to other terminal equipment. For example:

- the telephone impedance Z_{I6} is also applicable to the input impedance of the digital and cordless telephone interfaces Z_{I5} and Z_{I7};
- similarly, the telephone balance impedance Z_{B6} could be used as the balance impedance Z_{B5} and Z_{B7}. However, in this case, it should be noted that cordless instruments introducing transmission delays of longer than a few ms may require additional impedance control as "sidetone" will tend to be perceived as talker echo.

5.3 Digital local transmission

This subclause covers the case where network modernization has extended the 4-wire chain out to a point at, or close to the customer's premises. The customer is then provided with either a 2-wire interface using a remote multiplexor or a digital interface at the primary or basic rate. From Figure 1 the key interfaces are:

- H4, the remote multiplexor providing the 2-wire interface to the customer's premises;
- H8, the PABX interface providing the 2-wire point for connection of PBX extension equipment.

These interfaces have similar positions in the transmission plan, in that they both terminate the national and international chain of 4-wire circuits and in some cases will provide the only contribution to the overall stability and echo of a connection. The impedances adopted for H4 and H8 should therefore be based on the H2 impedances developed in 5.2. However, as the 2-wire loop associated with H4 and H8 is likely to be short in length, the choice should reflect any short line option selected for H2.

H4 and H8 impedances based on these criteria should result in acceptable sidetone performance and acceptable values for echo and stability losses.

5.4 Analogue/digital interworking situations

The hybrids in Figure 1 that have not been covered are those providing interworking functions that will tend to disappear as networks evolve. However, for most Administrations they represent a large part of the installed base and need to be considered for impedance planning. Considering each in turn:

H9 – PABX 2-wire loop interface.

Z_{B9} influences the sidetone experienced by PABX users. Following the discussion in 4.2, Z_{B9} should have similar values to the telephone balance impedance Z_{B6}. Z_{I9}, the impedance presented to the public network, should have similar values to the telephone input impedance Z_{I6}.