INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

K.10

(10/96)

SERIES K: PROTECTION AGAINST INTERFERENCE

Low frequency interference due to unbalance about earth of telecommunication equipment

ITU-T Recommendation K.10

(Previously CCITT Recommendation)

ITU-T K-SERIES RECOMMENDATIONS

PROTECTION AGAINST INTERFERENCE

For further details, please refer to ITU-T List of Recommendations.

FOREWORD

The ITU-T (Telecommunication Standardization Sector) is a permanent organ of the International Telecommunication Union (ITU). 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, establishes the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

The approval of Recommendations by the Members of the ITU-T is covered by the procedure laid down in WTSC Resolution No. 1 (Helsinki, March 1-12, 1993).

ITU-T Recommendation K.10 was revised by ITU-T Study Group 5 (1993-1996) and was approved by the WTSC (Geneva, 9-18 October, 1996).

NOTES

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

2. The status of annexes and appendices attached to the Series K Recommendations should be interpreted as follows:

- an *annex* to a Recommendation forms an integral part of the Recommendation;
- an *appendix* to a Recommendation does not form part of the Recommendation and only provides some complementary explanation or information specific to that Recommendation.

CONTENTS

SUMMARY

This Recommendation gives limiting values of unbalance about earth of telecommunication equipment for the domain of the low frequency band (below a few tens of kHz), presents methods of measurements permitting characterization of the effects of unbalance and provides information about the choice of relevant means of protection.

LOW FREQUENCY INTERFERENCE DUE TO UNBALANCE ABOUT EARTH OF TELECOMMUNICATION EQUIPMENT

(Mar del Plata, 1968; revised in 1984, 1993, 1996)

1 Introduction

When a telecommunication installation located in an electromagnetic environment presents an unbalance of impedances about a reference conductor (earth, common conductor), it exposes the network not only to noise effects disturbing the useful signals (reception aspect) but also to radiating phenomena able to disturb other telecommunication installations placed in the vicinity (emission aspect).

From this point of view, the balance constitutes a fundamental aspect of quality which is necessary for the electromagnetic compatibility of networks.

This Recommendation presents methods of measurement permitting characterization of the effects of unbalance and also gives some information about the choice of relevant means of protection. The user will find in Appendix I some theoretical tools useful for the analysis of unbalanced equipment.

In addition, information is given in several other ITU-T publications concerning the theory of disturbing mechanisms, the definitions of unbalance parameters and some principles of measurement [1] and [2].

2 Scope

This Recommendation covers the domain of the low frequency band extending from the fundamental frequency (16 2/3 Hz, 50 Hz, 60 Hz) and its harmonics, generated by the electrical power and traction systems, up to higher frequencies (up until a few tens of kHz) generated by any other industrial or domestic electrical equipment.

In this frequency range and considering a normal situation (very low unbalance), the emission effects due to unbalance are negligible. Consequently, this Recommendation will consider only the reception aspect of unbalance as the conversion from common mode to differential mode process.

Considering the low frequency band, the typical equipment under study will be the terminating equipment connected at the ends of lines, such as the interfaces in exchange and the subscriber’s terminal including indoor cabling. The cables will not be taken into consideration, due to the fact that they present a balance much higher than that normally found in equipment. Furthermore, ISDN equipment is not covered by this Recommendation.

The methods of measurement presented in this Recommendation refer to the field of testing in the laboratory and some aspects of maintenance activities.

3 Reference texts

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

[1] ITU-T Directives, Volumes II, III, VI and IX.

[2] CCITT Recommendation O.9 (1988), *Measuring arrangements to assess the degree of unbalance about earth.*

[3] ITU-T Recommendation G.117 (1996), *Transmission aspects of unbalance about earth.*

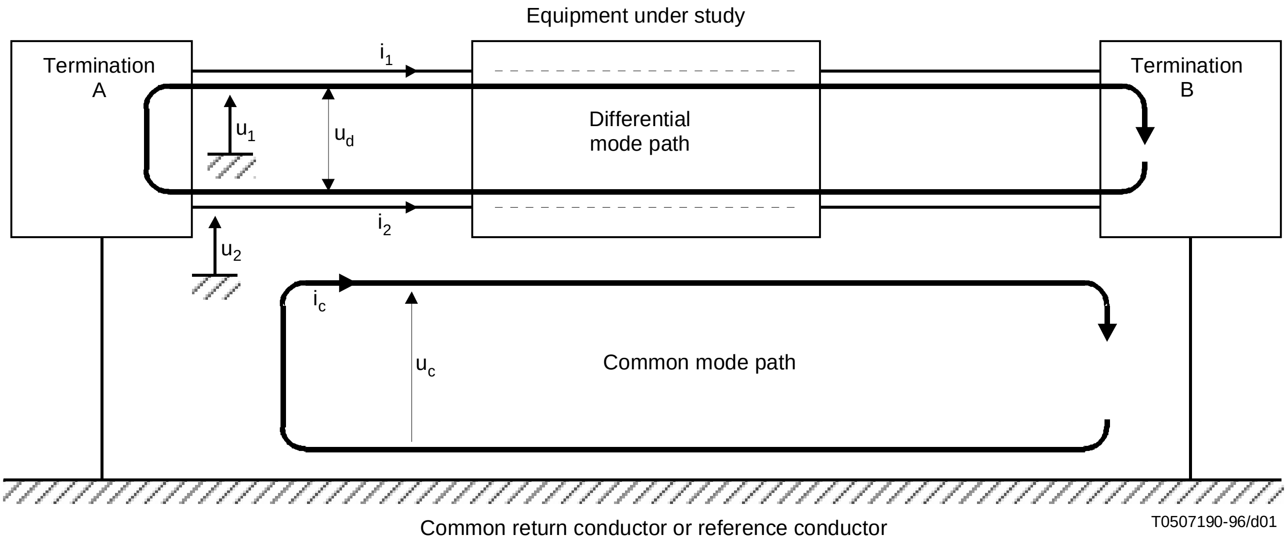
[4] ITU-T Recommendation G.712 (1996), *Transmission performance characteristics of pulse code modulation.*

[5] ITU-T Recommendation Q.552 (1996), *Transmission characteristics at 2-wire analogue interfaces of digital exchanges.*

4 Definitions

4.1 Reference circuit representation

Figure 1 gives a general representation of a telecommunications circuit showing the different transmission paths involved in the noise generation mechanism.



$u_c = \frac{u_1 + u_2}{2}$ common mode voltage

$i_c = i_1 + i_2$ common mode current

$u_d = u_1 - u_2$ differential mode voltage

Figure 1/K.10 – General representation of a disturbed system

4.2 longitudinal path: The term longitudinal path is applied to any loop with reference earth return. By definition, such a circuit is totally unsymmetric.

4.3 common mode path: The common mode path shown in Figure 1 is made of the two wires of a symmetrical pair with a reference conductor. In case of a cable line with a metallic sheath, the analysis of the problem of interference generally needs to distinguish two circuits:

1) The external longitudinal loop (see 4.2) formed by the sheath and the external return (earth).

2) The internal common mode loop formed by a pair with its terminations and the common mode return (sheath).

4.4 common mode interference: Interference appearing between both conductors of a pair and a common reference plane (earth). It causes the same potential to appear on both conductors relative to the common reference.

4.5 common mode voltage and current:

voltage: The mean of the phasor voltages appearing between each conductor and a specified reference, usually earth or local zero voltage reference points (refer to Figure 1).

current: The sum of the phasor currents flowing in any two or a specified set of active conductors (refer to Figure 1).

4.6 common mode parameters: The series impedance of a pair with reference to the return conductor and the shunt admittance of a pair to the reference conductor (internal or external).

4.7 longitudinal electromotive force (emf, E_{L1}): A source or a phasor sum of sources acting in a loop composed of one or more conductor(s) and return path, usually earth or local zero voltage reference points.

4.8 differential mode voltage and current:

voltage: The voltage between any two of a specified set of conductors, usually a symmetrical pair.

current: The current flowing in any two or a specified set of conductors, usually a symmetrical pair.

4.9 conversion from common mode to differential mode: The process by which the common mode interference applied to an unbalanced circuit produces a differential mode signal (noise).

4.10 unbalance about reference conductor: The unbalance about reference conductor (earth or any other reference conductor) is the difference between the common mode parameters of the different paths of transmission loop. The unbalance may be characterized by a difference between series impedances or shunt admittances.

The term balance is generally used as a factor of quality of the installation regarding the unwanted effects of conversion.

4.11 longitudinal conversion loss (LCL): LCL is defined in Recommendation O.9 as the ratio expressed in decibel, of the value of electromotive force impressed in the longitudinal path and the value of the differential mode voltage appearing at the input port of the equipment under test (refer to Figure 2).

$$LCL = 20 \cdot Log_{10}\left(\frac{E_{L1}}{Ud_1}\right) \text{ dB}$$ (applicable for one or two ports network)

When the measurement is made under real conditions, the longitudinal conversion loss is denoted LCL_R (see 5.3.2).

4.12 longitudinal conversion transfer loss (LCTL): LCTL is defined in Recommendation O.9 as the ratio expressed in decibel, of the value of electromotive force impressed in the longitudinal path and the value of the differential mode voltage appearing at the output port of the equipment under test (refer to Figure 2).

$$LCTL = 20 \cdot Log_{10}\left(\frac{E_{L1}}{Ud_2}\right) \text{ dB}$$ (applicable for two port network only)

4.13 equipment under test (EUT): The equipment under test may be a line interface in an exchange (or transmission centre) or a piece of transmission or terminal equipment.

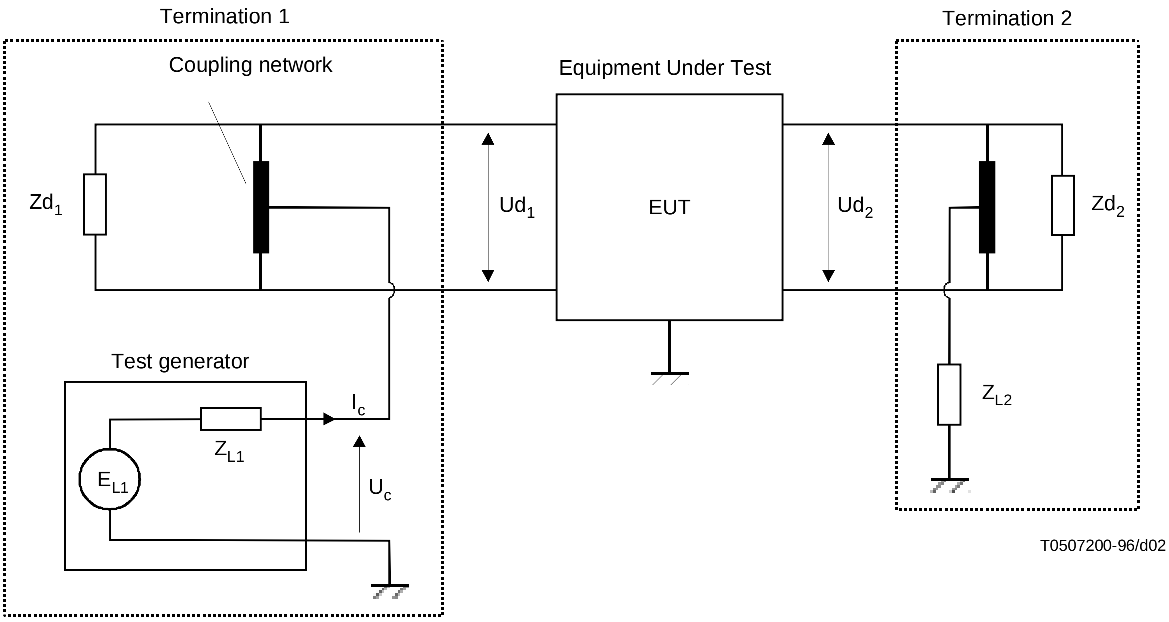
More particularly the term "equipment" will designate an interface circuit connected at the end of a cable.

5 Unbalance test

5.1 Test arrangement

The test of the effects of unbalance of a two port equipment can be made in accordance with Figure 2. In the case of a one port equipment, the termination 2 is included inside the EUT.

Termination 1 represents the induced source with an appropriate common mode generator and terminating impedances for both common and differential modes, e.g. induced line with its remote termination.



Zd_1, Zd_2	differential mode impedance of terminations
Z_{L1}	common mode impedance of the termination 1 (disturbing source)
Z_{L2}	common mode impedance of termination 2
E_{L1}	disturbing longitudinal emf impressed at the input of EUT
U_c	common mode voltage applied at the input of EUT
I_c	current flowing in the common mode circuit
Ud_1, Ud_2	differential mode voltages at the input port and output port of the EUT respectively

Figure 2/K.10 – General method for testing the effects of unbalance of equipment

5.2 Testing conditions

5.2.1 Parameters

Testing Device: It should not noticeably affect the equipment under test.

Coupling network: It can be realized by a centre tapped coil or any other equivalent circuit having the same function. Such a circuit should have balance much better than the equipment. It must not noticeably affect the values of the differential mode impedances of the circuit.

Ud_1, Ud_2: The differential mode signals should be measured with an apparatus which will not affect the balance of the whole circuit under test.

Terminations: The terminations shall represent the common mode and differential mode impedances as close as possible to the real impedances connected at the end of the equipment.

Zd_1, Zd_2: The differential mode impedances will generally be identified as the characteristic impedance relevant to the measuring frequency.

Z_{L1}: The common mode impedance of the induced source will be determined according to the specifications of Recommendation O.9 (see 5.3.1) or by measurement under real operational conditions (see 5.3.2). A comparison of the two methods is included in 5.3.2.

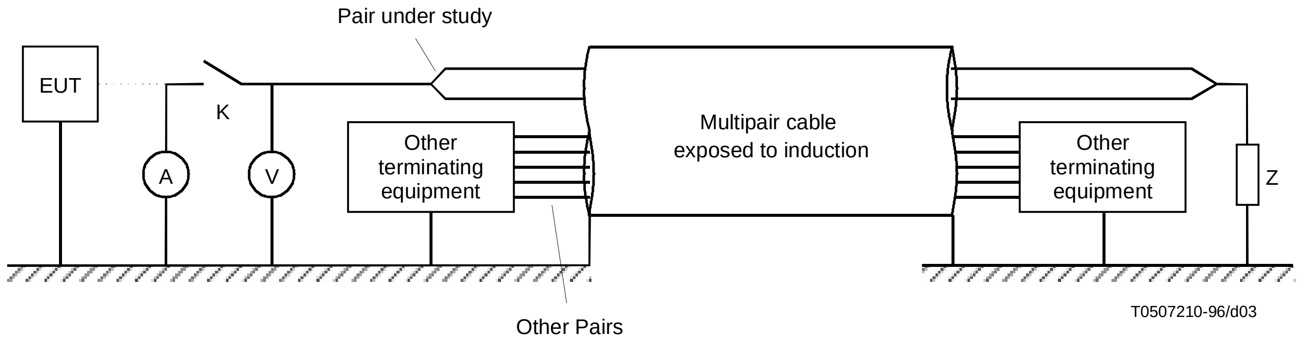
Z_{L2}: The common mode impedance characterizing termination 2 shall be determined either by calculation or measurement.

E_{L1}: The longitudinal emf provided by the induced source shall be estimated according to the principles given in 5.2.2.

5.2.2 Identification of parameters for measurement under real operational conditions

The parameters E_{L1} and Z_{L1}, which characterize the disturbing generator, can be estimated by theoretical calculations, but such an approach remains a complex task due to the large number and variability of the parameters involved in the whole process of noise effects.

A more practical approach is measuring such parameters in the field with real disturbing environments. These measurements should be made in a large enough number to perform a statistical treatment in order to obtain values representative of the environment. In order to achieve this, the common mode parameters E_{L1} and Z_{L1} shall be measured according to Thévenin's principle and under a real configuration of communication. Figure 3 gives an example of the measurement of Thévenin's parameters.



Z common mode impedance characterizing the remote termination connected at the pair under study

Figure 3/K.10 – Characterization of the equivalent disturbing generator

5.3 Measurements

5.3.1 LCL measurement with a test bridge (Recommendation O.9)

In case of measurement with a test bridge as specified in Recommendation O.9, the common mode impedance Z_{L1} is equal to a quarter of the differential mode impedance of the termination (typically Z_{L1} = 150 ohm).

The value LCL indicates the conversion to the differential mode voltage only for that condition when the disturbing source has a low common mode impedance (e.g. a long cable or a cable with the remote end terminated in a low common mode impedance).

5.3.2 LCL_R measurement under real conditions

When measuring under real conditions, the common mode impedance of the test generator will be the real common mode impedance of the line with its remote termination (see 5.2.2).

Due to the difference between the real source impedances and the one specified in Recommendation O.9, the LCL_R and LCL values will generally be different.

The following simplified formula (5-1) will permit a conversion between the two methods:

$$LCL_R = LCL + 20 \cdot Log\left(\frac{Zcm_L + Zcm_{eqt}}{Z_{L1} + Zcm_{eqt}}\right) \qquad (5\text{-}1)$$

LCL_R	Longitudinal Conversion Loss measured under real conditions (Figure 3)
LCL	Longitudinal Conversion Loss measured under O.9 specifications
Zcm_L	common mode impedance of a real disturbing source (Figure 3)
Zcm_{eqt}	common mode impedance of the equipment under test
Z_{L1}	common mode impedance specified in Recommendation O.9

From a practical point of view, when measuring at the end of a cable with an earth free remote termination (e.g. a measurement point at the interface exchange and a remote termination as a subscriber's terminal) the common mode impedance Zcm_L will be significantly higher than the common mode impedance Z_{L1} of the O.9 test bridge. In that case, it can be seen from the expression (5-1) that the LCL value obtained under real conditions will be much higher than the LCL value obtained with a test bridge.

6 Admissible values

In order to offer a minimum quality regarding the symmetry of an equipment of telecommunication, it is recommended that the admissible minimum values concerning the Longitudinal Conversion Loss (LCL) measured with the specifications of Recommendation O.9 should be equal to:

40 dB from 300 Hz up to 600 Hz

46 dB from 600 Hz up to 3400 Hz

When measuring under real conditions (see 5.3.2), the minimum values are in most cases higher than those recommended above, by at least about 6 dB. When evaluating real interference situations, these higher values may be used.

As a rule, a minimum LCL_R value guarantees the compatibility of an equipment by maintaining the noise level under a maximum admissible limit in a given environment characterized by a level E_{L1}. This principle can be expressed with the expression (5-2).

$$LCL_{R\,\min} = 20 \cdot Log\left(\frac{E_{L1}}{u_{d\,\max}}\right) \text{dB} \qquad (5\text{-}2)$$

From the expression (5-2), it can be seen that the constraint about the minimum LCL_R value logically increases with the level of common mode interference. It is important to emphasize that the level of interference generally reaches a maximum at ends which are free from earth and consequently the LCL_R constraint should be higher at these locations. This is the reason why the 40 – 46 dB minimum values specified above will be acceptable limits for equipment such as line interfaces in exchange. On the other hand, the minimum values should be much higher for the subscriber's installation or for any comparable unfavourable configuration (see I.2).

In conclusion, the solutions of the problems of compatibility will always require a technical and economical choice between decreasing the level of interference and/or improving the degree of quality.

7 Protection against effects of unbalance of equipment

The very first solution of protection is to respect the minimum LCL values required in clause 6.

When the LCL value is incompatible with the environment, because of too high a level of interference, it will be appropriate to adopt one or several of the following solutions:

a) Decreasing the level of inducing effects in the disturbing system.

b) Decreasing the level of interference impressed on the telecommunication installation.

   One or several of the following solutions may be used:

   – decreasing the coupling by separation where the sections of cable are suffering exposure;

   – use of shielded cables. The sheath must be continuous between both terminations and extend to the reference conductor (earthing or common conductor) of the terminal equipment wherever possible. When the environment is strongly disturbing, the use of cable with steel armouring (ferromagnetic shield) is recommended;

   – use of neutralizing transformers in cable.

   NOTE – When using a cable with sheath having a limited reducing effect, earthing may increase the common mode magnitude between the pairs and the sheath, and consequently increase the noise due to unbalance. This is why the respect of sheath continuity is more important than earthing in the low frequencies range.

   When using a cable with a screening factor (when the transfer impedance becomes different from the d.c. resistance of the sheath), the sheath shall be earthed.

c) Decreasing the level of interference impressed at the input port of the equipment by common mode filtering.

Appendix I

Disturbing mechanisms

I.1 Origin of noise effects

When installations of telecommunication are located in an electromagnetic environment, induced voltage and current may appear between the active conductors and the reference conductor (earth or any other common conductor). This interference called common mode interference will propagate through the network along the metallic wiring structures (pairs, sheath, earth conductor) and generate noise voltages superimposed on the useful signals. This disturbing effect may be caused by one or more of the following phenomena:

1) Conversion from common mode to differential mode due to unbalance in the lines, the terminal, the switching equipment, and any other equipment inserted in the longitudinal path.

2) Saturation of the feeding circuit, coder filter, and so on.

3) Quantizing distortion of the differential mode voltage produced by unbalance.

4) Intermodulation between differential mode voltage appearing at the fundamental frequency and the voiceband signal.

Frequently, the effect of unbalance takes place at the first stage in all these processes.

Unbalance concerns impedances and admittances. It may be distributed along the lines or concentrated at the input port of equipment. When a common mode interference is impressed on an unbalance, it will generate a differential source (noise generator) due to a process called *common mode conversion*. The different noise sources can be represented as follows:

a) Distributed or discrete series emf equivalent to the difference of the voltage drop in unbalanced series impedances. The signals from such sources are proportional to the common mode current and unbalance values (delta Z).

b) Distributed or discrete shunt current source equivalent to the difference of the current flowing in parallel admittances. The signals from such sources are proportional to the common mode voltage and shunt unbalance values (delta Y).

Then the noise sources will generate noise voltages which will propagate through the network according to classical transmission theory.

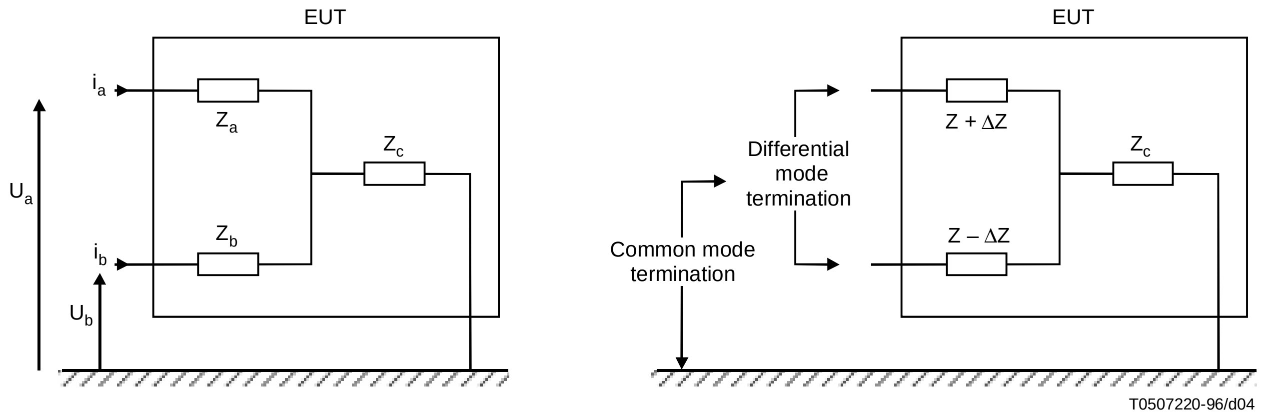
The whole process involves many parameters which can be summarized as follows:

- the magnitude and frequency of the impressed common mode quantities at the point of unbalance;
- the value of unbalance between the parameters about reference conductor (delta Z and delta Y);
- the transmission function between the point of conversion and the point of measurement.

From a practical point of view, the analysis of the noise conversion in a cable appears quite difficult because of the large variability of the parameters above and their random distribution along the cable. On the other hand, the analysis of the noise conversion at the input of the equipment is much easier because all these parameters are simpler to characterize. Subclause I.2 presents a simplified theoretical approach which will be useful for a better understanding of the conversion phenomena at the input of the equipment.

I.2 Conversion mechanism at the input of an equipment

The input circuit of a one port equipment can be represented by means of the equivalent circuit shown in Figure I.1.



Z_a, Z_b, Z_c wye representation of the input circuit

$Z = \frac{Z_a + Z_b}{2}$ average value of unbalanced impedances

$\Delta Z = \frac{Z_a - Z_b}{2}$ equivalent unbalance of impedances

Figure I.1/K.10 – wye equivalent circuit of an equipment with unbalance about common conductor

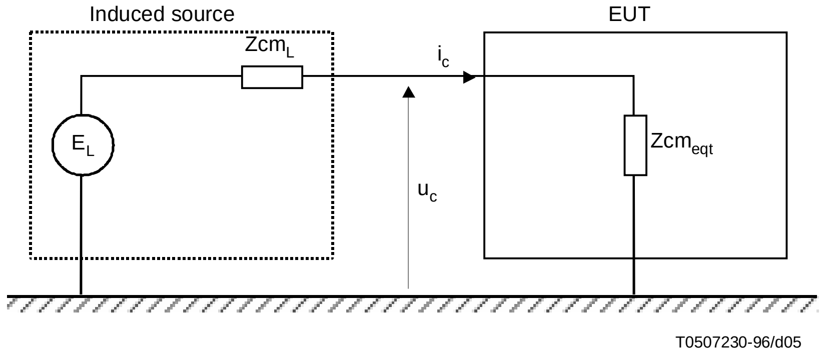
A simplified method of calculation consists of studying in two steps the common mode circuit and the differential mode circuit.

Considering an equipment connected to a line exposed to induction, the whole common mode circuit will be represented as shown in Figure I.2.

From Figure I.2, the following expressions for the common mode quantities can be deduced:

$$u_c = \frac{Zcm_{eqt}}{Zcm_{eqt} + Zcm_L} \cdot E_L$$ common mode voltage (I-1)

$$i_c = \frac{E_L}{Zcm_{eqt} + Zcm_L}$$ common mode current (I-2)

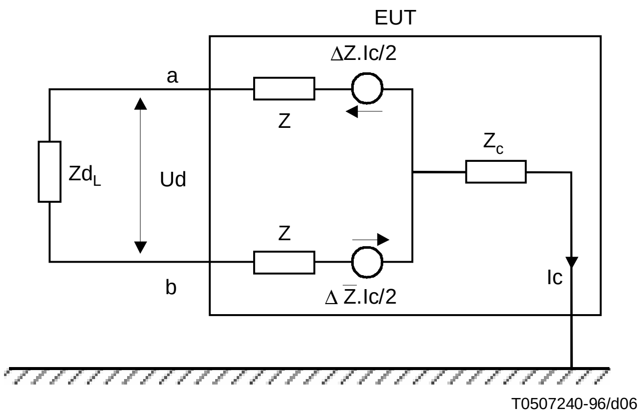


E_L	equivalent common mode emf
Zcm_L	common mode impedance of the disturbing source
$Zcm_{eqt} = \frac{Z}{2} + Z_c$	common mode impedance of the equipment
$u_c = \frac{u_a + u_b}{2}$	common mode voltage
$i_c = i_a + i_b$	common mode current

Figure I.2/K.10 – Model of the common mode circuit

In these expressions, it is important to notice that the E_L and Z_L are equivalent parameters characterizing a real disturbing generator. Such parameters can be estimated by theoretical calculations (multiconductor method [1]) or by measurement applying Thévenin's principle at the end of the induced line.

The difference of the voltage drop produced by the current flowing through the input series impedances can be modelled by a series noise emf inserted in the differential mode circuit. This phenomenon called conversion from common mode to differential mode is illustrated in Figure I.3.



Zd_L differential mode impedance measured at the end of the line connected to the EUT

Figure I.3/K.10 – Model of the differential mode circuit

From the circuit on Figure I.3, we can express the noise voltage seen at the input port of the equipment by:

$$Ud = \frac{Zd_L \cdot \Delta Z}{Zd_L + 2 \cdot Z} \cdot ic = \frac{Zd_L \cdot \Delta Z}{Zd_L + 2 \cdot Z} \cdot \frac{uc}{Zcm_{eqt}} = \frac{Zd_L \cdot \Delta Z}{\left(Zd_L + Zd_{eqt}\right)} \cdot \frac{E_L}{\left(Zcm_L + Zcm_{eqt}\right)} \qquad \text{(I-3)}$$

with: $Zd_{eqt} = 2 \cdot Z$

From the expression (I-3), we deduce the expression of the Longitudinal Conversion Loss under real conditions (LCL_R):

$$LCL_R = 20 \cdot Log\left(\frac{E_L}{U_d}\right) = 20 \cdot Log\left(\frac{\left(Zd_L + Zd_{eqt}\right)}{Zd_L} \cdot \frac{\left(Zcm_L + Zcm_{eqt}\right)}{\Delta Z}\right) \qquad \text{(I-4)}$$

When the differential mode impedances of equipment and lines are equal, the expression (I-4) can be written:

$$LCL_R = 20 \cdot Log\left(2 \cdot \frac{\left(Zcm_L + Zcm_{eqt}\right)}{\Delta Z}\right) \text{ dB} \qquad \text{(I-5)}$$

From expressions (I-4) and (I-5) it is important to emphasize the following points:

– LCL_R depends not only on the intrinsic parameters of the equipment but also on the impedances of the whole common mode loop. In particular, the LCL_R value increases with the common mode impedance of both the equipment and the disturbing generator.

Figure I.4 illustrates a practical case showing the required minimum LCL_R value as a function of the disturbing level.

$$LCL_{R\min} = 20 \cdot Log\left(\frac{E_L}{10^{\frac{-66}{20}}}\right)$$

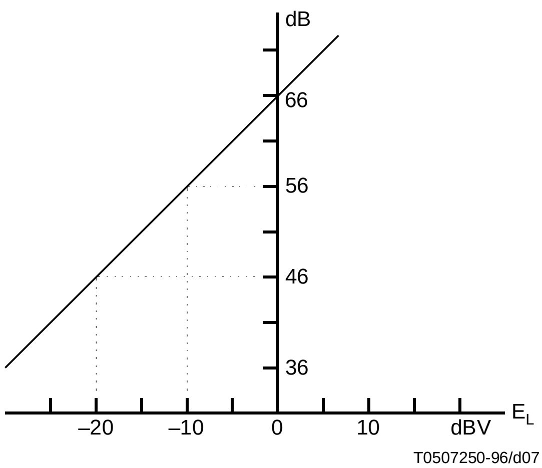


Figure I.4/K.10 – Admissible minimum LCL_R value as a function of the interference level parameter Ud = 0.5 mV (– 66 dBV)

Experience shows that the minimum values specified in Recommendation Q.552 are generally acceptable for line interfaces in the exchange, because at this place the parameters of the disturbing generator are favourable (E_{L1} value is strongly reduced by the effects of low impedance earthing of other pairs and Z_{L1} value is generally high due to the capacitive impedance of the line).

Consequently, the real situation and the electrical parameters of the whole circuit should be taken into account in any analysis of a problem of unbalance.

From Figure I.4 it can be noticed that, when the impressed level of disturbance reaches about 1 volt, the minimum LCL_R value will reach a value which may be difficult to achieve in practice depending on the technology used. In such a case, it may be more appropriate to solve problems of compatibility by inserting a protection device at the input of the equipment to filter the common mode signal (see clause 7).

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