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OF ITU

**O.9**

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SERIES O: SPECIFICATIONS OF MEASURING  
EQUIPMENT

General

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**Measuring arrangements to assess the degree  
of unbalance about earth**

ITU-T Recommendation O.9

(Previously CCITT Recommendation)

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ITU-T O-SERIES RECOMMENDATIONS  
**SPECIFICATIONS OF MEASURING EQUIPMENT**

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## **ITU-T RECOMMENDATION O.9**

### **MEASURING ARRANGEMENTS TO ASSESS THE DEGREE OF UNBALANCE ABOUT EARTH**

#### **Summary**

This Recommendation provides procedures to assess the degree of unbalance about earth and defines the applicable measuring arrangements. Seven parameters, which are most relevant in practice, are covered. In addition, some basic requirements concerning the measurement of unbalance are given.

#### **Source**

ITU-T Recommendation O.9 was revised by ITU-T Study Group 4 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on the 26th of March 1999.

#### **Keywords**

Common-mode rejection, input longitudinal interference loss, longitudinal conversion loss, longitudinal conversion transfer loss, output signal balance, test bridges, transverse conversion loss, transverse conversion transfer loss, unbalance measuring arrangements

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## Recommendation O.9

### MEASURING ARRANGEMENTS TO ASSESS THE DEGREE OF UNBALANCE ABOUT EARTH

(Geneva, 1972; amended at Malaga-Torremolinos, 1984; Melbourne, 1988;  
revised in 1999)

#### 1 Scope

This Recommendation describes arrangements for measuring the following parameters:

- longitudinal conversion loss;
- transverse conversion loss;
- longitudinal conversion transfer loss;
- transverse conversion transfer loss;
- input longitudinal interference loss;
- common-mode rejection;
- output signal balance.

In practice, the above parameters are the seven most significant unbalance parameters. Limits for these parameters, special considerations for terminating impedances and the measurement frequencies to be used are given in the relevant Recommendation for the item under test.

This Recommendation is in agreement with the principles, the nomenclature and the definitions, addressed in Recommendation G.117 [1], which considers the transmission aspects of unbalance about earth. References are made in the following clauses to the appropriate parts of Recommendation G.117 [1].

In clause 5, guidance is given regarding the construction of a test bridge along with values of the required components.

#### 2 References

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 Recommendation G.117 (1996), *Transmission aspects of unbalance about earth*.
- [2] CCITT Recommendation Q.45 (1984), *Transmission characteristics of an analogue international exchange*.
- [3] ITU-T Recommendation O.133 (1993), *Equipment for measuring the performance of PCM encoders and decoders*.

### 3 Abbreviations

This Recommendation uses the following abbreviations:

- CMR Common-Mode Rejection
- EMF Electro Motive Force
- ILIL Input Longitudinal Interference Loss
- LCL Longitudinal Conversion Loss
- LCTL Longitudinal Conversion Transfer Loss
- OSB Output Signal Balance
- TCL Transverse Conversion Loss
- TCTL Transverse Conversion Transfer Loss

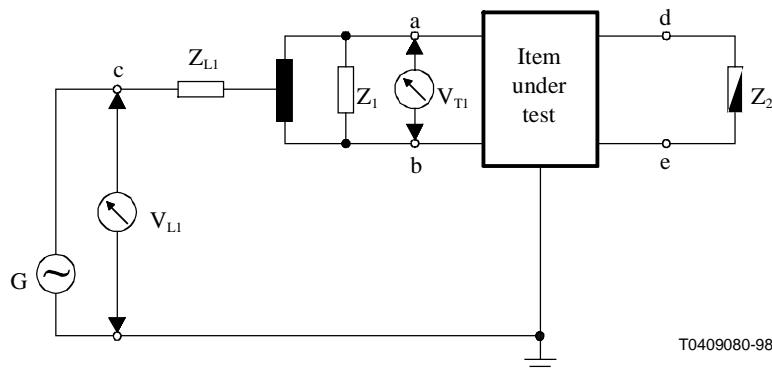
### 4 Measuring arrangements

#### 4.1 longitudinal conversion loss (LCL)

The LCL of a one- or two-port network is a measure (a ratio expressed in dB) of the degree of unwanted transverse signal produced at the terminals of the network due to the presence of a longitudinal signal on the connecting leads. It is calculated as

$$\text{Longitudinal Conversion Loss (LCL)} = 20 \lg \left| \frac{V_{L1}}{V_{T1}} \right| \text{ dB}$$

and measured as shown in Figure 1. This technique is applicable to either the input or output terminals, e.g. transpose terminals a and b with d and e respectively. (See 4.1.3/G.117 [1].)



G Signal generator. For details about  $Z_1$ ,  $Z_2$ ,  $Z_{L1}$ , see 5.2.

NOTE – This test bridge configuration, with transversal impedance  $Z_1$  and longitudinal impedance  $Z_{L1}$ , does not in all cases represent conditions found in practice. Thus, some care is needed when translating measured unbalance parameters into unbalance information applicable to practical cases. This is discussed in more detail in Appendix I.

**Figure 1/O.9 – Measurement of Longitudinal Conversion Loss**

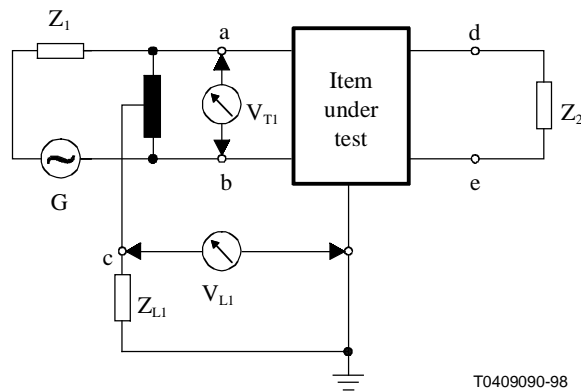


## 4.2 transverse conversion loss (TCL)

The TCL of a one- or two-port network is a measure (a ratio expressed in dB) of the degree of unwanted longitudinal signal produced at the input (or output) of a network due to the presence of a transverse signal at the same port. TCL is calculated as

$$\text{Transverse Conversion Loss (TCL)} = 20 \lg \left| \frac{V_{T1}}{V_{L1}} \right| \text{ dB}$$

and measured as shown in Figure 2. (See 4.1.2/G.117 [1].)



G Signal generator. For details about  $Z_1$ ,  $Z_2$ ,  $Z_{L1}$ , see 5.2.

NOTE – The transverse signal is expressed as a voltage at port a/b (or d/e). Any specification referring to the source voltage of the signal generator G will lead to the same result if the input (output) impedance of the item under test equals  $Z_1$  ( $Z_2$ ).

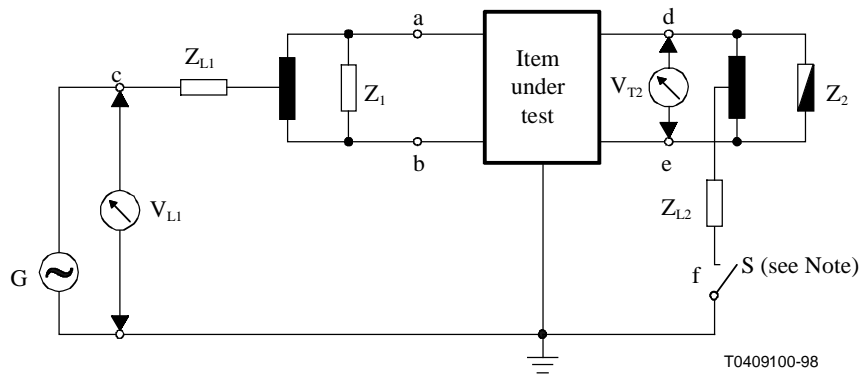
**Figure 2/O.9 – Measurement of Transverse Conversion Loss**

## 4.3 longitudinal conversion transfer loss (LCTL)

The LCTL is a measure (a ratio expressed in dB) of an unwanted transverse signal produced at the output of a two-port network due to the presence of a longitudinal signal on the connecting leads of the input port. It is calculated as

$$\text{Longitudinal Conversion Transfer Loss (LCTL)} = 20 \lg \left| \frac{V_{L1}}{V_{T2}} \right| \text{ dB}$$

and measured as shown in Figure 3. (See 4.2.3/G.117 [1].)



G Signal generator. For details about  $Z_1$ ,  $Z_2$ ,  $Z_{L1}$ ,  $Z_{L2}$ , see 5.2.

NOTE – Measurements are normally made, and limits specified, with switch S closed. However, for certain equipment, e.g. those described in Recommendation Q.45 [2], it may be necessary to specify limits for LCTL with switch S closed and with switch S open.

**Figure 3/O.9 – Measurement of Longitudinal Conversion Transfer Loss**

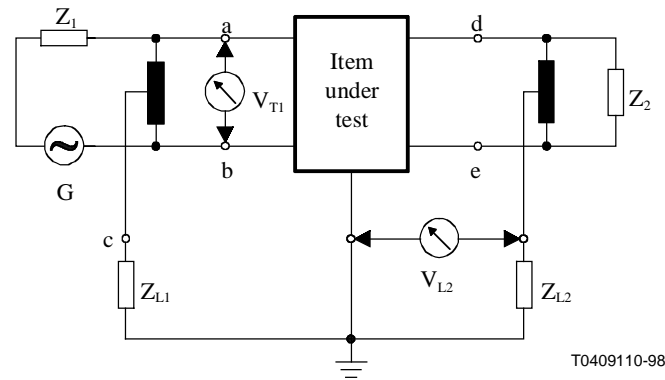
If the item under test exhibits gain or loss between ports a/b and d/e, this must be taken into account when specifying LCTL. In addition to the general requirements of clause 5, the measurement range of the test equipment must also take into account the gain or loss of the item under test. In addition, if the item under test performs a signal conversion (e.g. in FDM or TDM multiplexers), then the signal measured at  $V_{T2}$  may not be at the same frequency as that of the energizing signal designated  $V_{L1}$ . The signal at  $V_{T2}$  may even appear in coded form as a digital signal.

#### 4.4 transverse conversion transfer loss (TCTL)

Transverse conversion transfer loss is a measure (a ratio expressed in dB) of an unwanted longitudinal signal produced at the output of a two-port circuit due to the presence of a transverse signal at the input port. It is calculated as

$$\text{Transverse Conversion Transfer Loss (TCTL)} = 20 \lg \left| \frac{V_{T1}}{V_{L2}} \right| \text{ dB}$$

and measured as shown in Figure 4. If a signal conversion is performed by the item under test (e.g. in FDM or TDM multiplexers), then the signal measured at  $V_{L2}$  may not be at the same frequency as that of the energizing signal designated  $V_{T1}$ . The energizing signal may even be applied in coded form as a digital signal. (See 4.2.2/G.117 [1].)



G Signal generator. For details about  $Z_1$ ,  $Z_2$ ,  $Z_{L1}$ ,  $Z_{L2}$ , see 5.2.

NOTE – The transverse signal is expressed as the voltage at port a/b. Any specification referring to the source voltage of the signal generator G will lead to the same results if the input impedance of the item under test equals  $Z_1$ .

**Figure 4/O.9 – Measurement of Transverse Conversion Transfer Loss**

#### 4.5 input longitudinal interference loss (ILIL)

The measurement of this parameter is applicable to receiving devices (e.g. amplifiers, level meters, etc.). ILIL is a measure (a ratio expressed in dB) of the sensitivity of a receiving device to longitudinal disturbances. It is calculated as (see Figure 5a)

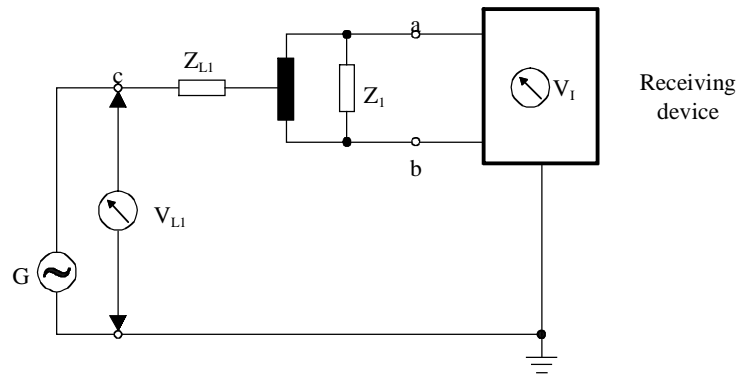
$$\text{Input Longitudinal Interference Loss (ILIL)} = 20 \lg \left| \frac{V_{L1}}{V_I} \right| \text{ dB}$$

or as (see Figure 5b)

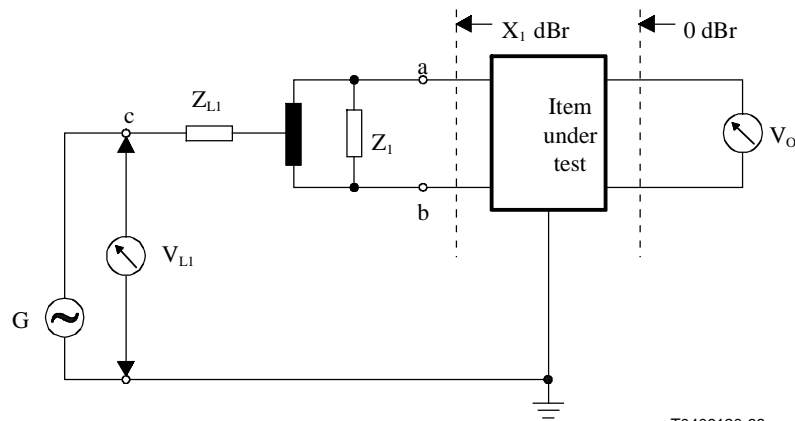
$$\text{Input Longitudinal Interference Loss (ILIL)} = 20 \lg \left| \frac{V_{L1}}{V_O} \right| \text{ dB}$$

and measured as shown in Figures 5a) and 5b). In principle, it is similar to the longitudinal conversion loss (LCL) measurement. However, since the measurement is performed internally (using a built-in indicating device) or at the output of the item under test, not only the impedance balance at port a/b, but also the effect of common-mode rejection is measured. (See 4.4.1/G.117 [1].)

Measurements in accordance with Figure 5b) are also applicable to devices which perform a signal conversion (e.g. VF/CF side of channel translating equipment, A/D side of PCM multiplex equipment, etc. See item f) of clause 2/G.117 [1]). In this case the measurement at the output of the device under test requires an appropriate analyzer, namely a selective level meter for measurements at channel translators or a digital analyzer (see Recommendation O.133 [3]) for measurements at PCM-multiplexers. In the equation to Figure 5b) it is assumed that  $V_O$  is measured at a 0-dBr point. The quantity  $X_1$  is the relative level at port a/b.



a) Measurement of input longitudinal interference loss with item under test containing built-in indicating device



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NOTE – Values of  $X_1$  differing from 0 dBr must be taken into account when calculating ILIL.

b) Measurement of input longitudinal interference loss with item under test having external indicating device

- G Signal generator. For details about  $Z_1$ ,  $Z_{L1}$ , see 5.2.
- $V_I$  Reading of built-in indicating device.
- $V_O$  Output Voltage

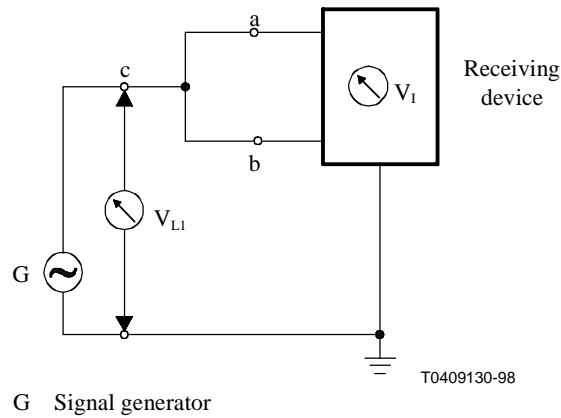
**Figure 5/O.9 – Measurement of Input Longitudinal Interference Loss**

#### 4.6 common-mode rejection (CMR)

Common-mode rejection is another measurement (a ratio expressed in dB) that is appropriate for receiving devices is calculated as

$$\text{Common Mode Rejection (CMR)} = 20 \lg \left| \frac{V_{L1}}{V_I} \right| \text{ dB}$$

and is measured as shown in Figure 6. Note that in this arrangement the input terminals are short-circuited and then energized. (See 5.1/G.117 [1].)



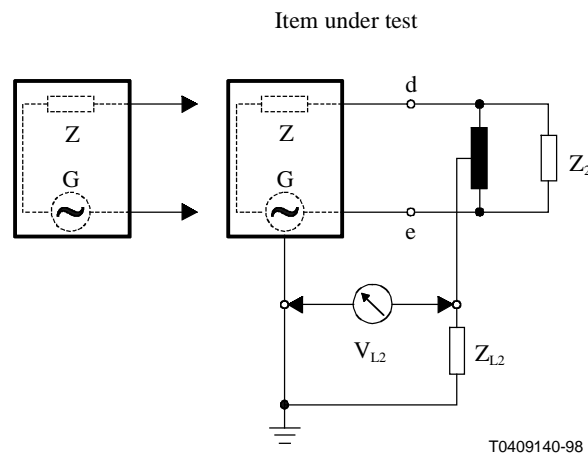
**Figure 6/O.9 – Measurement of Common-Mode Rejection**

#### 4.7 output signal balance (OSB)

This measurement (a ratio expressed in dB) is applicable to signal outputs. OSB is a measure of unwanted longitudinal signals at the output of a device. It is calculated as

$$\text{Output Signal Balance (OSB)} = 20 \lg \left| \frac{V_{T2}}{V_{L2}} \right| \text{ dB}$$

and measured as shown in Figure 7 (See 4.3.1/G.117 [1].)



For details about  $Z_2$ ,  $Z_{L2}$ , see 5.2.

**Figure 7/O.9 – Measurement of Output Signal Balance**

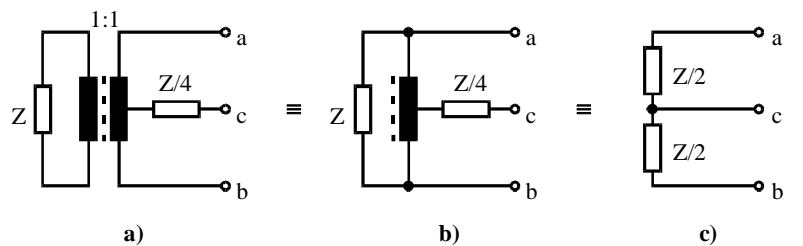
The signal source G shown in Figure 7 can be internal or external to the device under test. OSB measurements are also applicable to devices which perform a signal conversion (e.g. CF/VF side of channel translating equipment, D/A side of PCM multiplex equipment, etc. See item f) of clause 2/G.117 [1]). In this case an appropriate external signal source, namely a signal generator for measurements at channel translators or a digital signal generator (see Recommendation O.133 [3]) for measurements at PCM-multiplexers is required.

## 5 Requirements for the measuring arrangements

### 5.1 Inherent balance

The measuring arrangements shown in Figures 1 through 7 include two independent impedances and a centre-tapped inductor arranged as indicated to yield the equivalence of two matched impedances of the value  $Z/2$ . The coil should be iron-cored with an accurate centre-tapped connection, both the tightly coupled half windings being as symmetrical as possible. The circuits shown in Figure 8 are electrically equivalent and any one can be used to perform the measurements described in this Recommendation. It should be noted that in the case of option c) of Figure 8, the connection of point c to earth must be made via an impedance which is virtually zero. For very low frequencies, the arrangements a) and b) of Figure 8 may be unsuitable and it may be more convenient to use arrangement c) of Figure 8, with a small (e.g. 1 ohm) resistor being inserted in the longitudinal arm, so that a measure of longitudinal current can be obtained to derive the equivalent voltage across  $Z/4$ .

The inherent balance of any measuring arrangements must be determined and found to be sufficiently good before a measurement is made. This may be done by replacing the equipment being tested with a second test bridge. The inherent longitudinal conversion loss of the measuring arrangements should be 20 dB greater than the limit set for the item under test. This balance should also be obtained when the connections at a and b are reversed. This permits an accuracy in the order of  $\pm 1$  dB. An example of a practical test bridge is given in Figure 21/G.117 [1].



NOTE – Impedance  $Z = Z_1$  or  $Z_2$

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**Figure 8/O.9 – Electrical correspondence between centre-tapped coil configuration and centre-tapped resistors**

### 5.2 Impedances $Z_1$ , $Z_2$ , $Z_{L1}$ and $Z_{L2}$

$Z_1$  and  $Z_2$  are the impedances connected in parallel to the input and/or output port respectively of the item under test.  $Z_1$  and  $Z_2$  are generally within  $\pm 25\%$  of the nominal impedance of the port to which they are connected. If measurements are made via high-impedance input ports, an additional impedance  $Z_1$  should be connected between points a and b. The longitudinal impedances  $Z_{L1}$  and  $Z_{L2}$  are nominally equal to  $Z_1/4$  or  $Z_2/4$  respectively. Different values, however, may be used. This may be necessary to more properly simulate operating conditions of the item under test. In such cases the value of  $Z_{L1}$  and/or  $Z_{L2}$  shall be specified by the Recommendation covering the item under test.

### 5.3 Measuring and generating the test signals

The voltages  $V_L$  and  $V_T$  are measured with high-impedance voltmeters, and in such a way that the balance is not disturbed. The actual values of the internal impedance and EMF. of the generator G are irrelevant if  $V_{L1}$  is measured. The design of the item under test may impose a limit on the permissible magnitude of the longitudinal excitation.

When the equipment being tested as shown in Figure 1 is a signal generating device,  $V_{T1}$  must be measured selectively if it is required to measure the longitudinal conversion loss while the signal generator is active. Selective measurements are also preferable when high losses are to be measured.

#### 5.4 Other considerations

It may be necessary in some measurements to make provisions for supplying a d.c. line holding current or a d.c. line current termination. In these cases the Recommendation covering the requirements for the item under test shall also specify the requirements for such d.c. line current treatment.

### APPENDIX I

#### Aspects of conversion from longitudinal to transversal signals at analogue ports in some practical cases<sup>1</sup>

##### I.1 Introduction

Cables for telecommunication purposes sometimes have to pass areas that have strong, disturbing electromagnetic fields which may cause significant longitudinal signals along the cables. For voiceband telephone signals, the established technique is to use well-balanced cables and equipment so that the conversion from longitudinal to transversal signals is sufficiently suppressed. In general, the cables have a much higher degree of balance than what is obtainable for terminal equipment. The governing factor is then the properties of the terminal equipment, i.e. the balance to earth of that port which is connected to the cable. The balancing properties of an equipment port can be expressed in many ways. The most commonly used parameter appears to be the "Longitudinal Conversion Loss", LCL. The general definition of LCL is given in 4.1 which in principle applies to all cases. However, in *equipment* specifications, LCL most often is understood to be a value which is obtained in a specific measuring set-up according to Figure 1, where the transverse terminating impedance  $Z_1$  is made 600  $\Omega$  resistive and the longitudinal source impedance  $Z_{L1} = Z/4$  thus is 150  $\Omega$  resistive. The advantage of this latter definition is that LCL is obtained in a well-defined manner and that this LCL value gives a general indication of how well the port is balanced to earth. However, the configuration in Figure 1 does not correspond too well with a realistic representation of actual, practical cases:

- 1) The transverse terminating impedance nowadays is not always 600  $\Omega$  resistive but can be a complex, nominal impedance as given for instance in Recommendation Q.552.
- 2) The longitudinal source impedance is resistive only in exceptional cases but rather like a high capacitance.

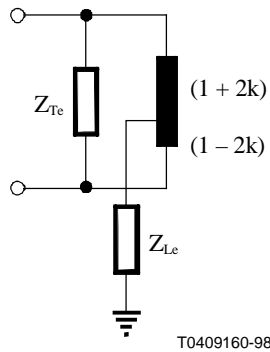
Thus, when a more accurate analysis of the actual longitudinal-to-transversal conversion is needed, either a special test set-up, simulating actual conditions, has to be used and/or a more detailed circuit analysis has to be performed. In what follows, such an analysis will be made in order to illustrate the difference between a measured LCL and the actual conversion LCL. To distinguish the cases, the Longitudinal Conversion Loss measured in the 600/150  $\Omega$  test bridge will be designated  $LCL_m$ , and the Longitudinal Conversion Loss in the actual circuit  $LCL_c$ .

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<sup>1</sup> This Appendix is based on information obtained from Recommendation G.117. It is especially applicable to voiceband telephone signals.

## I.2 Calculation of the longitudinal conversion loss

The unbalance properties of an equipment port or a network port can be described in many ways by equivalent circuits. The one shown in Figure I.1, employing an ideal choke with a tap, will be used here because it leads to simple expressions. (The factor  $k$  is a measure of the degree of unbalance.)

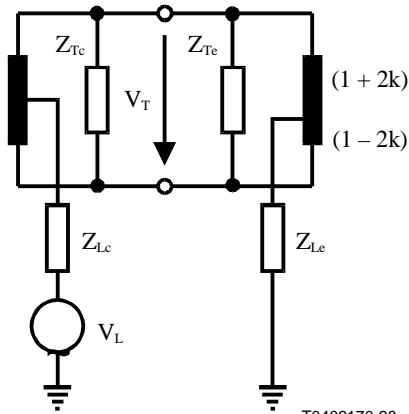


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$Z_{Te}$  Transverse impedance  
 $Z_{Le}$  Longitudinal impedance  
 $k$  Transverse Conversion Factor

**Figure I.1/O.9 – Equivalent circuit for the unbalance-to-earth at a port**

This equivalent circuit type can be used both for the circuit (cable or the test bridge), that introduces the longitudinal voltage, and for the terminating equipment, as Figure I.2 depicts. (Note that the cable and the test bridge are supposed to be perfectly balanced.)



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$Z_{Te}, Z_{Le}$  Transverse or longitudinal impedance of the equipment  
 $Z_{Tc}, Z_{Lc}$  Transverse or longitudinal impedance of the cable or the test bridge

**Figure I.2/O.9 – Equivalent circuit for conversion of the longitudinal voltage  $V_L$  to the transversal voltage  $V_T$**



Using the equivalent circuit, the following expression for the Longitudinal Conversion Loss  $LCL_c$  in the general case is derived:

$$LCL_c = 20 \cdot \lg \left| \frac{1}{k} \left\{ (Z_{Lc} + Z_{Le}) \cdot \left( \frac{1}{Z_{Tc}} + \frac{1}{Z_{Te}} \right) + k^2 \right\} \right| \text{ dB}$$

Note that this equation is valid for all values of  $k$ , i.e. even if the port would be totally unbalanced. However, in general, the terminating equipment is reasonably well-balanced, i.e.  $k$  is small, so that the above equation can be simplified to:

$$LCL_c = 20 \cdot \lg \left| \frac{1}{k} (Z_{Lc} + Z_{Le}) \cdot \left( \frac{1}{Z_{Tc}} + \frac{1}{Z_{Te}} \right) \right| \text{ dB}$$

In the measuring set-up for the longitudinal conversion loss we have:

$Z_{Lc} = 150 \Omega$  and  $Z_{Tc} = 600 \Omega$  so that:

$$LCL_m = 20 \cdot \lg \left| \frac{1}{k} (150 + Z_{Le}) \cdot \left( \frac{1}{600} + \frac{1}{Z_{Te}} \right) \right| \text{ dB}$$

### I.3 The difference between $LCL_c$ and $LCL_m$ in a practical case: two examples

The disturbing circuit is assumed to be a subscriber cable, perfectly balanced, and the terminating equipment the input analogue port of a digital exchange. The terminal equipment has a slight unbalance to earth.

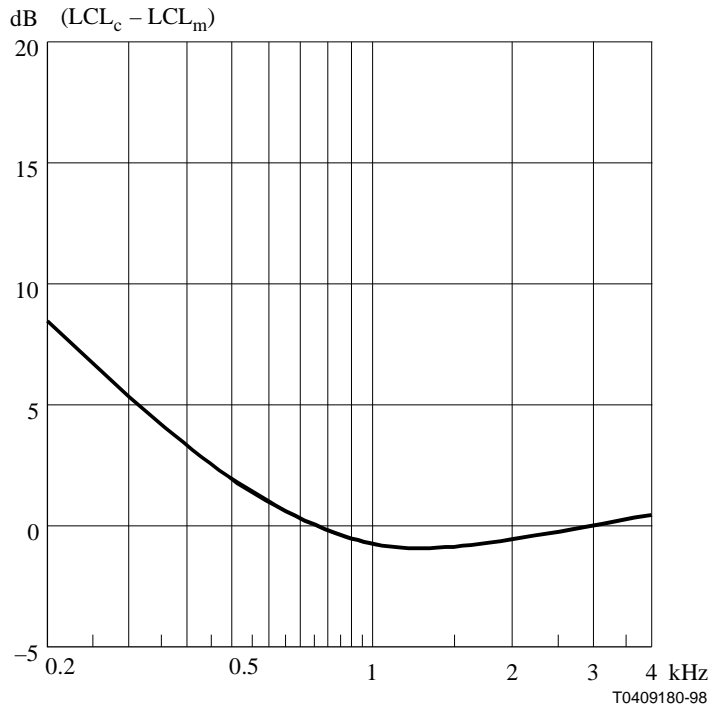
The equipment transversal impedance  $Z_{Te}$ , is complex, and can be represented by a resistance of  $275 \Omega$  and a parallel combination of a resistance of  $780 \Omega$  and a capacitance of  $150 \text{ nF}$ . This impedance is a sufficiently close match to the input transversal impedance of the cable circuit so that  $Z_{Tc} = Z_{Te}$ .

The equipment longitudinal impedance  $Z_{Le}$  is assumed to be  $300 \Omega$  resistive.

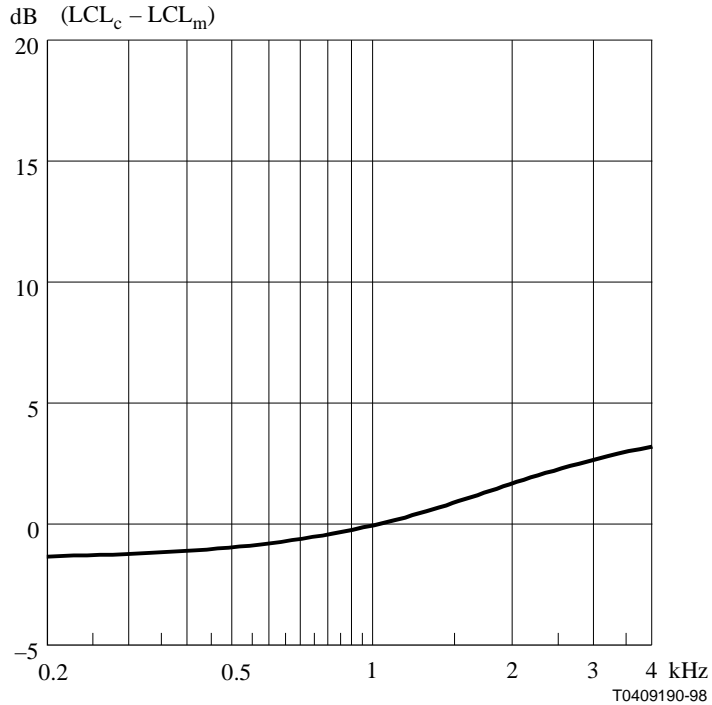
In the first example, the cable is terminated by a telephone set with a very high longitudinal impedance to earth. Then the circuit, i.e. the cable, input longitudinal impedance  $Z_{Lc}$  can be represented by a capacitance  $C_s$  in series with a small resistance. Here  $C_s = 500 \text{ nF}$  and  $R_s = 75 \Omega$  are chosen values as being typical for a subscriber line.

In the second example, the subscriber line is terminated by an equipment, perfectly balanced, but with a very low longitudinal impedance to earth. Then  $Z_{Lc}$  can be considered as a pure resistance, three times higher than in the first case, i.e.  $Z_{Lc} = 225 \Omega$ .

The difference ( $LCL_c - LCL_m$ ) for the two cases is shown in Figures I.3 and I.4 respectively.



**Figure I.3/O.9 – Difference between actual longitudinal conversion loss  $LCL_c$  and  $LCL_m$ , measured with the standard test bridge (High longitudinal impedance to earth at the far end)**



**Figure I.4/O.9 – Difference between actual longitudinal conversion loss  $LCL_c$  and  $LCL_m$ , measured with the standard test bridge (Low longitudinal impedance to earth at the far end)**

#### **I.4 Additional insight into Longitudinal Conversion Loss**

A more complete analysis of LCL differences between actual longitudinal conversion loss circuits and standard longitudinal conversion loss test arrangements is given above. Two conclusions are noteworthy:

- 1) The real difference between the test set-up and the actual longitudinal conversion loss is rather independent of the terminal input impedance and therefore this analysis applies to virtually all reasonable input impedances including  $600\ \Omega$  and  $900\ \Omega + 2.16\ \mu\text{F}$ .
- 2) The difference between the actual longitudinal conversion loss and the longitudinal conversion loss as measured by the test set-up is compensated for by the lower LCL limits at lower frequencies as e.g. noted in Recommendation Q.553. Recommendation Q.553 requires a minimum of 40 dB LCL from 300 Hz to 600 Hz and 46 dB of LCL from 600 Hz to 3400 Hz.



## ITU-T RECOMMENDATIONS SERIES

- Series A Organization of the work of the ITU-T
- Series B Means of expression: definitions, symbols, classification
- Series C General telecommunication statistics
- Series D General tariff principles
- Series E Overall network operation, telephone service, service operation and human factors
- Series F Non-telephone telecommunication services
- Series G Transmission systems and media, digital systems and networks
- Series H Audiovisual and multimedia systems
- Series I Integrated services digital network
- Series J Transmission of television, sound programme and other multimedia signals
- Series K Protection against interference
- Series L Construction, installation and protection of cables and other elements of outside plant
- Series M TMN and network maintenance: international transmission systems, telephone circuits, telegraphy, facsimile and leased circuits
- Series N Maintenance: international sound programme and television transmission circuits
- Series O Specifications of measuring equipment**
- Series P Telephone transmission quality, telephone installations, local line networks
- Series Q Switching and signalling
- Series R Telegraph transmission
- Series S Telegraph services terminal equipment
- Series T Terminals for telematic services
- Series U Telegraph switching
- Series V Data communication over the telephone network
- Series X Data networks and open system communications
- Series Y Global information infrastructure and Internet protocol aspects
- Series Z Languages and general software aspects for telecommunication systems