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(Revision of ANSI/IEEE Std 455-1976)

An American National Standard

IEEE Standard Test Procedure for Measuring Longitudinal Balance of Telephone Equipment Operating in the Voice Band

Sponsor
Transmission Systems Committee
of the
IEEE Communications Society

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IEEE Standards Board

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American National Standards Institute

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Foreword

(This Foreword is not a part of ANSI/IEEE Std 455-1985, IEEE Standard Test Procedure for Measuring Longitudinal Balance of Telephone Equipment Operating in the Voice Band.)

The first edition of ANSI/IEEE Std 455-1976, IEEE Standard Test Procedure for Measuring Longitudinal Balance of Telephone Equipment Operating in the Voice Band, was issued on September 30, 1976.

Following issuance of the standard, members of the Subcommittee on Susceptibility of the IEEE Transmission Systems Committee made extensive measurements of the balance of communications cable pairs and of equipment associated with cable. A subcommittee report on this work, including five papers by inidividual members, was presented at the 1979 National Telecommunications Conference (NTC 79). See NTC-79 Conference Record, pp 31.1.1–31.5.6. Contributing to this report were D. V. Batorsky, G. A. DeBalko, D. K. Guha, and C. D. Hansell (chairman); W. M. Haynes, Jr, J. A. Olszewski, D. E. Robinson, and D. S. Wilson. Further work on this subject was reported by A. K. Knowles at the 1981 International Conference on Communications (ICC 81). See ICC-81 Conference Record, pp 39.4.1–39.4.5.

Experience gained over the past several years by those who have used the standard and those who have built test equipment intended to comply with its provisions has identified some areas for improvement. On March 11, 1982, the IEEE Standards Board approved a Project Authorization Request from the Susceptibility Subcommittee of the IEEE Transmission Systems Committee to undertake a revision of the standard. This edition, ANSI/IEEE Std 455-1985 , is the result of that action.

Some highlights of this revised edition are

1) The applicable frequency range has been extended from 1500 Hz to 4000 Hz
2) The measurement of longitudinal balance of active devices is addressed. The previous edition addressed longitudinal balance measurement on passive devices only.
3) The standard terminating test circuit has been revised to permit more accurate determination of the effects of shunt imbalance.
4) The description of required equipment has been expanded to better define the types of voltmeter that are suitable for measuring longitudinal balance in conformance with the standard.
5) The recommended calibration procedures have been completely rewritten to improve clarity and eliminate possible sources of error.
6) Alternate measurement circuits consistent with CCITT recommendations have been added.
7) The measurement of cable-pair balance is addressed briefly. The subcommittee has concluded that the establishment of detailed cable-pair balance measurement requirements is beyond the scope of this standard.

The opinion of the membership of the Susceptibility Subcommittee is that this revision significantly enhances the usefulness of the standard. Special thanks are due L. S. Baker, R. H. Campbell, P. L. Dillon, and A. K. Knowles for their significant contributions to the revised standard.

The members of the Susceptibility Subcommittee of the Transmission Systems Committee of the IEEE Communications Society when this revision was prepared were:

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CLAUSE PAGE

An American National Standard

IEEE Standard Test Procedure for Measuring Longitudinal Balance of Telephone Equipment Operating in the Voice Band

1. Introduction

ANSI/IEEE Std 455-1976 was widely accepted by organizations in the United States and Canada as the standard method for measuring longitudinal balance.

Prior to the issue of the standard in 1976, telephone companies and equipment manufacturers had generally agreed on a definition for longitudinal balance for many years. This agreement extended also to the basic approach followed when measuring balance. Testing a device for balance involves the application of a longitudinal voltage. Then, any resulting metallic voltage is measured, and the ratio of the two voltages is used to develop a balance number.

Unfortunately, agreement ended at about this point. A number of different test circuits were used by different segments of the telephone industry. Although all of the existing test circuits had some merits supporting their use, the mere existence of varied circuits led to differences in test results.

In addition to differences related to the test set, test conditions and procedures can also affect the result. When an item of equipment is to be tested, there is often a test set or procedure, or both, capable of giving any desired result.

Agreement on one way of testing for longitudinal balance had been sought. The first edition of ANSI/IEEE Std 455-1976 , IEEE Standard Test Procedure for Measuring Longitudinal Balance of Telephone Equipment Operating in the Voice Band, issued September 30, 1976, represented such agreement. Experience gained over the past several years by those who have used the standard and those who have built test equipment intended to comply with its provisions have led to this revised edition. It defines the basic requirements of a standard test circuit. Reasonable tolerances are included so that a test-set designer will find considerable latitude to make the set according to his design.

Besides defining the requirements for a test circuit, this standard specifies test conditions and procedures to be followed when longitudinal balance is measured. As a result, all test sets designed and used in accordance with the standard will produce a consistent and repeatable balance number for a given test specimen. Similarly, comparing balance numbers for different devices will become more meaningful when all come from tests meeting the standard.

Longitudinal balance, as defined in this standard, specifically refers to longitudinal-to-metallic balance. This differs from the FCC definition for longitudinal balance which refers to metallic-to-longitudinal balance (see Appendix E for details).

2. Purpose and Scope

The purpose of this standard is threefold:

1) To define the basic requirements of a test circuit which can be used to measure longitudinal balance. This test circuit will be capable of yielding consistent and repeatable test results.
2) To define test conditions to be established while using the test circuit. Standard test conditions are considered vital for obtaining consistent results from a suitable circuit.
3) To describe standard test procedures to be followed when the test circuit is operated.

This standard specifies the elements of the test circuit only in general terms to allow considerable freedom when a test set is being designed. It thereby precludes the possibility that only one set of circuit elements will be capable of meeting the standard.

This standard is based on a resistive test circuit, although pure resistance is not essential. Resistive elements are specified because they are generally considered easy to duplicate and balance. Repeatable and consistent balance numbers are the object of issuing this standard.

Balance circuits are used at frequencies extending well into the megahertz range and there may be a need for measuring longitudinal balance at high frequencies. The definition of **degree of longitudinal balance** and the general configuration of the driving test circuit given in this standard are applicable at all frequencies. However, the test circuit impedances and other requirements for measurement outside the voice band are beyond the scope of this standard.

3. Definitions

balanced circuit: A circuit in which two branches are electrically alike and symmetrical with respect to a common reference point, usually ground.

circuit: A network providing one or more closed paths.

communication conductor: A conductor used in a communication network.

device: An item of electric equipment that is used in connection with, or as an auxiliary to, other items of electric equipment.

driving test circuit: A test circuit used to convert an exciting test voltage into balanced longitudinal voltages on tip and ring leads.

element: Any electric device (such as inductor, resistor, capacitor, generator, or line) with terminals at which it may be directly connected to other devices, elements, or apparatus.

frogging: A switching technique whereby the tip and ring leads of the test specimen are reversed relative to the driving or terminating test circuits, or both.

longitudinal balance, degree of: The ratio of the disturbing longitudinal voltage V_s and the resulting metallic voltage V_m of the network under test expressed in decibels, as follows:

longitudinal balance = $20 \log | V_s/V_m |$ (dB)[1]

[1]Here and throughout this standard, log is assumed to mean log to the base 10.

where

V_s and V_m are of the same frequency.

longitudinal circuit: A circuit formed by one communication conductor (or by two or more communication conductors in parallel) with a return through ground or through any other conductors except those which are taken with the original conductor or conductors to form a metallic circuit.

longitudinal impedance: Impedance presented by a longitudinal circuit at any given single frequency.

longitudinal circuit port: A place of access in the longitudinal transmission path of a device or network where energy may be supplied or withdrawn, or where the device or network variables may be measured.

metallic circuit: A circuit of which the ground (earth) forms no part.

metallic impedance: Impedance presented by a metallic circuit at any given single frequency, at or across the terminals of one of its transmission ports.

metallic transmission port: A place of access in the metallic transmission path of a device or network where energy may be supplied or withdrawn, or where the device or network variables may be measured. The terminals of such a port are sometimes referred to as the tip and ring terminals.

NOTE — In any particular case, the transmission ports are determined by the way the device is used, and not by its structure alone.

metallic voltage: The voltage across a metallic circuit.

network: A combination of elements or devices.

nominal metallic impedance: Impedance based on lumped constants of a metallic circuit at a given single frequency.

terminating test circuit: A network connected to a transmission port of a circuit to terminate it in a suitable balanced termination for longitudinal balance testing. This circuit is used when a driving test circuit is connected to one such port and the test specimen has additional transmission ports.

voice band: That part of the audio frequency range that is employed for the transmission of speech. For the purpose of this standard, the voice band extends from 50 Hz to 4000 Hz.

4. Terminal Constraints

To determine the longitudinal balance of a test specimen, a longitudinal voltage V_s is applied through a driving test circuit to both tip and ring leads of the specimen while the resulting metallic voltage V_m is monitored (Metallic voltage may also be called transverse voltage). Balance is expressed as the logarithmic ratio of the longitudinal to metallic voltages.

$$\text{Longitudinal balance} = 20 \log \left| V_s / V_m \right| \tag{1}$$

The major factors which influence how the test circuit affects the longitudinal balance of a test specimen include the following items:

1) The actual balance of the test specimen
2) The longitudinal and metallic impedances of the driving test circuit and the terminating test circuit
3) The frequency of the applied test voltage
4) The internal balances of the driving test circuit and the terminating test circuit
5) The levels of ac and dc signals applied

Because of these interactions, it was possible, in the past, to obtain widely different balances on identical specimens simply by modifying the impedances or balance of the driving test circuit. It is the intent of this standard therefore to specify the values and tolerances of these impedances and the balance in a suitable driving test circuit. Furthermore, the range and amplitude of the test frequencies are also specified. In this way, uniform results will be obtained by anyone testing a specimen according to this standard. The following sections provide these circuit definitions.

An important part of this standard is the stipulation that the balance obtained after the specimen's input terminals are reversed (frogged) should be the same as the balance before frogging. This verifies the calibration of the driving test circuit and yields reliable readings.

5. Metallic Impedance of Driving Test Circuit

In the standard driving test circuit, longitudinal voltages are introduced to a specimen through balanced networks. Lumped impedance elements are used to transform a signal generator's output to a longitudinal output. In Fig 1, Z_1, and Z_2 are the lumped elements of the driving test circuit.

V_s is the source voltage measured from the center of the lumped elements with respect to ground. OSC is the alternating voltage source, and V_m is the metallic voltage measured across the tip and ring terminals of the specimen.

The lumped elements Z_1 and Z_2, in general, could be either real or complex quantities. For this standard however the elements are specified as impedances which may be resistive, since resistance elements are more easily duplicated and balanced than inductive and capacitive elements.

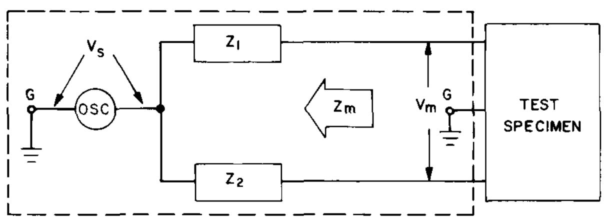

Figure 1—Standard Driving Test Circuit

The metallic impedance Z_m of the driving test circuit is given by the following equation:

$$Z_m = Z_1 + Z_2 \qquad (2)$$

The value of the metallic impedance chosen for this standard is 736 Ω (This value was selected to provide a uniform circuit impedance for testing and is not intended to match specimen impedance). See 8.2. Assuming only resistances are used for the lumped element, the metallic impedance becomes

$$Z_m = 736\Omega \angle 0^\circ \qquad (3)$$

To ensure that balance measurements are not limited to one circuit configuration, and to provide for a measuring accuracy of ± 1 dB, the magnitude of Z_m permitted to vary by as much as 5%. Furthermore, Z_m need not be pure resistance; a small amount of capacitance or inductance can be tolerated. The following equation, then, defines the metallic impedance Z_m of the standard test circuit:

$$Z_m = 736\ \Omega \pm 5\% \angle 0^\circ \pm 4^\circ \qquad (4)$$

The wide tolerance enables a test-set designer some freedom in choosing circuit components for a test set that meets the requirements of this standard. Stiff, it ensures that comparable readings will be obtained from equipment of slightly different design. The tolerances were developed from studies on specimens with balances from 60 dB to 100 dB, and with metallic impedances from 200 Ω to 1200 Ω.

Since Z_m will be divided into two balanced impedances Z_1 and Z_2, the lumped elements will have the following values:

$$Z_1 = Z_2 = 368\ \Omega \pm 5\% \angle 0^\circ \pm 4^\circ \tag{5}$$

6. Longitudinal Impedance of Driving Test Circuit

The longitudinal impedance Z_1 is the parallel combination of Z_1 and Z_2. Assuming that Z_1 and Z_2 are nearly perfectly balanced, the longitudinal impedance of the driving test circuit will be as follows:

$$Z_L = Z_m/4 = 184\ \Omega \pm 5\% \angle 0^\circ \pm 4^\circ \tag{6}$$

In Eq 6, it is assumed that the source voltage V_s, is the voltage measured from the midpoint of Z_1 and Z_2 to ground. If this were not the case, the impedance of the generator would disturb the configuration.

7. Internal Balance of Driving Test Circuit

The required balance of the driving test circuit depends on the specimen impedances, the phase of the impedances, the balance and required accuracy. In some instances, it may be desirable to calculate the tolerances on Z_1 and Z_2 for a given balance maximum. The following formula defines the match required between Z_1 and Z_2 of the driving test circuit to achieve a measurement accuracy of 1 dB for one-port balance measurement.

$$|Z_1 - Z_2| = k \left| (184 + Z_L)\left(1 + \frac{736}{Z_m}\right) \right| 10^{-(LB/20)} \tag{7}$$

The constant k has a minimum value of 0.22 when the imbalance terms are in phase. Longitudinal Balance (LB) is the maximum longitudinal balance of the test specimen as defined in Section 4. and Z_L and Z_m are the longitudinal and metallic impedances, respectively, of the test specimen. It is necessary to consider the phases of Z_L and Z_m when solving the equation.

The corresponding minimum test circuit balance (TCB) is given by

$$\mathrm{TCB} = 20 \log \left| \frac{1472}{Z_1 - Z_2} \right| \tag{8}$$

where

$|Z_1 - Z_2|$ = value calculated from Eq 7. Alternatively, Eqs 7 and 8 may be expressed

$$\mathrm{TCB} = \mathrm{LB} + 20 \log \frac{1472}{k \left| (184 + Z_L)\left(1 + \frac{736}{Z_m}\right) \right|} \tag{9}$$

Table 1 shows the maximum impedance differences for each of three levels of measuring capability when the value of k in Eq 7 is 0.22. The values are for a specimen with a metallic impedance of 600 Ω and a longitudinal impedance of 150 Ω. A measured test-circuit balance (see Appendix B) of at least 19 dB greater than the specimen balance measurement is necessary to ensure 1 dB accuracy. (For a specimen with high metallic impedance and low longitudinal impedance, a somewhat higher test-circuit balance margin may be needed for the same measurement accuracy. The value may be calculated from Eq 9.)

Table 1—Maximum Difference (Z_1 – Z_2) and Corresponding Minimum Test-Circuit Balance to Ensure 1 dB Measurement Accuracy

Measurement Capability (dB)	$Z_1 - Z_2$ (Ω)	TCB (dB)
40	1.6	59
60	0.16	79
80	0.016	99

8. Terminating Test Circuit

8.1 Standard Terminating Test Circuit

It is necessary at times to make measurements according to this standard on devices with two ports (two metallic transmission ports) and on devices with one metallic transmission port. Whenever a device with more than one port is measured, the driving test circuit is connected to one port. The remaining port is terminated with the terminating test circuit. This circuit is illustrated in Fig 2. It is used with passive devices and with active devices that do not require a specific metallic termination for proper operation.

The standard terminating test circuit is made up of impedances Z_3, Z_4, and Z_5, and switches S1 and S2. Since the impedance necessary to terminate a wide range of telephone equipment falls within the same range as that of the driving test circuit, the same restrictions are placed on impedances Z_3 and Z_4 as are placed on Z_1 and Z_2 of the driving test circuit. Namely,

$$Z_3 = Z_4 = 368\ \Omega \pm 5\%\ \angle 0^\circ \pm 4^\circ \tag{10}$$

The required balance of the terminating test circuit is the same as that of the driving test circuit, as specified in Section 7.

Impedance Z_5 and switches S1 and S2 are included in the terminating circuit to emphasize differences between the effects of series and shunt imbalances.

$$Z_5 = 2000\ \Omega \pm 5\%\ \angle 0^\circ \pm 4^\circ \tag{11}$$

Figure 3 will show this further.

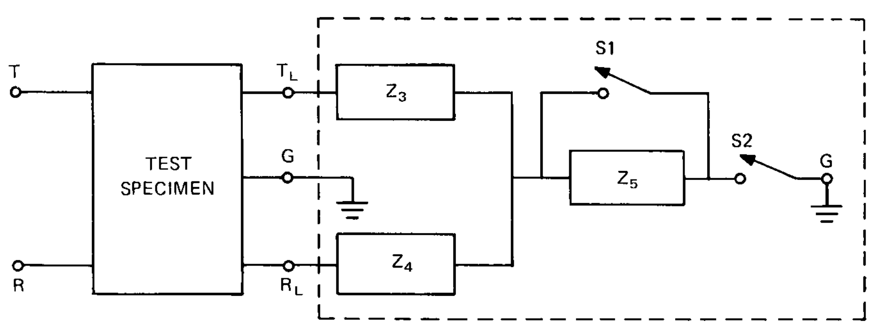

Figure 2—Standard Terminating Test Circuit

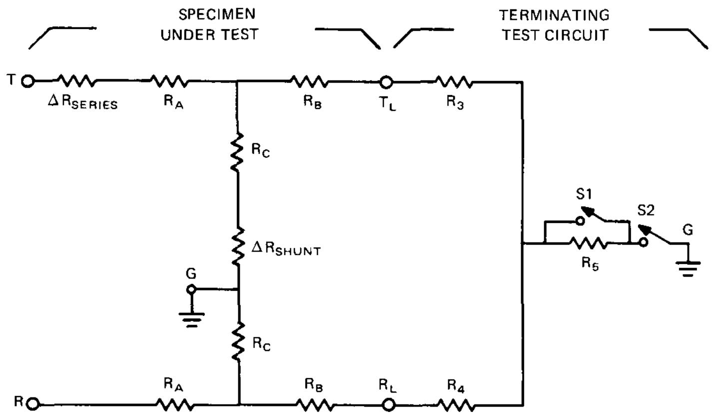

Figure 3—Shunt Versus Series Imbalance

When S2 is open, the longitudinal impedance of the terminating circuit is an open circuit.

When switches S1 and S2 are both closed, the standard terminating test circuit has its lowest possible longitudinal impedance (184 Ω). In this condition, the longitudinal current through the test specimen and the effect of series imbalance ($\Delta\ R_{SERIES}$) on the balance measurement are both maximized. Conversely, with S2 open, there is no longitudinal current except that which flows through a longitudinal path in the test specimen itself, and the effect of series imbalance is minimized. Also, with S2 open, the longitudinal voltage at the test specimen and the effect of shunt imbalance ($\Delta\ R_{SHUNT}$) on the balance reading are both maximized. Thus, the difference in balance measurement between the SERIES condition (S1 and S2 closed) and the SHUNT condition (S2 open) can provide an important indication as to the nature of the imbalance.

When S2 is closed and S1 is open, the terminating test circuit has a moderately high value of longitudinal impedance (nominally 2184 Ω). This condition was specified for SHUNT balance measurement in the 1976 edition of this standard. It is included in the present edition so that SHUNT balance measurements in conformance with the earlier edition can be made for comparison purposes.

8.2 Alternate Terminating Test Circuit

Some active two-port devices have port-to-port feedback paths and require a precise metallic termination to ensure their proper operation. Examples of such devices include, but are not limited to, two-wire hybrid or negative impedance voice frequency repeaters, carrier systems with two-wire channels at both terminals, and two-wire to two-wire connections through Pulse Code Modulation (PCM) telephone switching systems. The standard terminating circuit cannot be used to terminate the undriven port of these devices or large measurement errors can result. In extreme cases, the device may become unstable.

When such active devices are operated with port-to-port gain, or with a loss of less than 2 dB, they require that the undriven port be terminated in the proper value of metallic impedance. This value is not, in general, the port's characteristic impedance, although this may be the case. Adequacy of the metallic termination, which is provided by the terminating test circuit, is verified by acceptable return loss performance measured at the driven port. The reference for the return loss measurements is the characteristic impedance of the driven port.

When the necessary value of metallic terminating impedance is not equal to the 736 Ω (Z_3 + Z_4) of the standard terminating test circuit, an alternate terminating test circuit is required. This alternate circuit should have separately controlled metallic and longitudinal impedances. A full description of the alternate terminating test circuit used shall be included in the report of test results. See 11.3 (5). An example of such a circuit is described in Appendix D.

The longitudinal impedances presented by the alternate terminating test circuit should include an open circuit and the nominal 184 Ω and 2184 Ω impedances described in 8.1, except in the case where the longitudinal circuit of the test specimen is known not to extend port to port. In this case, the longitudinal termination does not influence the measurement.

When the longitudinal circuit does not extend port-to-port, the terminating test circuit may be greatly simplified. The longitudinal termination is not important in this case and it is sufficient to terminate the undriven port with the proper metallic impedance Z_T. Since the longitudinal termination is arbitrary, it may be an open circuit or any convenient value which results from the realization of Z_T.

The driving test circuit illustrated in Fig 1 is always used regardless of the terminating circuit employed. It is the intent of this standard that the terminating test circuit of Fig 2 be used unless it is demonstrated that the results of such a measurement are not representative of the true performance of the device under test.

9. Test Equipment

9.1 General

The various equipment items recommended for testing and requirements for each one are specified in this section. Of prime importance, however, is the necessity that these items connected together shall preserve the balance integrity and not affect the test-circuit impedances specified in the standard during any and all tests.

9.2 Equipment Required

The test equipment required for determining the degree of longitudinal balance consists of the following items:

1) An alternating voltage source
2) Voltmeter(s)
3) Driving test circuit
4) Terminating test circuit
5) DC supply circuit
6) DC terminating circuit

Items (5) and (6) are optional as their use is dependent on test specimen requirements.

9.2.1

The alternating voltage source consists of a variable frequency signal generator. It shall be capable of supplying any frequency from 50 Hz to 4000 Hz. The frequency calibration shall be within 5%. The value of the source voltage V_s is not specified but shall be included in the presentation of test results (see Section 11.). The impedance of the voltage source is not specified and is not important provided that the source voltage V_s is the actual voltage from the junction of Z_1 and Z_2 to ground. See Fig 1.

9.2.2

The voltmeter is an electric device suitable for measuring ac voltage. This standard requires one or two high-impedance voltmeters. The voltmeter(s) shall be selected so that the impedance of the circuit being bridged is not altered beyond the tolerances of this standard. The meter used for the metallic measurement shall have high longitudinal impedance and high balance (see 9.2.6, NOTE).

9.2.2.1

A voltmeter having a broad-band frequency response, used for measuring the metallic voltage V_m, will respond to any metallic voltage which may be present, including noise from external sources. Under field conditions, metallic circuit noise may totally mask the imbalance voltage and produce a false indication of poor balance. This condition can be avoided by using a frequency-selective voltmeter sharply tuned to the signal generator frequency.

9.2.2.2

There shall be some means for verifying that the reading is caused by imbalance and not by extraneous noise or tones. For example, this requirement could be met by a check to see that a change in the longitudinal source voltage V_s produces a corresponding change in the measured metallic voltage V_m.

9.2.3

The driving test circuit is a balanced network used to apply the longitudinal test voltage equally to tip and ring leads of the test specimen. This circuit is defined more fully elsewhere in this standard. An example of a practical circuit is given in Appendix A1.

9.2.4

The terminating test circuit is a balanced passive network used to terminate the second port of a two metallic transmission port test specimen. It is assumed that the driving test circuit is connected to the other metallic transmission port whenever this circuit is in use.

9.2.5

The dc supply circuit provides direct current to a metallic transmission port when required (see 9.2.6, NOTE).

9.2.6

The dc terminating circuit completes the dc path through the specimen when required.

NOTE — Any bridged meter, bridged dc supply, or bridged dc termination shall have a balance and longitudinal impedance sufficiently high that the balance and longitudinal impedance of the overall test setup, including the bridged circuit components, meet the requirements of this standard as set forth in Sections 7. and 8.

10. Test Procedures

This section of the standard is divided into four parts: test conditions, test set calibration, tests of one-port specimens, and tests of two-port specimens. Throughout this standard, distinction is made between the metallic and longitudinal ports. While it is recognized that the longitudinal port is an important part of the network characterization, the designation of the number of ports of a given network is limited to the number of metallic transmission ports.

10.1 Conditions

Balance measurements made according to this standard are considered as *laboratory* or *bench* tests and not *field* tests. Regardless of the actual conditions encountered by a specimen while in use, the balance test should be performed under room conditions. Sufficient time should be allowed for the temperatures of the test circuits and the specimen to stabilize before tests are started. Components or devices which in their normal use require dc bias or power should, whenever possible, be tested under simulated operational conditions.

This standard may be used for measurement of the balance of devices having internal active circuits or internal signal or noise sources, provided that any signals or noise at other than the test frequency have no significant effect on the measurement. This requirement shall be verified as provided in 9.2.2.2.

This standard is intended primarily for the measurement of balance of components or devices, rather than of cable pairs or extensive systems. If the standard is used for the measurement of cable-pair balance, the balance so measured is the *port* balance, which may be different at the two ends of the cable. The longitudinal balance, measured in accordance with this standard at the end of a cable-pair considered as a port, is not the same as the longitudinal balance measurement resulting from induced longitudinal interference that is distributed along the length of the cable. The correlation between the port longitudinal balance and the distributed longitudinal circuit balance in cable-pairs has not been investigated in detail.

10.2 Calibration

This standard requires that tests will be performed only after the test circuit is properly balanced. The test circuit shall have some means of calibration to ensure that test conditions are correct. A calibration procedure shall be adopted that will ensure that the driving test set balance is sufficiently better than the highest level of balance to be measured. Since this procedure depends on the particular design of the measuring circuit, it is not possible to include a universally applicable calibration procedure in this standard. The test circuit balance requirements are met when it is verified that, with the terminating test circuit connected directly to the driving test circuit, the balance reading is sufficiently higher than the highest balance to be measured (see section 7.) and *does not change* when the connection between terminating test circuit and driving test circuit is frogged. See also Appendix B.

10.3 Measurement of One-Port Specimens

The test specimen is connected to terminals X1, X2, and G (ground) of the driving test circuit. The ac source is connected between ground and the tie point between balanced impedances Z_1 and Z_2. See Fig 4.

The source voltage V_s will cause nearly equal voltages to appear from terminals X1 and X2 to ground. Any imbalance in either the tip T or ring R sides of the test specimen, referenced to ground, causes a metallic voltage V_m to be developed across terminals X1 and X2. The balance is computed from Eq 1. If the test specimen requires some dc bias to operate, it is applied between terminals X1 and X2 in some way that does not affect the driving test circuit. (This can be accomplished through the use of a large inductance—on the order of 20 H.)

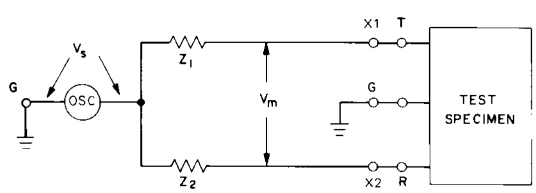

Figure 4—Connections for One-Port Test Specimen

In the course of the test, the frequency of the alternating-voltage source OSC is varied to obtain the frequency response. The dc bias and the voltage V_s are varied to determine whether the specimen exhibits a nonlinear characteristic. Four parameters and the units of their measurement are recorded to completely characterize any one-port specimen. They are as follows:

1) The test frequency, Hz
2) The applied voltage V_s
3) The dc bias current
4) The balance (determined from V_s and the resulting metallic voltage V_m)

For each set of readings, the balance is computed according to Eq 1, provided that the same voltage (or balance) readings are obtained when the specimen input terminals are frogged.

10.4 Measurement of Two-Port Specimens

The test specimen is connected to both the driving and terminating test circuits for these tests. Two configurations shall be tested: first with the specimen in one direction (input of specimen connected to the driving test circuit) and then with it reversed (output of specimen connected to the driving test circuit). These connections are illustrated in Fig 5.

Measurements should be made, in both the forward and reverse configurations, with switch S2 both open and closed (switch S1 closed). This procedure makes it possible to observe the extent of the series and shunt imbalances in the specimen. When both switches S1 and S2 are closed, the series imbalance is emphasized (see 8.1) and the result is referred to as a series-balance measurement. When switch S2 is open the result is a high longitudinal terminating impedance (open circuit) shunt-balance measurement. A moderately high longitudinal terminating impedance (2000 Ω) shunt-balance measurement, as required in the 1976 edition of this standard, is obtained when switch S2 is closed with switch S1 open.

The parameters recorded to completely characterize any two-port specimen are as follows:

1) The test frequency, Hz
2) The applied voltage V_s
3) The dc bias current, and to which terminals it is applied

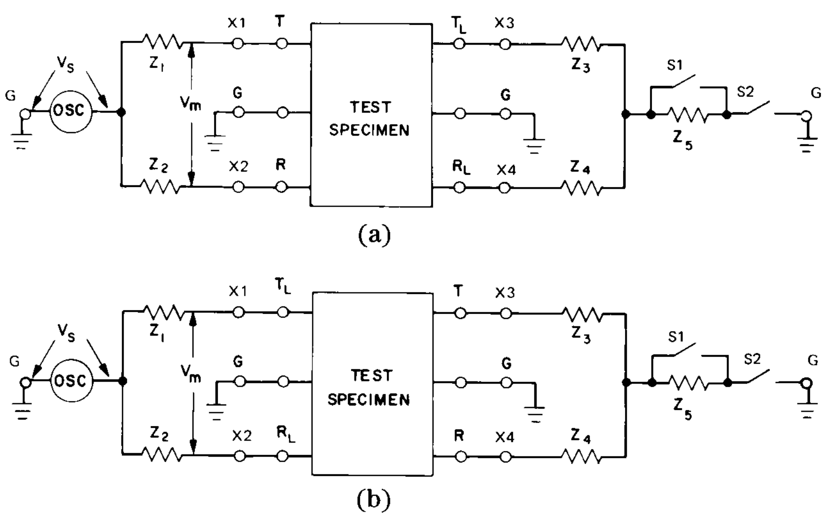

Figure 5—Connections for Two-Port Specimen (a) Forward Direction (b) Reverse Direction

4) The balance in the forward direction (determined from V_s and the resulting V_m) with switch S2 both open (shunt balance) and closed (series balance)
5) The balance in the reverse direction (determined from V_s and the resulting V_m) with switch S2 both open (shunt balance) and closed (series balance)

Switch S1 is always closed unless shunt balance measurement in conformance with the 1976 edition of this standard is required.

For each set of readings, the balance of the specimen is computed in both directions according to Eq 1, provided that the same voltage (or balance) readings are obtained when the specimen input terminals are frogged.

11. Presentation of Test Results

Results of any balance test performed in accordance with this standard should contain a notation such as the following:

Longitudinal balance tests performed in accordance with ANSI/IEEE Std 455-1985.

Test results should be reported on a tabulated data sheet. The report shall include all of the following items.

11.1

For each equipment tested:

1) Date and place of test
2) Name or initials of person testing
3) Full identification of equipment tested (type, serial No, etc)
4) Calibration balance of test circuit
5) One-port or two-port

11.2

For each individual measurement, whether one- or two-port:

1) Measurement frequency
2) V_s
3) DC bias current at measurement terminals
4) The measured balance

11.3

Additional items for each two-port measurement:

1) Identification of measurement port (T-R, T1-R1, etc)
2) DC bias current at the other port
3) Series-balance measurement (S1 and S2 closed) or shunt-balance measurement (S2 open).
4) If measurement is shunt-balance in accordance with the 1976 edition of this standard (S1 open and S2 closed), this shall be indicated in the report.
5) If the terminating port is not terminated in the standard terminating test circuit shown in Fig 3, but in an alternative terminating test circuit as provided for active circuits in 8.2, then a full description of the terminating test circuit used shall be included in the report.

Annex A Balance Measuring Set Example (Informative)

It should be emphasized that the circuit configurations shown in the Appendixes are examples only. Many other configurations are possible, and any configuration that meets the requirements of the standard as set forth in Sections 4. through 9. is acceptable.

This balance measuring set is one example of a circuit that meets the requirements of this standard. It consists of two parts

1) A driving test circuit applies the longitudinal test voltage and contains the test points where voltage measurements are made. This circuit is used for all balance testing procedures.
2) A terminating test circuit provides a suitable termination for test specimens that have a second port. This circuit is used in conjunction with the driving test circuit for all balance tests of specimens with two ports.

The driving test circuit is shown in Fig A-1.

This circuit applies an alternating voltage V_S to the test set and the specimen under test. As a result of the applied voltage, a longitudinal current I_L flows. Because R1 and R2, and C1 and C2 are balanced closely, the current I_L divides equally between the upper and lower paths (ignoring for now the effect of imbalance in the specimen). The return path for I_L is through the ground connections at the two ends of the circuit.

The terminating test circuit is shown in Fig A-2.

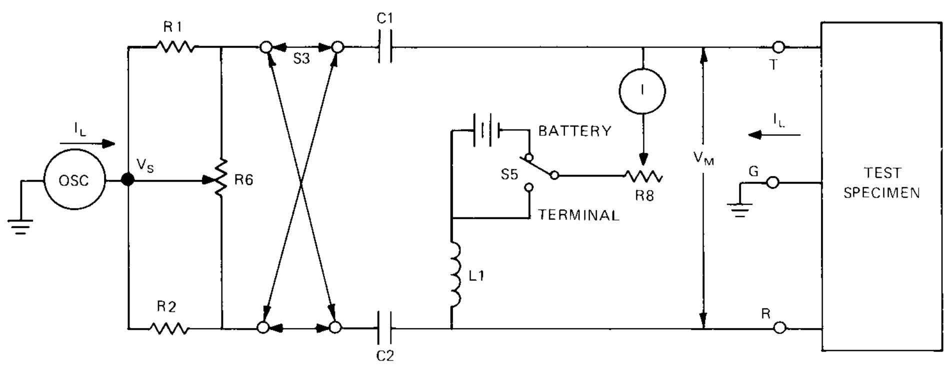

Figure A-1—Driving Test Circuit of Balance Measuring Set

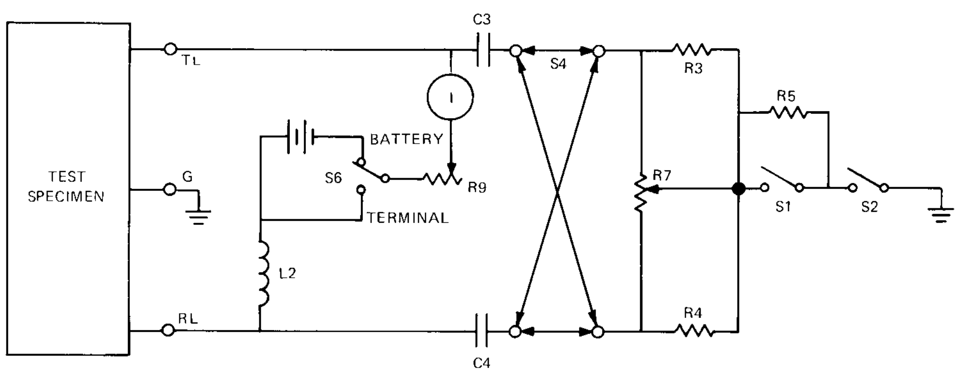

Figure A-2—Terminating Test Circuit of Balance Measuring Set

This circuit is connected to a second port of a two-port specimen at the same time that the driving circuit is connected to the first port (So-called two-port test specimens include repeat coils, real or artificial cable pairs, range extenders, and other devices which are inserted into the telephone line).

Depending on the magnitudes of the series and shunt impedances of the test specimen, a portion of current I_L will return to ground through the G terminal and the remainder through the balanced resistors R3 and R4.

Resistor R5 and switches S1 and S2 are used to determine the relative degree of series and shunt imbalance.

In the event that the test specimen requires a direct-current bias, a suitable battery or a variable resistor can be switched into the metallic circuit. The dc bias flows through a large inductance which presents a high impedance to ac signals. The capacitors present a high impedance to the dc bias and prevent any dc from flowing through the test circuit.

Some devices which require a battery feed voltage require that voltage to be referenced to ground. They will not function properly with the floating bias network shown in Figs A-1 and A-2. The bias network in Fig A-3 can be used in these cases. Transformer T1 provides a low-resistance battery-feed path while offering a high-metallic impedance to the test signals. The inductor L3 provides a low-resistance dc path for the reference ground and presents a high-impedance path to longitudinal alternating current. The transformer T1 is recommended over two matched inductors because balance is easier to obtain with a transformer. The high-longitudinal impedance, which could be provided by the matched inductors, is provided by L3. If this bias network is used, it is necessary that it be in place when the test circuits are calibrated. Whenever possible, the bias network in Figs A-1 and A-2 should be used.

Components for the driving and terminating test circuits in this example are as follows:

1) *Oscillator*. This is the test circuit alternating-voltage source. It has provisions for varying the output amplitude to 10 V rms, and the frequency range from 50 Hz to 4000 Hz. See 9.2.1.

2) *Resistor Pairs* R1–R2 and R3–R4. These are two pairs of balanced resistors. All have the resistance value of 368 Ω ±5%. The resistance values of each pair are closely matched, but the values of one pair need not match the values of the other pair. See Sections 5. and 8.

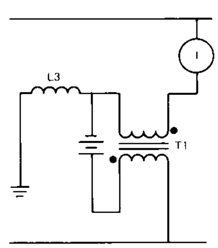

Figure A-3—Grounded-Bias Circuit of Balance Measuring Set

3) *Resistors* R6 and R7. These are trimming potentiometers with approximately 250 kΩ resistance, 0.5 W each. These potentiometers are adjusted during calibration of the test circuit to get resistor pairs R1–R2 and R3–R4 effectively balanced to the desired degree. See Section 7..

4) *Capacitor Pairs* C1–C2 and C3–C4. These nonelectrolytic capacitors block dc from the test circuit and are specified at 100 μF each. To preserve test-set accuracy of ±1 dB, each pair of capacitors is kept balanced to within 0.2 μF. That is, $|C1–C2| \leq 0.2$ μF and $|C3–C4| \leq 0.2$ μF.

5) *Inductors* L1 and L2. These components block ac from the bias circuit. Each has an inductance value of 20 H and a current capacity of 100 mA dc. See 9.2.5 and 9.2.6.

6) *Transformer* T1 *and Inductor* L3. These components provide an alternative to inductors L1 and L2, as described elsewhere in this Appendix. Each has an inductance of 20 H. T1 has a current capacity of 100 mA dc and L3 has a current capacity as required by the test specimen.

7) *Switches* S3 *and* S4. These are DPDT switches used during test set calibration by the user. They permit frogging without changing the polarity of dc bias applied to the test specimen.

8) *Resistors* R8 *and* R9. These variable resistors are used to establish the desired dc bias conditions of voltage and current. Nominal resistance is 3000 Ω, 3 W.

9) *Switches* S1 *and* S2. These switches are used to set the longitudinal impedance of the terminating test circuit. When both switches are closed, the longitudinal impedance is one-quarter of the metallic test-circuit impedance or 184 Ω. When S1 is open and S2 is closed the longitudinal impedance is increased by 2000 Ω, the value of R5. When S2 is open, the longitudinal path is removed. See 8.1.

10) *Resistor* R5. This resistor has a nominal value of 2000 Ω, 0.5 W.

Annex B Balance Set Calibration (Informative)

With proper calibration, the balance measuring set can be made to measure balance in the order of 100 dB. Basically, calibration consists of balancing the internal impedance of the driving test circuit portion of the measuring set against the internal impedances of the terminating test circuit portion. Once the longitudinal-voltage oscillator and the metallic-voltage measuring circuit portions of the measuring set are properly calibrated using conventional methods, no additional generating or measuring equipment is needed for the balance calibration.

B.1 Basic Balance Calibration

Figure B-1 shows a driving test circuit such as that of Fig A-1 connected to a terminating test circuit such as that of Fig A-2.

Balance adjustment is shown in both the driving and terminating test circuits. (The balance adjustment may consist of a separate potentiometer as shown in Figs A-1 and A-2.). Switches S1 and S2 are in the closed position so that the junction of Z3 and Z4 is connected to ground. For simplicity, let us assume that the impedances Z1 through Z4 are all pure resistances with values R1 through R4.

With the driving and terminating test circuits connected as shown by the solid lines in Fig B-1, adjust R1 and R2 for a null in the measured metallic voltage V_m (maximum balance reading). At V_n null, R1/R2 = R3/R4. Note the position of the balance adjustment potentiometer. Now, frog the interconnection between driving and terminating test circuits, as shown by the broken lines in Fig B-1. Readjust R1 and R2 for a new V_m null. This will set R1/R2 = R4/R3. Note the position of the adjustment and turn it to approximately midway between the two positions noted. The ratio R1/R2 will then be somewhere between R3/R4 and R4/R3 and therefore R1 and R2 are closer to balance than R3 and R4.

Repeat the same procedure but this time adjust R3 and R4: adjust for V_m null and note the adjustment position; frog; adjust for a new V_m null and note the position; move to a position between the two noted. Repeat the procedure several times, adjusting first R1, R2, and then R3, and R4 until frogging no longer has any effect on the V_m null. At this point, both the driving test circuit and the terminating test circuit are, in principle, ideally balanced.

B.2 Practical Considerations

The basic balance calibration, involving resistance only, is simple and effective for the final calibration by the user before any balance measurement is made. The procedure used in balancing the entire balance measurement set when it is built is more complex because of the presence of reactive components in the balance impedances. Series dc blocking capacitance, if present, has to be well balanced for low-frequency measurements. At higher frequencies, stray capacitance to ground or to the longitudinal voltage source, present in wiring or component part placement, also needs to be balanced. The principle however is the same as for the basic resistance balance calibration:

1) Choose a convenient frequency near the center of the range and perform a resistive balance calibration. If there are large reactive imbalances, a good V_m null (high-balance reading) will not be obtained, but obtain as good a balance as possible.

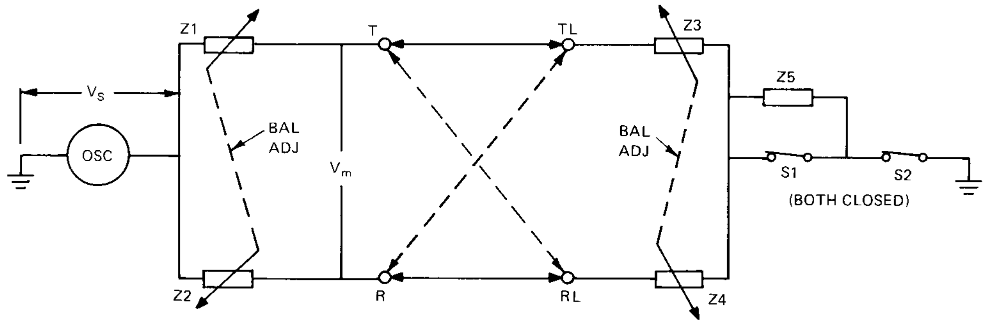

Figure B-1—Basic Balance Calibration

2) If there are series capacitors as in Figs A-1 and A-2, choose next a low frequency because this is where series capacitance has the greatest effect. The C1/C2 ratio and the C3/C4 ratio are adjusted by shunting the appropriate capacitor with small values of additional capacitance. Adjust C1/C2 for V_m null; frog; readjust and choose a compromise. Repeat with C3/C4, then C1/C2 again and so on.
3) Choose a high frequency next and follow a similar procedure to balance shunt capacitance. Opening switch S2 will increase the sensitivity to shunt imbalance and make it easier to balance shunt capacitance. Very small increments of shunt capacitance will be needed. The use of small adjustable trim capacitors will usually be helpful. Stray capacitance is usually to ground, but may also occur to the longitudinal voltage source, effectively in parallel with R1 or R2.
4) These balance adjustments may be interactive. Resistance should be rebalanced frequently during the procedure, and the final overall balance should be checked over the full range of frequencies.
5) The dc bias components, such as L1, L2, L3, T1, R8, R9, batteries and current meters of Fig A-1, A-2, and A-3, and also the input to the V_m measuring circuit, can have a major effect on measuring circuit balance. It is essential therefore that these components be present in the balance measuring circuit during the calibration procedure.
6) Where internal frogging switches are provided, such as S3 and S4 of Figs A-1 and A-2, overall balance should be checked by external frogging, at the terminals, for all possible combinations of internal frogging-switch positions.
7) When balance calibration is complete, the overall measuring-circuit balance at any frequency is the highest balance reading that is not affected by frogging at the terminals. In the limiting case, where the specimen metallic impedance is greater than 7500 Ω and its longitudinal impedance is less than 15 Ω, a measuring-circuit balance 31 dB higher than the highest balance that is to be measured will be necessary to ensure 1 dB accuracy. In most cases, 19 dB is adequate. See Section 7.

Annex C Alternative Circuits (Informative)

Other measuring circuits can be used provided they are equivalent to the circuits described in this standard. Balance measurements have frequently been made with the longitudinal voltage applied through the center tap of a balanced inductor or transformer. By means of the equivalence shown in Fig C-1, the inductor or transformer, with associated impedances, can be made equivalent to the driving and terminating test circuits described in Sections 5. through 8. of this standard.

Another equivalent driving circuit with dc blocking capacitors is shown in Fig C-2.

In this arrangement, Z3 consists of an active circuit dynamic impedance that is made as small as possible at test frequencies while still blocking dc. As Z3 approaches zero, the effects on circuit balance of both the series resistance and capacitive reactance of C1 and C2 become noncritical and only resistor calibration is needed.

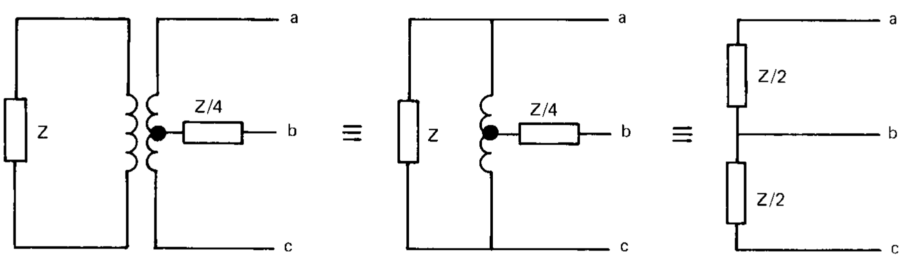

Figure C-1—Equivalent Circuits

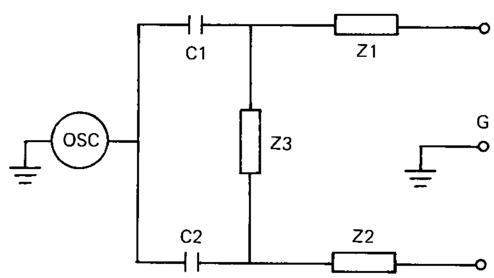

Figure C-2—Alternate Circuits with DC Blocking

Annex D Alternate Terminating Test Circuit (Informative)

Figure D-1 shows one example of a terminating test circuit that allows separate control of longitudinal and metallic impedances and has been used to terminate active devices requiring specific metallic terminations.

ZT is the metallic impedance required to properly terminate the test specimen. Z5 and Z6 are respectively the nominal 2000 Ω and 184 Ω longitudinal impedances required by the standard. S1 and S2 have the same function in the modified terminating test circuit as they have in the standard terminating test circuit, and permit switching in the same values of longitudinal impedance. See 8.1.

Transformer T1 permits independent control of longitudinal and metallic impedance. It should be sufficiently well balanced to permit the modified terminating test circuit to be balanced to the same degree as the driving test circuit. Additionally, T1 has sufficient inductance, and its parasitic reactances and those of its interconnecting wiring are sufficiently well controlled that ZT, as reflected by T1, suitably terminates the test specimen over the required frequency band.

For the same reason, and also to maintain the proper longitudinal impedance, the winding resistance of T1 should be controlled or, alternately, allowed for, by changing Z6 and ZT appropriately. Note that if the physical realization of the terminating impedance ZT has no longitudinal path to ground, or a sufficiently high-longitudinal impedance, it may be placed directly across the primary of T1 with no connection made to the secondary. Thus, T1 may be replaced by a balanced, center tapped inductor with ZT placed directly across TL and RL.

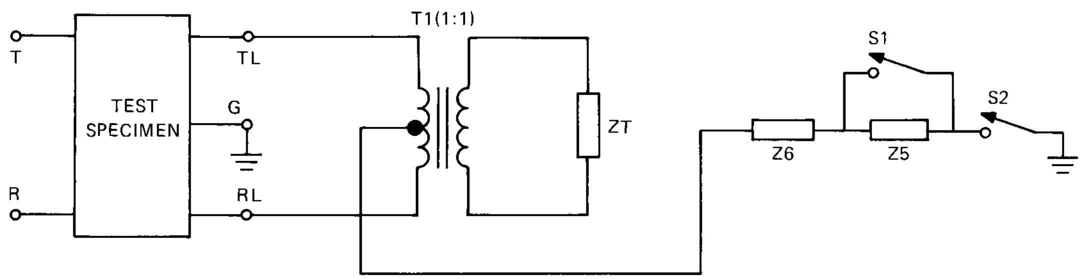

Figure D-1—Alternate Terminating Test Circuit

Annex E Other Standards and References (Informative)

The CCITT, Yellow Book, 1980,[2] Recommendation G 117, defines several functions of impedance balance in one-port and two-port networks. Longitudinal conversion loss, as defined in Recommendation G 117, 4.1.3 is essentially the same as the longitudinal balance covered in this standard except for test-circuit impedance values. Recommendation G 117 does not specify standardized test-circuit impedances but does specify that the longitudinal impedance shall be one quarter of the transverse (metallic) impedance.

The FCC Rules and Regulations,[3] Part 68, 68.310, defines longitudinal balance as meaning a metallic-to-longitudinal balance coefficient that is appropriate for evaluation of harm to the network. This contrasts with the longitudinal-to-metallic longitudinal balance of this standard, which is directed more toward evaluation of susceptibility to interference from longitudinal induction. The FCC balance corresponds (except for test-circuit impedance values) to the transverse conversion loss defined by the CCITT in Recommendation G 117, 4.1.2. The term *transverse balance* has been suggested for balance as defined by the FCC, since this would distinguish it from the longitudinal balance of this standard and come closer to CCITT usage (longitudinal conversion loss and transverse conversion loss). While longitudinal balance as defined in this standard and as defined by the FCC are not equivalent, there is a quantifiable correlation between the two. It is therefore possible to use the measurement of either one, with appropriate allowances, to ensure that the other is within acceptable limits, if measurement is restricted to linear passive networks.

[2]CCITT publications are available in the United States from National Technical information Service, Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161, USA.
[3]FCC publications are available from the Federal Communications Commission, Washington, DC 20402, USA.