

TECHNICAL REPORT

IEC
TR 62152

First edition
2004-08

Background of terms and definitions of cascaded two-ports

Withdrawn



Reference number
IEC/TR 62152:2004(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

Consolidated editions

The IEC is now publishing consolidated versions of its publications. For example, edition numbers 1.0, 1.1 and 1.2 refer, respectively, to the base publication, the base publication incorporating amendment 1 and the base publication incorporating amendments 1 and 2.

Further information on IEC publications

The technical content of IEC publications is kept under constant review by the IEC, thus ensuring that the content reflects current technology. Information relating to this publication, including its validity, is available in the IEC Catalogue of publications (see below) in addition to new editions, amendments and corrigenda. Information on the subjects under consideration and work in progress undertaken by the technical committee which has prepared this publication, as well as the list of publications issued, is also available from the following:

- **IEC Web Site** (www.iec.ch)

- **Catalogue of IEC publications**

The on-line catalogue on the IEC web site (www.iec.ch/searchpub) enables you to search by a variety of criteria including text searches, technical committees and date of publication. On-line information is also available on recently issued publications, withdrawn and replaced publications, as well as corrigenda.

- **IEC Just Published**

This summary of recently issued publications (www.iec.ch/online_news/justpub) is also available by email. Please contact the Customer Service Centre (see below) for further information.

- **Customer Service Centre**

If you have any questions regarding this publication or need further assistance, please contact the Customer Service Centre:

Email: custserv@iec.ch
Tel: +41 22 919 02 11
Fax: +41 22 919 03 00

TECHNICAL REPORT

IEC
TR 62152

First edition
2004-08

Background of terms and definitions of cascaded two-ports

Withdrawn

© IEC 2004 — Copyright - all rights reserved

No part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from the publisher.

International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch



Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE

X

For price, see current catalogue

CONTENTS

FOREWORD.....	4
1 General.....	6
2 Operational, image and insertion transfer functions and complex attenuations or losses	6
3 Terms and definitions	7
Annex A (normative) Concepts of normalized voltage waves, square root of power waves and operational attenuation and losses.....	9
A.1 General.....	9
A.2 Complex operational attenuation or operational propagation coefficient Γ_B	9
A.3 Impedance	10
A.4 Operational reflection coefficient.....	10
A.5 Return loss.....	10
A.6 General coupling transfer function.....	11
A.7 Benefits of the concept of operational quantities.....	12
Annex B (normative) Two-port transmission technique – Terms.....	13
Annex C (normative) Two-port theory and fundamental concepts in transmission engineering	14
C.1 General.....	14
C.2 Transfer equations for a passive two-port.....	14
C.3 Chain matrix.....	15
C.4 The symmetries and impedances of a two-port.....	19
C.5 Impedance matching.....	21
C.6 Level concepts.....	23
C.7 Attenuation and gain concepts	24
C.8 Concepts related to return loss and matching	28
C.9 Scattering parameter.....	35
C.9.1 Scattering parameter of a one-port	35
C.9.2 Scattering parameters and scattering matrix of a two-port.....	38
C.10 Examples.....	43
C.10.1 Example 1	43
C.10.2 Example 2	45
C.11 Reference documents.....	46
Figure 1 – Defining the transfer functions of a two-port.....	6
Figure 2 – Constant value A_S and A_T curves on a complex plane $z = x + jy$	8
Figure A.1 – Coupling between two systems.....	12
Figure C.1 – A quadripole or two-port.....	14
Figure C.2 – An impedance-unsymmetrical two-port (a) with its equivalent circuit (b).....	16
Figure C.3 – Two chained two-ports	17
Figure C.4 – An impedance-symmetrical two-port	19
Figure C.5 – An impedance-unsymmetrical two-port for which $Z_1 \neq Z_2$ when $Z_A = Z_B$	19
Figure C.6 – A two-port terminated with an impedance Z_B	20
Figure C.7 – Reflection less matching	

Figure C.8 – Power matching for maximizing the effective power	22
Figure C.9 – Absolute and nominal level in a system	24
Figure C.10 – Definition of the complex image attenuation Γ of a two-port.....	24
Figure C.11 – Definition of the complex operational attenuation of a two-port.....	25
Figure C.12 – Definition of residual attenuation	27
Figure C.13 – Measurement of the sending reference equivalent	27
Figure C.14 – Measurement of the receiving reference equivalent.....	28
Figure C.15 – Definition of the complex return loss	28
Figure C.16 – Apollonius' circle	29
Figure C.17 – Return loss	30
Figure C.18 – Curves for constant values of A_S or A_r in the complex plane	32
Figure C.19 – Curves for constant values of A_S or A_r in the complex plane	33
Figure C.20 – Smith chart for transmission lines	34
Figure C.21 – One-port	35
Figure C.22 – Homogenous transmission line	36
Figure C.23 – One-port fed from a generator with source impedance Z_g	37
Figure C.24 – Two-port	39
Figure C.25 – Termination Z_B by virtue of the stray parameters of the two-port	40
Figure C.26 – Ideal transformer.....	43
Figure C.27 – Determination of a scattering matrix of a passive reciprocal two-port.....	45

Withholding

INTERNATIONAL ELECTROTECHNICAL COMMISSION

BACKGROUND OF TERMS AND DEFINITIONS OF CASCADED TWO-PORTS

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 62152, which is a technical report, has been prepared by IEC technical committee 46: Cables, wires, waveguides, r.f. connectors, r.f. and microwave passive components and accessories.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
46/129/DTR	46/133/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

A bilingual edition of this document may be issued at a later date.

Withdrawn

BACKGROUND OF TERMS AND DEFINITIONS OF CASCADED TWO-PORTS

1 General

It is important and practical that components of a transmission chain can be separated and tested separately. This means well-defined interfaces and measuring techniques including agreed terms and definitions. It is advantageous to operate, by the square root of a reference impedance (normally application impedance of the system), with normalized voltage waves corresponding to the square root of power waves.

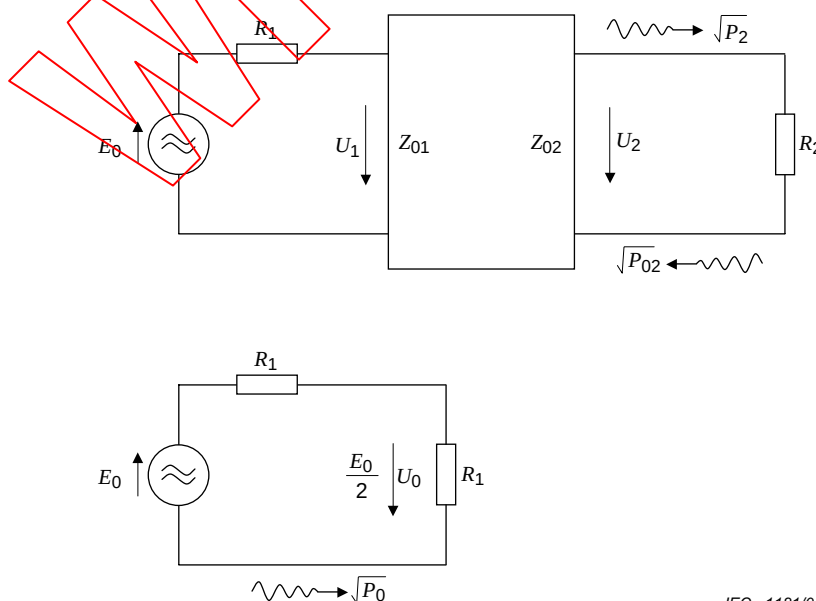
This technical report has two main goals. It lays the foundation for agreement on the fundamental terms and definitions to be used world wide in describing the transmission properties of a two-port or quadripole end and builds a bridge between the classical quadripole theory and the scattering matrix presentation which is based on incident and reflecting square root of power waves at the input and output of a two-port. Finally, it is shown that the two concepts are bound together through simple equations and are fundamentally identical.

The quadripole theory was originally developed for voice- and carrier-frequency technologies and transmission, and later for microwaves, but both can be used through the whole frequency range.

2 Operational, image and insertion transfer functions and complex attenuations or losses

a) Operational transfer function

T_B is defined as the square root of the power wave into the load (equal to reference impedance R_2) of a two-port $\sqrt{P_2}$ compared with an unreflected square root of power wave $\sqrt{P_0}$ from the generator with a source impedance equal to the reference impedance R_1 .



IEC 1181/04

Figure 1 – Defining the transfer functions of a two-port

$$T_B = \frac{\sqrt{P_2}}{\sqrt{P_0}} = \frac{U_2/\sqrt{R_2}}{U_0/\sqrt{R_1}} = S_{21} = \frac{\sqrt{P_2}}{\sqrt{P_0}} \bigg|_{\sqrt{P_{02}}=0} \quad (1)$$

which is equal to the forward transfer scattering parameter S_{21} .

The operational transfer function becomes

- b) the image transfer function T when the reference impedance becomes equal to the input and output characteristic impedances Z_{01} and Z_{02} of the two-port; and
- c) the insertion transfer function T'_B when $R_1 = R_2 = R$.

Correspondingly, the complex attenuations or losses are as follows.

Complex operational attenuation

$$\Gamma_B = A_B + jB_B = \ln \frac{1}{T_B} = -20 \log |T_B| \text{ in [dB]} - j \cdot \arg(T_B) \text{ in [rad]} \quad (2)$$

Complex image attenuation

$$\Gamma = A + jB = \ln \frac{1}{T} = -20 \log |T| \text{ in [dB]} - j \cdot \arg(T) \text{ in [rad]} \quad (3)$$

Complex insertion attenuation or loss

$$\Gamma'_B \bigg|_{R_1=R_2=R} = A'_B + jB'_B = \ln \frac{1}{T'_B} = -20 \log |T'_B| \text{ in [dB]} - j \cdot \arg(T'_B) \text{ in [rad]} \quad (4)$$

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

operational attenuation

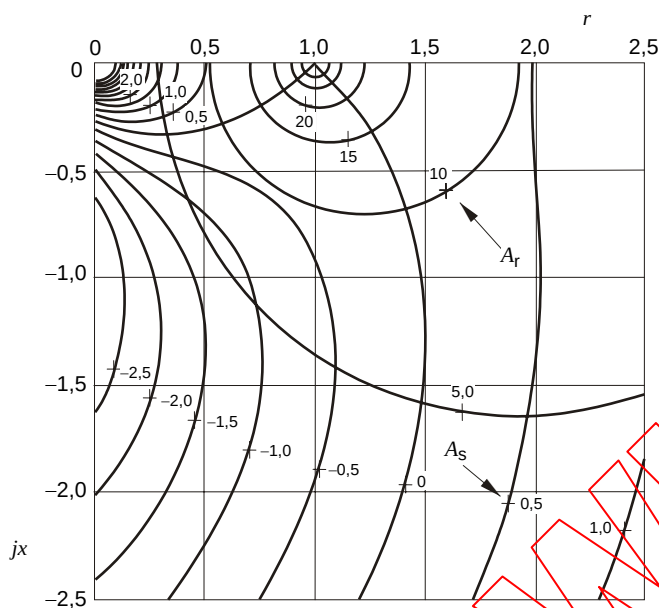
quotient of the unreflected square root of the power wave fed into the reference impedance of the input of the two-port and the square root of the power wave consumed by the load of the two-port expressed in dB and radians

NOTE By defining a new quantity operational insertion loss in the same way as the operational attenuation, at least when the reference impedances on both sides of the two-port are the same, the problem of insertion loss and operational attenuation is solved.

3.2

operational insertion loss

quotient of the unreflected square root of the power wave fed into the reference impedance of the input of the two-port and the square root of the power wave consumed by the load of the two-port expressed in dB and radians



Reflection loss

$$A_s = 20 \log \left| \frac{z_N + 1}{2\sqrt{z_N}} \right| \text{ [dB]}$$

Return loss

$$A_r = 20 \log \left| \frac{z_N + 1}{z_N - 1} \right| \text{ [dB]}$$

$$z_N = \frac{Z_2}{Z_1}$$

(= normalized impedance) = $r + jx$

Figure 2 – Constant value A_s and A_r curves on a complex plane $z = x + jy$

3.3

operational attenuation and insertion loss

quotient of the unreflected square root of the power wave fed into the reference impedance of the input of the two-port and the square root of the power wave consumed by the load of the two-port expressed in dB and radians

NOTE In the IECV, insertion loss is understood as the loss produced by inserting a two-port into a separated point of the transmission chain. Because of varying terminating impedances of the two-port, this leads to insertion loss or operational attenuation deviation, that is, depending on where, in the chain, the two-port is inserted.

It is obvious that the insertion of a two-port with a certain operational attenuation or operational insertion loss causes different attenuation increases (or decreases) in separate circuit points of different impedances.

This is called the Insertion Loss Deviation (ILD).

ILD has proved to be a very important subject of discussion in the standardization of a data channel.

Annex A (normative)

Concepts of normalized voltage waves, square root of power waves and operational attenuation and losses

A.1 General

It is important and practical that components of a transmission chain can be separated and tested separately. This means well-defined interfaces and measuring techniques including agreed terms and definitions. It is advantageous to operate, by the square root of a reference impedance (normally application impedance of the system), with normalized voltage waves corresponding to the square root of power waves.

In this way, for instance, the scattering parameters are defined. For example, S_{21} is the forward operational transfer function and S_{11} is the operational reflection coefficient.

Two of the reasons for using the square root of the impedance normalized voltage waves or the square root of the power waves are

- a) that the network analyser is measuring voltages, and
- b) because the natural logarithm, $\ln$, of a complex quantity $z = x + jy = |z| \cdot e^{j \arg z}$ is directly $\ln|z|$ nepers can be expressed in decibels $20 \cdot \log_{10}|z|$ and the imaginary part still remains $\arg(z)$ in radians, as, for example,

$$\Gamma_B = A_B + jB_B = -20 \log_{10}|S_{21}| + j \arg(z)$$

(see equation (A.1))

A.2 Complex operational attenuation or operational propagation coefficient Γ_B

The complex operational attenuation (complex operational loss) introduced by a two-port component, cascade of components, link, cable assembly etc. into a system is defined by using the scattering parameter S_{21} as

$$\Gamma_B = A_B + jB_B = \ln(1/S_{21}) = -\ln|S_{21}| - j \cdot \arg(S_{21}) \quad (\text{A.1a})$$

$$\Gamma_B = A_B + jB_B = -20 \log_{10}|S_{21}| - j \cdot \arg(S_{21}) \quad (\text{A.1b})$$

where

$$\text{in (A.1a)} \quad -\ln|S_{21}| = A_B \quad [\text{Np}]$$

$$\text{in (A.1b)} \quad -20 \log_{10}|S_{21}| = A_B \quad [\text{dB}]$$

$$\text{in (A.1a) and (A.1b)} \quad -\arg(S_{21}) = B_B \quad [\text{rad}]$$

where

A_B is the operational attenuation = $20 \log_{10}(1/|S_{21}|)$ (dB)

B_B is the operational attenuation phase constant = $-\arg(S_{21})$ (rad)

NOTE 1 A_B is equal to the ratio of the unreflected complex power (voltage $\times$ current) sent into a two-port, to the complex power consumed by the load of the two-port, in decibels. The load is normally a resistance equal to the application impedance of the system Z_N . When the generator and load impedances are the same **operational attenuation** becomes **insertion loss**.

NOTE 2 From the theory of complex functions:

$$\ln z = \ln|z| + j \cdot \arg z$$

where

$$z = x + jy = |z| \cdot e^{j \arg z}$$

and, by using the square root of power waves, we can write, for the natural logarithms of the ratio of two square root of complex power waves:

$$\ln \frac{\sqrt{P_1}}{\sqrt{P_2}} = \ln \left| \frac{\sqrt{P_1}}{\sqrt{P_2}} \right| + j \cdot \arg \left(\frac{\sqrt{P_1}}{\sqrt{P_2}} \right) = \Gamma = A + jB$$

where A is in nepers and B in radians.

When A is expressed in decibels, B will not be affected; it remains in radians.

A.3 Impedance

- The nominal characteristic impedance Z_{CN} (of a two-port) is the resistive part of the mean characteristic impedance Z_C specified with tolerance at a given frequency.
- Z_N is the nominal impedance of the system terminals between which the two-port is operating.
- Z_R is the (nominal) reference impedance used in measurements. Normally $Z_R = Z_N$.

A.4 Operational reflection coefficient

The operational reflection coefficient of the two-port is equal to the scattering parameter S_{11} of a two-port. It equals the reflection coefficient r_c at the input when the two-port is terminated with its reference impedances Z_R , normally equal to the nominal impedances of the system terminals.

$$S_{11} = r_B = \frac{Z_{in} - Z_R}{Z_{in} + Z_R} \quad (A.2)$$

A.5 Return loss

- Complex operational return loss RL_B

$$\begin{aligned} RL_B &= \ln \frac{1}{r_B} = -\ln(r_B) = -\ln|r_B| [\text{Np}] - j \cdot \arg(r_B) [\text{rad}] \\ &= -20 \cdot \log_{10} |r_B| [\text{dB}] - j \cdot \arg(r_B) [\text{rad}] \end{aligned} \quad (A.3)$$

- Structural return loss SRL

The return loss where the mismatch effects at the input and output of two-port have been eliminated (compare with the continuous wave (CW) burst measurement method).

NOTE It is important to define the structural return loss, although it is not measured direct from the cable assemblies, because it shows that there are differences between different kinds of return losses.

c) Reflection loss of a junction (see Figure 2)

$$\Gamma_r = -\ln \sqrt{1-S^2} = -\ln \left| \sqrt{1-S^2} \right| \text{ [Np]} - j \cdot \arg(\sqrt{1-S^2}) \text{ [rad]} \quad (\text{A.4a})$$

or

$$\Gamma_r = -\ln \sqrt{1-S^2} = -20 \cdot \log_{10} \left| \sqrt{1-S^2} \right| \text{ [dB]} - j \cdot \arg(\sqrt{1-S^2}) \text{ [rad]} \quad (\text{A.4b})$$

$$\Gamma_r = -\ln \sqrt{1-S^2} = -10 \cdot \log_{10} |1-S^2| \text{ [dB]} - j \cdot \frac{1}{2} \arg(1-S^2) \text{ [rad]} \quad (\text{A.4c})$$

d) Mismatch loss of a junction (not recommended)

$$\Gamma_m = -\ln \sqrt{1-|S|^2} = -\ln \left| \sqrt{1-|S|^2} \right| \text{ [Np]} - j \cdot \arg(\sqrt{1-|S|^2}) \text{ [rad]} \quad (\text{A.5a})$$

or

$$\Gamma_m = -\ln \sqrt{1-|S|^2} = -20 \cdot \log_{10} \left| \sqrt{1-|S|^2} \right| \text{ [dB]} - j \cdot \arg(\sqrt{1-|S|^2}) \text{ [rad]} \quad (\text{A.5b})$$

$$\Gamma_m = -\ln \sqrt{1-|S|^2} = -10 \cdot \log_{10} |1-|S|^2| \text{ [dB]} - j \cdot \frac{1}{2} \arg(1-|S|^2) \text{ [rad]} \quad (\text{A.5c})$$

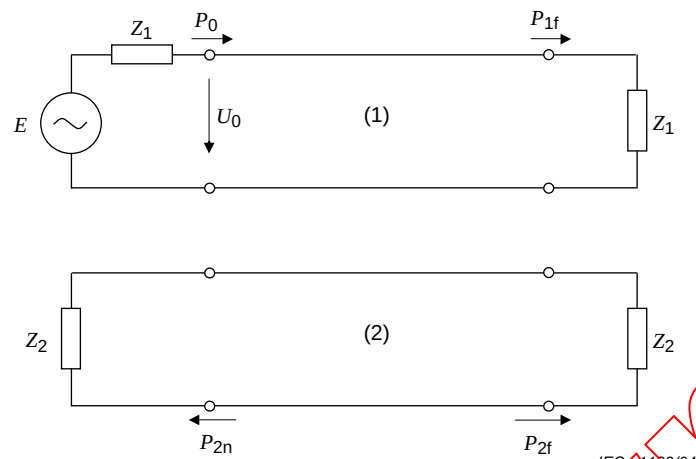
In c) and d) S is the complex reflection coefficient of the junction

$$P \text{ ---->} \quad \begin{array}{c} \hline Z_1 \quad Z_2 \\ S = r = \frac{Z_2 - Z_1}{Z_2 + Z_1} \end{array} \quad (\text{A.6})$$

A.6 General coupling transfer function

This is distinguished between the near-end and far-end coupling transfer functions T_n and T_f .

$$T_{n,f} = \frac{\sqrt{P_{2n,f}}}{\sqrt{P_0}} = \frac{U_{2n,f} / \sqrt{Z_{2n,f}}}{U_0 / \sqrt{Z_1}} = \frac{\sqrt{Z_1}}{U_0} \frac{U_{2n,f}}{\sqrt{Z_{2n,f}}} \quad (\text{A.7})$$



Key

P_0 is the unreflected power sent into the near end of the system (1).

System (1) is disturbing system (2).

Figure A.1 – Coupling between two systems

Coupling transfer function is a general term valid through the whole frequency range.

It may be expressed in decibels and radians

$$T_{n,f} [\text{dB \& rad}] = 20 \log_{10} \left| \frac{\sqrt{P_{2n,f}}}{\sqrt{P_0}} \right| [\text{dB}] + j \cdot \arg(T_{n,f}) [\text{rad}] \quad (\text{A.8})$$

and the (complex) operational transfer, coupling screening, unbalance, attenuation, etc. are

$$\Gamma_x = A_x + jB_x = -20 \log_{10}|T| - j \arg(T) \quad (\text{A.9})$$

where

A_x is the (operational) attenuation (dB);

B_x is the (operational) attenuation phase constant (rad).

A.7 Benefits of the concept of operational quantities

Measurements are always taken between well-defined resistive terminations.

This means that the impedances at a reference plane between the cascaded units of the system are specified.

Individual units can be specified and tested separately and made by different manufacturers.

This makes open systems, networks and cabling possible.

Annex B (normative) Two-port transmission technique – Terms

a) Image transfer function $T = \frac{\sqrt{P_{OUT}}}{\sqrt{P_{IN}}} = \frac{V_{OUT}}{V_{IN}}$

b) Image transfer attenuation or loss $A = 20 \log \left| \frac{1}{T} \right|$

Z_{C1} and Z_{C2} are the image or characteristic impedances of the input or output of the two-port, equal to the input and output impedances when the opposite port is terminated with its image impedance.

$\sqrt{P_{IN}} = V_{IN}$ and $\sqrt{P_{OUT}} = V_{OUT}$ are the input and output square root of complex powers.

When defining the image, there are reflections at the input and output; in other words, the input and output are terminated with their image impedance.

c) Complex image attenuation $\Gamma = 20 \log \left| \frac{1}{T} \right| [\text{dB}] + j \arg \frac{1}{T} [\text{rad}] = A + jB$

d) Image attenuation $A = 20 \log \left| \frac{1}{T} \right| [\text{dB}]$

e) Image phase shift $B = \arg \frac{1}{T} [\text{rad}]$

f) Image phase propagation time or delay $\tau_p = \frac{B}{\omega}$

g) Image group propagation time or delay $\tau_g = \frac{dB}{d\omega}$

h) Image phase velocity $v_p = \frac{1}{\tau_p}$

i) Image group velocity $v_g = \frac{1}{\tau_g}$

j) Complex operational attenuation $\Gamma_B = A_B + jB_B$

k) Operational attenuation $A_B = 20 \log \left(\frac{V_{i1}}{V_{r2}} \Big|_{V_{i2}=0} \right)$

l) Operational phase shift $B_B = \arg \left(\frac{V_{i1}}{V_{r2}} \Big|_{V_{i2}=0} \right)$