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BACKGROUND OF TERMS AND DEFINITIONS OF CASCADED TWO-PORTS

FOREWORD

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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- withdrawn;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.

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.

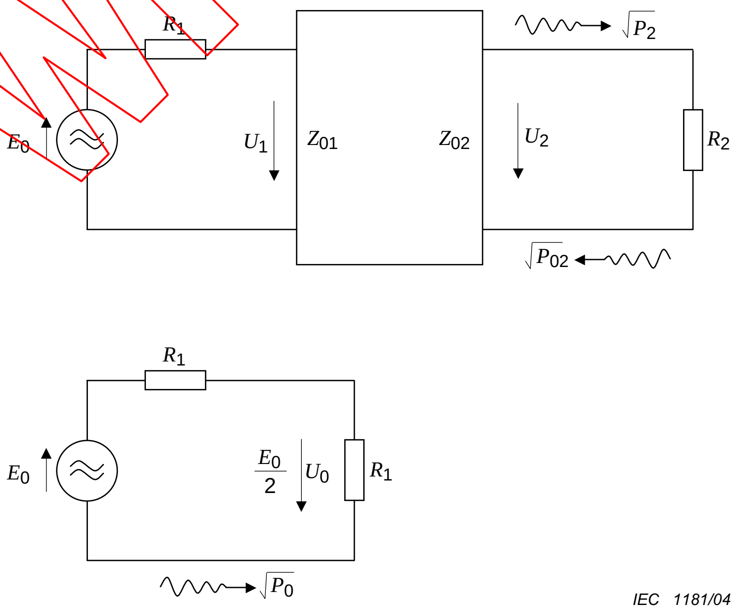
This technical report has two main goals. It lays the foundation for agreement on the fundamental terms and definitions to be used world wide in describing the transmission properties of a two-port or quadripole end and builds a bridge between the classical quadripole theory and the scattering matrix 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

$$T_{\mathrm{B}} = \frac{\sqrt{P_2}}{\sqrt{P_0}} = \frac{U_2 \big/ \sqrt{R_2}}{U_0 \big/ \sqrt{R_1}} = S_{21} = \frac{\sqrt{P_2}}{\sqrt{P_0}} \Bigg|_{\sqrt{P_{02}}=0} \tag{1}$$

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

$$\Gamma_{\mathrm{B}} = A_{\mathrm{B}} + \mathrm{j}B_{\mathrm{B}} = \ln\frac{1}{T_{\mathrm{B}}} = -20\,\log\left|T_{\mathrm{B}}\right| \text{ in } [\mathrm{dB}] - \mathrm{j}\cdot\arg(T_{\mathrm{B}}) \text{ in } [\mathrm{rad}] \tag{2}$$

Complex image attenuation

$$\Gamma = A + \mathrm{j}B = \ln\frac{1}{T} = -20\,\log\left|T\right| \text{ in } [\mathrm{dB}] - \mathrm{j}\cdot\arg(T) \text{ in } [\mathrm{rad}] \tag{3}$$

Complex insertion attenuation or loss

$$\Gamma'_{\mathrm{B}}\Big|_{R_1=R_2=R} = A'_{\mathrm{B}} + \mathrm{j}B'_{\mathrm{B}} = \ln\frac{1}{T'_{\mathrm{B}}} = -20\,\log\left|T'_{\mathrm{B}}\right| \text{ in } [\mathrm{dB}] - \mathrm{j}\cdot\arg(T'_{\mathrm{B}}) \text{ in } [\mathrm{rad}] \tag{4}$$

3 Terms and definitions

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

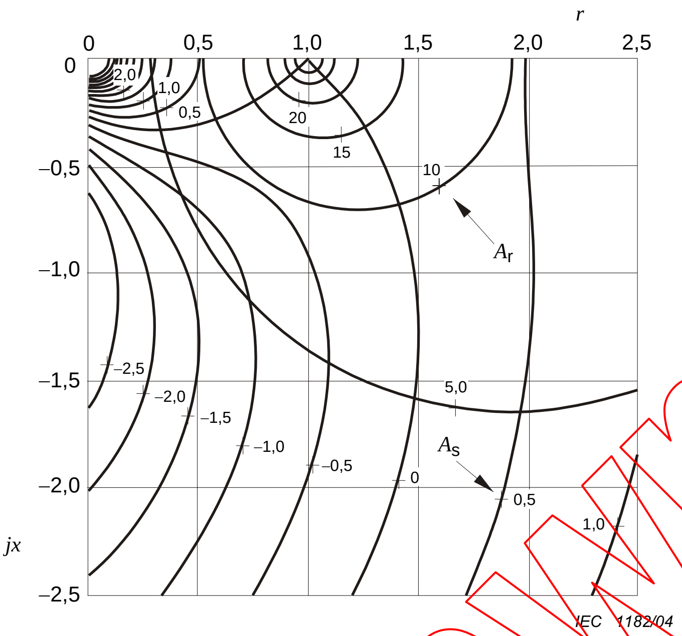
3.1
operational attenuation

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 IEV, 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 $z = x + \mathrm{j}y = |z| \cdot e^{\mathrm{j} \cdot \arg z}$ is directly l, and 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,

$$\Gamma_{\mathrm{B}} = A_{\mathrm{B}} + \mathrm{j}B_{\mathrm{B}} = -20\log_{10}|S_{21}| + \mathrm{j}\arg(z)$$

(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

$$\Gamma_{\mathrm{B}} = A_{\mathrm{B}} + \mathrm{j}B_{\mathrm{B}} = \ln(1/S_{21}) = -\ln|S_{21}| - \mathrm{j}\cdot\arg(S_{21}) \quad \text{(A.1a)}$$

$$\Gamma_{\mathrm{B}} = A_{\mathrm{B}} + \mathrm{j}B_{\mathrm{B}} = -20\log_{10}|S_{21}| - \mathrm{j}\cdot\arg(S_{21}) \quad \text{(A.1b)}$$

where

in (A.1a) $-\ln|S_{21}| = A_{\mathrm{B}} \ [\mathrm{Np}]$

in (A.1b) $-20\log_{10}|S_{21}| = A_{\mathrm{B}} \ [\mathrm{dB}]$

in (A.1a) and (A.1b) $-\arg(S_{21}) = B_{\mathrm{B}} \ [\mathrm{rad}]$

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 × 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:

$$\ln z = \ln|z| + \mathrm{j} \cdot \arg z$$

where

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

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:

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

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

a) 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.

b) Z_N is the nominal impedance of the system terminals between which the two-port is operating.

c) 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.

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

A.5 Return loss

a) Complex operational return loss RL_B

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

b) 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)

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

or

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

$$\Gamma_{\mathrm{r}} = -\ln\sqrt{(1-S^2)} = -10\cdot\log_{10}\left|(1-S^2)\right| \; [\mathrm{dB}] - \mathrm{j}\cdot\frac{1}{2}\arg(1-S^2) \; [\mathrm{rad}] \qquad \text{(A.4c)}$$

d) Mismatch loss of a junction (not recommended)

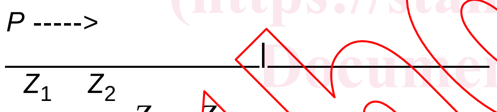
$$\Gamma_{\mathrm{m}} = -\ln\sqrt{(1-|S|^2)} = -\ln\left|\sqrt{(1-|S|^2)}\right| \; [\mathrm{Np}] - \mathrm{j}\cdot\arg(\sqrt{(1-|S|^2)}) \; [\mathrm{rad}] \qquad \text{(A.5a)}$$

or

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

$$\Gamma_{\mathrm{m}} = -\ln\sqrt{(1-|S|^2)} = -10\cdot\log_{10}\left|(1-|S|^2)\right| \; [\mathrm{dB}] - \mathrm{j}\cdot\frac{1}{2}\arg(1-|S|^2) \; [\mathrm{rad}] \qquad \text{(A.5c)}$$

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

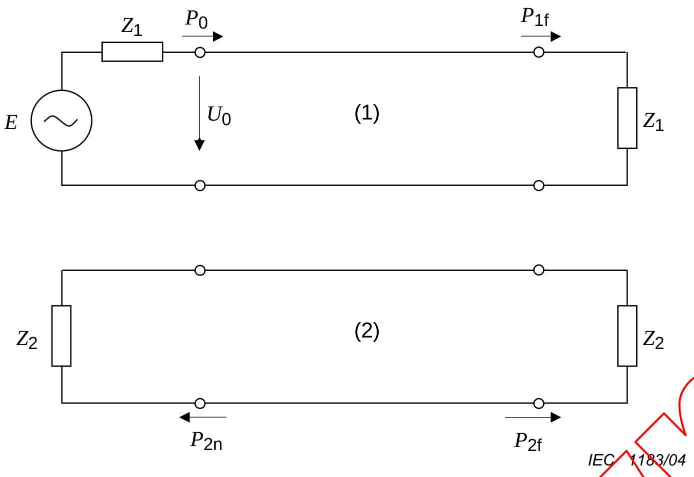


$$S = r = \frac{Z_2 - Z_1}{Z_2 + Z_1} \qquad \text{(A.6)}$$

A.6 General coupling transfer function

This is distinguished between the near-end and far-end coupling transfer functions T_{n} and T_{f}.

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



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

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

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

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

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.