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BSI Standards Publication

EMC IC modelling

Part 4: Models of integrated circuits for RF immunity behavioural simulation — Conducted immunity modelling (ICIM-CI)

bsi.

National foreword

This British Standard is the UK implementation of EN 62433-4:2016. It is identical to IEC 62433-4:2016.

The UK participation in its preparation was entrusted to Technical Committee EPL/47, Semiconductors.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Modèles de circuits intégrés pour la CEM -
Partie 4: Modèles de circuits intégrés pour la simulation du comportement d'immunité aux radiofréquences - Modélisation de l'immunité conduite (ICIM-CI)
(IEC 62433-4:2016)

EMV-IC-Modellierung - Teil 4: Modelle integrierter Schaltungen für die Simulation des Verhaltens der HF-Störfestigkeit - Modellierung der Störfestigkeit gegen leitungsgeführte Störungen (ICIM-CI)
(IEC 62433-4:2016)

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European foreword

The text of document 47A/988/FDIS, future edition 1 of IEC 62433-4, prepared by SC 47A “Integrated circuits” of IEC/TC 47 “Semiconductor devices” was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62433-4:2016.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-04-21
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Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu

Publication	Year	Title	EN/HD	Year
IEC 62132-1	-	Circuits intégrés - Mesure de l'immunité électromagnétique - Partie 1: Conditions générales et définitions	EN 62132-1	-
IEC 62132-4	-	Circuits intégrés - Mesure de l'immunité électromagnétique 150 kHz à 1 GHz - Partie 4: Méthode d'injection directe de puissance RF	EN 62132-4	-
IEC 62433-2	-	Modèles de circuits intégrés pour la CEM - Partie 2: Modèles de circuits intégrés pour la simulation du comportement lors de perturbations électromagnétiques - Modélisation des émissions conduites (ICEM-CE)	EN 62433-2	-
ISO 8879	1986	Traitement de l'information - Systèmes bureautiques - Langage normalisé de balisage généralisé (SGML)	-	-
ISO/IEC 646	1991	Technologies de l'information - Jeu ISO de caractères codés à 7 éléments pour l'échange d'information	-	-
CISPR 17	-	Méthodes de mesure des caractéristiques d'antiparasitage des dispositifs de filtrage CEM passifs	EN 55017	-

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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EMC IC MODELLING –

Part 4: Models of integrated circuits for RF immunity behavioural simulation – Conducted immunity modelling (ICIM-CI)

FOREWORD

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International Standard IEC 62433-4 has been prepared by subcommittee 47A: Integrated circuits, of IEC technical committee 47: Semiconductor devices.

The text of this standard is based on the following documents:

FDIS	Report on voting
47A/988/FDIS	47A/989/RVD

Full information on the voting for the approval of this standard 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 stability date indicated on the IEC website 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.

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EMC IC MODELLING –

Part 4: Models of integrated circuits for RF immunity behavioural simulation – Conducted immunity modelling (ICIM-CI)

1 Scope

This part of IEC 62433 specifies a flow for deriving a macro-model to allow the simulation of the conducted immunity levels of an integrated circuit (IC). This model is commonly called Integrated Circuit Immunity Model – Conducted Immunity, ICIM-CI. It is intended to be used for predicting the levels of immunity to conducted RF disturbances applied on IC pins.

In order to evaluate the immunity threshold of an electronic device, this macro-model will be inserted in an electrical circuit simulation tool.

This macro-model can be used to model both analogue and digital ICs (input/output, digital core and supply). This macro-model does not take into account the non-linear effects of the IC.

The added value of ICIM-CI is that it could also be used for immunity prediction at board and system level through simulations.

This part of IEC 62433 has two main parts:

- the electrical description of ICIM-CI macro-model elements;
- a universal data exchange format called CIML based on XML. This format allows ICIM-CI to be encoded in a more useable and generic form for immunity simulation.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62132-1, *Integrated circuits – Measurement of electromagnetic immunity – Part 1: General conditions and definitions*

IEC 62132-4, *Integrated circuits – Measurement of electromagnetic immunity 150 kHz to 1 GHz – Part 4: Direct RF power injection method*

IEC 62433-2, *EMC IC modelling – Part 2: Models of integrated circuits for EMI behavioural simulation – Conducted emissions modelling (ICEM-CE)*

ISO 8879: 1986, *Information processing – Text and office systems – Standard Generalized Markup Language (SGML)*

ISO/IEC 646: 1991, *Information technology – ISO 7-bit coded character set for information interchange (7-Bit ASCII)*

CISPR 17, *Methods of measurement of the suppression characteristics of passive EMC filtering devices*

3 Terms, definitions, abbreviations and conventions

3.1 Terms and definitions

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

3.1.1
section
XML element placed one level below the root element or within another section and that contains one or more XML elements, but no value

3.1.2
parent
keyword which is one level above another keyword

3.1.3
child
keyword which is one level below another keyword

3.1.4
external terminal
terminal of an integrated circuit macro-model which interfaces the model to the external environment of the integrated circuit

EXAMPLE Power supply pins and input/output pins.

Note 1 to entry: In this part of IEC 62433, a terminal is by default considered as external unless otherwise stated.

[SOURCE: IEC 62433-2:2008, 3.1, modified – Note 1 to entry has been changed, Example has been added]

3.1.5
internal terminal
terminal of an integrated circuit macro-model's component which interfaces the component to other components of the integrated circuit macro-model

[SOURCE: IEC 62433-2:2008, 3.2]

3.1.6
parser
tool for syntactic analysis of data that is encoded in a specified format

3.1.7
CIML
Conducted Immunity Markup Language
data exchange format for ICIM-CI model

3.1.8
CIMLBase
Conducted Immunity Markup Language Base
abstract type from which all CIML model components are directly or indirectly derived in the ICIM-CI model definition

3.1.9
DI
Disturbance Input
input terminal for the injection of RF disturbances

Note 1 to entry: It could be any pin of IC, an input, supply or an output.

3.1.10
DO
Disturbance Output
terminal whose load influences the impedance of DI terminal, and/or the transfer characteristics of PDN, and that outputs a part of the disturbance received on the DI terminals

3.1.11
OO
Observable Output
output terminal where the immunity criteria are monitored during the test

3.1.12
GND
Ground terminal
terminal that is used as reference for return path

3.1.13
PDN
Passive Distribution Network
block that describes the impedance network of one or more ports of the integrated circuit

3.1.14
IB
Immunity Behaviour
block that describes the internal immunity behaviour of the IC

3.1.15
IBC
Inter Block Coupling
block that describes the coupling network between different PDN blocks within an IC

[SOURCE: IEC TS 62433-1:2011, 3.3]

3.1.16
VNA
Vector Network Analyzer
instrument to measure complex network parameters such as S-, Y- or Z- parameters in the frequency domain

3.1.17
RFIP
Radio Frequency Injection Probe
probe for injecting RF disturbances into a pin of an IC allowing measurement of voltage and current

3.2 Abbreviations

CIM	Conducted Immunity Model
XML	eXtensible Markup Language
SPICE	Simulation Program with Integrated Circuit Emphasis
ESD	ElectroStatic Discharge

3.3 Conventions

For the sake of clarity, but with some exceptions, the writing conventions of XML have been used in text and tables.

4 Philosophy

Integrated circuits contain more and more gates, the integration density of technologies is increasing and supply voltages are becoming lower. The reduction of distance between on-chip signals, die geometry size reduction and the increase of unwanted currents in parasitic structures, such as isolation capacitances, leads to increased internal crosstalk. Consequently, the immunity of integrated circuits is becoming more and more critical.

Due to this increased risk of lower IC immunity, the use of models and simulation tools is required to optimize the immunity behaviour of both the IC and the application.

This part of IEC 62433 describes such macro-models for simulating immunity behaviour at the IC level. The model, called ICIM-CI, will be used to predict electromagnetic immunity at the application level. This model is based on files describing the PDN and the IB containing data on electromagnetic disturbances leading to a variation of one or more observable signals. The PDN is considered to be linear, while the inherent non-linearity of the IC is taken into account in the IB. This assumption is shown in 8.2 (see Figure 25). Users of the model should apply a failure criterion to the observable signal depending on their requirements.

ICIM-CI model data is arranged in a decipherable nested manner using XML format. The objective of this exchange format, called Conducted Immunity Markup Language (CIML), is to create simple and practical universal access to the ICIM-CI model. The preliminary definitions for XML representation are given in Annex A.

5 ICIM-CI model description

5.1 General

The internal structure of an IC can be broken down into two parts:

a) Passive parts (parasitic elements of pins, bondings and tracks, ESD protection), which conduct the disturbances from the external environment to the internal IC blocks,
b) Active parts (CPU core, clock system, memory, analogue blocks). It is these active internal blocks which are sensitive to the incoming disturbances.

The ICIM-CI model consists of a set of data describing these two parts:

- PDN: the Passive Distribution Network is a multi-port circuit. It is composed of four different terminals:
  - DI: Terminals to which disturbances are applied,
  - DO: Terminals that can influence the impedance of the DI terminals and consequently receive a part of the disturbance applied on the DI terminals,
  - GND: PDN shall have one or more ground terminals (such as digital ground, analogue ground),
  - Internal terminals: Terminals that can influence the impedance of the DI terminals and are internal to the IC (at chip-level).
- IB: The Immunity Behaviour component that describes how the IC reacts to the applied disturbances (referenced to one ground terminal of the PDN). The immunity criterion is set on terminals that are called Observable Output (OO). These OO could be associated or not to the various DI, depending on the configuration of the IC.

NOTE 1 DI, DO, OO and GND terminals are external terminals and are interfaced at pin level. These pins connect to the external environment of the IC.

NOTE 2 OO terminals link the PDN to the IB. Though these terminals are external on the IC and are used to obtain the IB by monitoring the immunity criterion, they are virtually represented (internally) on the PDN of the ICIM-CI macro-model.

Figure 1 represents an example of ICIM-CI model structure.

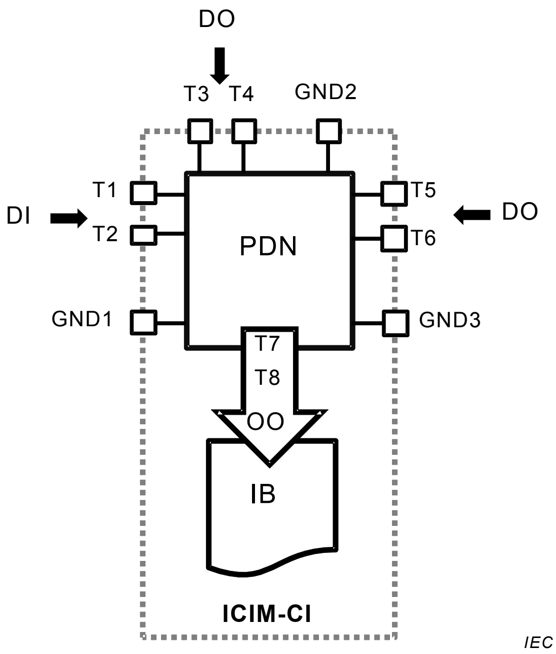


Figure 1 – Example of ICIM-CI model structure

There is no direct electrical connection between the PDN block and IB block. The PDN represents the input impedance of the DI. The power entering the DI is calculated by simulation based on the PDN and the external environment. IB links the power entering the DI to an immunity criterion monitored at OO. The IB is obtained by an immunity measurement of the IC, by means of monitoring the OO terminal.

Depending on the IC's operating conditions and stability, DO terminals may be present. One such example is illustrated in Annex B.

Different ICIM-CI models can be combined to model and describe a full electronic system such as an electronic board. That proposed structure can also be used to model an item of equipment. The DO terminal of one ICIM-CI model can be used to connect with the different terminals of neighbouring ICIM-CI blocks

Figure 2 gives an example of a complete ICIM-CI model of an electronic board. The board is fully described by three stand-alone ICIM-CI models. T12 and T21 are connected together and they receive the same disturbance. The ICIM-CI_1 propagates a fraction of its disturbance to the ICIM-CI_3 model through its T14 (DO) terminal, which is connected to the T31 (DI) terminal of the ICIM-CI_3 model.

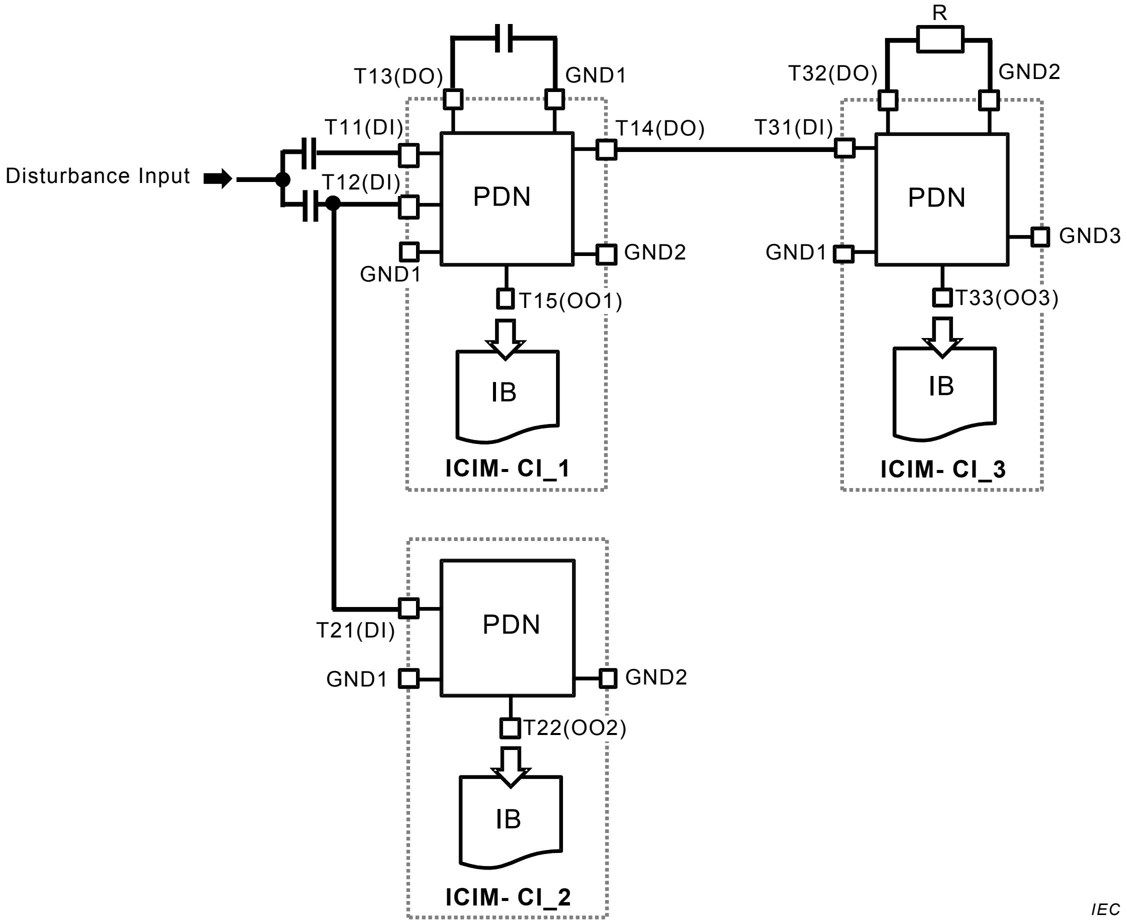


Figure 2 – Example of an ICIM-CI model of an electronic board

The valid frequency range of the ICIM-CI model is the same as that of the data (simulation or measurement) used for obtaining the PDN and IB parts.

5.2 PDN description

The PDN consists of passive elements for the package, bonding and on-chip interconnections. It represents the input network of the power and signal pins of the chip. PDN is a complete impedance network, containing both input injection terminals (DI), terminals which may have an influence on the impedance of the disturbed terminals (DO) and internal terminals. The PDN can contain linear and non-linear components such as resistance, capacitance and ESD diode protection. Nevertheless, the PDN data is defined for conditions under which the non-linear components are not activated.

PDN characterizes the coupling path for the RF disturbances, which can undergo filtering and distortion. Its impedance can vary considerably with frequency.

The PDN is defined in the frequency domain and can be characterized by different network parameters such as:

a) $Z(f)$: Impedance, which is the ratio of voltage and current at the disturbance input of the PDN. It represents the electrical schematic of passive input impedance, often consisting of parasitic elements and expressed using resistor (R), inductor (L) and capacitor (C) elements.
b) $Y(f)$: Admittance, which is the inverse of $Z(f)$.

c) *S(f)*: S-parameter, which is the ratio of the reverse and forward voltage waves at the disturbance input of the PDN. This parameter is typically used to measure the characteristics of radio frequency (RF) signal ports.

The conversion between the three types of parameters is described in Annex C. The frequency validity range of the PDN is defined by the measurement conditions.

The PDN can also be described as a circuit using a SPICE-like netlist.

An IC can have many identically designed pins with the same (similar) characteristics. Therefore, to reduce the number of DI to be modelled (for simplification purposes) the pins of an IC can be classified into families such as:

a) Supply pins,
b) Digital input/output pins,
c) Analogue input/output pins,
d) Data/address buses,
e) Communication buses.

For complex ICs, it may be essential to model the PDN as different blocks for better representation and easy understanding. These blocks may be internally coupled within the IC. For example, an IC can contain a digital and an analogue block with different ground terminals (which may be connected internally), and other terminals that are coupled within the IC. Such coupling phenomena can be modelled using an Inter-Block Coupling (IBC) network. A detailed description of an IBC network is presented in 5.3.

The PDN describes the linear behaviour of the device. The non-linear effects are not considered in the PDN of the ICIM-CI macro-model. Therefore, impedance measurements should be carried out in the typical operating conditions in a steady state mode. The proposed PDN of ICIM-CI model is limited to a level so that the protection devices are not triggered. The activation of internal protection devices would induce non-linearity in the model definition, which is not considered in the PDN. However, non-linear effects are inherently considered in the IB as described in 5.4.

The PDN could act as a filter for RF disturbances. PDN resonances may appear due to parasitic capacitive and inductive elements. Resonances can also be created by external components mounted on the DI and DO pins for IC operation. These can have a significant effect on the immunity of the devices. The PDN can stop, pass or amplify the disturbances and it can influence the immunity of the device.

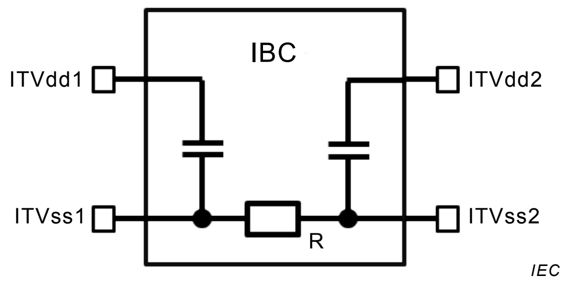
The PDN is valid in the conditions in which it has been established. Such conditions include (but not limited to):

a) Power supply voltage range
b) Applicable frequency range
c) Temperature range
d) Applicable load conditions on DI and/or DO pins

The PDN impedance behaviour allows to determine the power transmitted into the active part of the devices which is represented by the IB model. It is considered that the transmitted power at the pin is linked to the failure within the device.

5.3 IBC description

An Inter-Block Coupling (IBC) is a network of passive elements that presents a coupling effect between different PDN blocks. The IBC is thus a part of the PDN sub-model. The IBC is equipped with two or more internal terminals and can interface to internal terminals of PDN blocks. Such blocks can be used for modelling the coupling phenomena between different IC ground terminals, substrate losses, mutual inductances at die-level, insulation between internal ground and power terminals, etc. An example of an IBC network is shown in Figure 3.



NOTE ITVdd1, ITVss1, ITVdd2 and ITVss2 are internal nodes.

Figure 3 – Example of an IBC network

In this example (see Figure 3), both capacitors model the dielectric properties and the resistors model the resistive properties of the substrate. Other properties can be modelled using more complex IBC networks.

All specifications and conditions described for PDN in 5.2 are valid for IBC.

A block-based structure, using IBC components, is illustrated in Figure 4. The model consists of different PDN block components and IBC components constituting the PDN sub-model.

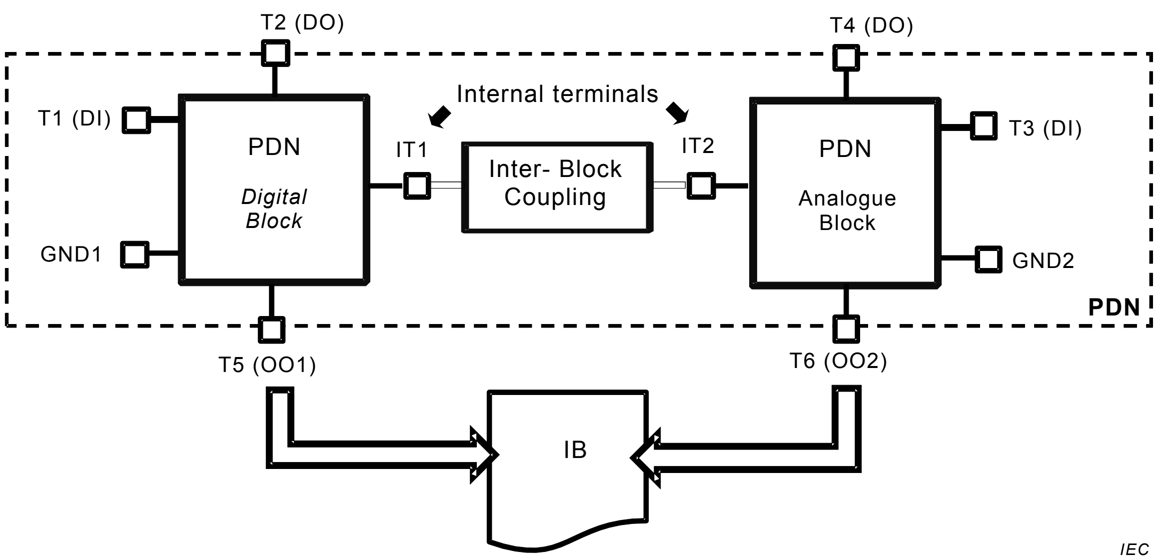


Figure 4 – ICIM-CI model representation with different blocks

5.4 IB description

The IB covers both in-band and out-band IC frequency response represented by a second sub-model. The information output, from the IB via one or more OO, describes the response of the IC to a disturbing signal applied to one or more DI. The IB should include parameters such as frequency, transmitted power, as well as the variations on one or more OO. The inherent non-linearity inducing the malfunction is considered in the IB. Depending on how the OO is tested, IB data can be obtained using pass/fail or non pass/fail test criteria.

As the name suggests, in pass/fail tests, the defect on the OO is directly tested against user-specified limits. Consequently, there is a dedicated IB sub-model per susceptibility criterion. In non pass/fail tests, the observed defects are not quantified as pass/fail (not tested against user-set limits). It represents the behavioural aspect of the OO as a function of transmitted power without specified limits. Consequently, the concerned IB sub-model is more generic and shall contain sufficient data to cover most of the practical use cases. Immunity criteria may be applied to the OO by the IC model user at a later stage during model simulation or usage.

As stated in 5.2, the PDN and IBC influence the IB sub-model. Therefore, the IB of an ICIM-CI model is valid in the conditions in which it has been established. Typical conditions include (but not limited to):

a) Power supply voltage range
b) Applicable frequency range
c) Temperature range
d) Applicable load conditions (consequently bias conditions) on DI and/or DO pin(s)
e) Immunity test criteria applied on the OO pin(s)

The frequency step-size and the range defining the IB data shall be the same as stated in IEC 62132-1. Critical frequencies such as clock frequencies and system frequencies of RF devices shall be tested using finer frequency steps, as agreed by the users of this procedure. IB sub-model's frequency range of validity is thus the same as that of the data (simulation or measurement) used for obtaining the IB.

6 CIML format

6.1 General

Data of the ICIM-CI model are arranged in XML format, henceforth called Conducted Immunity Markup Language (CIML). The model data are separated into seven parts:

a) Header containing general information
b) Description of IC's Lead definitions
c) Description of SPICE macro-models for use within the PDN data
d) Description of the model validity conditions
e) Description of the PDN data
f) Description of the IBC data
g) Description of the IB data

The inheritance hierarchy is depicted in Figure 5.

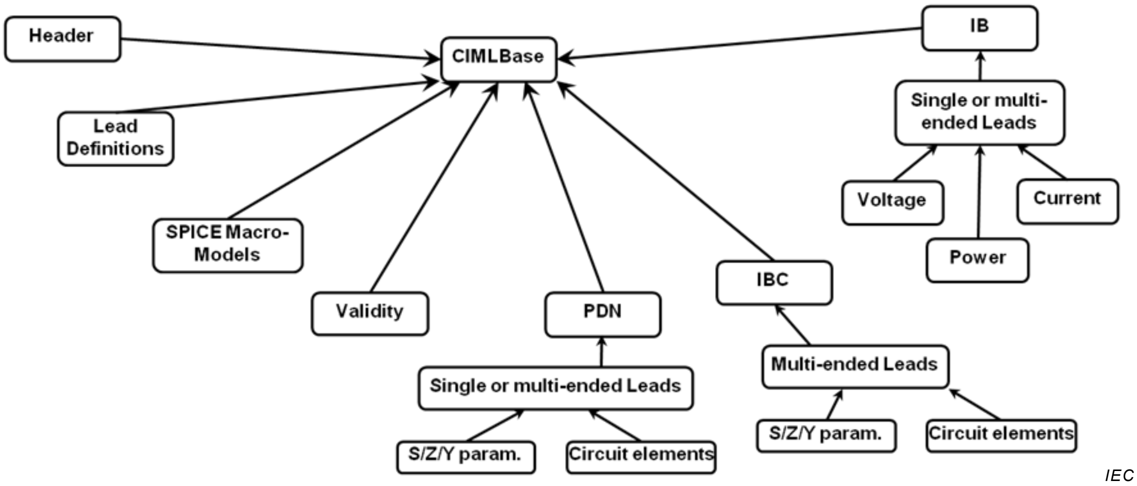


Figure 5 – CIML inheritance hierarchy

The top level of a CIML model definition simply consists of these components:

```
        beginning of model definition
            model header definition
            DUT lead definitions
SPICE macro-models
model validity conditions
            model PDN
model IBC
            model IB
        end of model definition
```

This exchange format uses eXtensible Markup Language (XML) 1.0 (Fourth Edition) to structure the information [1]. XML is derived from the Standard Generalized Markup Language (SGML) (ISO 8879:1986).

The XML encoding rules discussed in Annex A ensure that the XML (CIML) file can be correctly parsed by a Conducted Immunity Model (CIM) parser. An example of a CIML file conforming XML encoding format is given in Annex D.

6.2 CIML structure

The typical ICIM-CI model shall be represented in CIML format as shown below:

```
<?xml version="1.0" encoding="UTF-8"?>
<CImodel>
    <!-- HEADER -->
<Header>
...
</Header>
    <!-- DUT LEAD DEFINITIONS-->
<Lead_definitions>
...
</Lead_definitions>
<!-- SPICE MACRO-MODEL DEFINITIONS -->
<Macromodels>
...
</Macromodels>
<!-- MODEL VALIDITY CONDITIONS -->
    <Validity>
...
```

```
    </Validity>
    <!-- MODEL PDN DATA -->
    <Pdn>
...
    </Pdn>
    <!-- MODEL IBC DATA -->
    <Ibc>
...
    </Ibc>
    <!-- MODEL IB DATA -->
    <Ib>
...
    </Ib>
</CImodel>
```

CIML format is based on XML representation. The basic XML encoding rules in Annex A are applicable for CIML structure. The CIML keywords and their usage rules are detailed in Annex E.

The *Header*, *Lead_definitions*, *Validity*, *Pdn* and *Ib* sections are minimum and mandatory information of the ICIM-CI model. The *Macromodel* and *Ibc* sections are optional.

6.3 Global keywords

Documentation, *Notes*, *Unit* sections are global keywords and can be placed anywhere in the file except within an element containing a value. See E.4 for more information on their usage.

6.4 Header section

Readers may wonder about the motivations for an independent Header section. A simpler approach to creating the header information would be to place them all directly at the top level under <CImodel> ... </CImodel>. It is instead chosen to group them within the XML element <Header>, because this could help organize the components and makes visual reading of model definitions easier. It is thus proposed to define header information within the *Header* tag. The minimum details are the model version number, filename and the file version number. Other header contents are freely dimensioned, giving information such as:

- DUT reference
- Authors' name
- Date
- Measurement method
- Copyright
- Disclaimer
- Documentation

An example Header section is shown below:

```
<Header>
    <Cim_ver>1.0</Cim_ver>
    <Filename>ExampleICIMCI_file.ciml</Filename>
    <File_ver>1.0</File_ver>
    <Author_name>Valeo 1</Author_name>
    <Dut>LINTRCV</Dut>
    <Date>October 1, 2012</Date>
    <Meas_method>DPI</Meas_method>
</Header>
```

A detailed list of valid keywords under the *Header* section is available in E.2.

6.5 Lead definitions

This section describes the various leads (or pins) of the IC under test. Each lead in the *Lead_definitions* section is made using the *Lead* tag, whose definition is shown in Table 1. Several *Lead* structures are listed one after another to form the *Lead_definitions* structure.

Table 1 – Attributes of *Lead* keyword in the *Lead_definitions* section

Lead
Id: pin identity as a valid string (required)
Name: Name of the pin as designated in the datasheet (optional). Default = "None"
Mode: Mode in which the pin is used for ICIM-CI ("DI", "DO", "OO", " GND"). See 5.1. Default="None"
Type: type of the lead ("internal" or "external") (optional). Default = "external"

Every *Lead* structure in the *Lead_definitions* section has one required field, *Id*, representing the identity of the lead. The lead may be additionally defined with its *Name*, *Mode* and *Type*. If the *Name* field is undefined or absent, it defaults to "None". The *Mode* field is considered as "None" under the following conditions:

- If *Mode* for a particular pin is absent
- If explicitly set as "None" since the respective pin is not DI, DO, OO or GND.

The *Type* field is optional and is always considered as "external" for DI, DO, OO and GND mode pins. The lead type can also be "internal" for interfacing different blocks of the ICIM-CI PDN (see Figure 4) and such pins shall be defined with Mode="None". These leads are dedicated for interfacing the inter-block coupling network (see 5.3 for more information on IBC description).

If a pin is used in more than one mode, then the different modes are represented as a single field separated by a comma (",") character. No other characters are allowed as delimiters. An example is shown below:

```
<Lead Id="1" Name="T1" Mode="DI,OO"/>
```

The above line tells the CIM parser that lead with Id="1" with name "T1" is used as both DI and OO. By default, the lead is an external terminal (Type="external").

Table 2 lists the compatibility between the *Mode* and *Type* fields of the *Lead* structure for correct CIML annotation by the CIM parser.

Table 2 – Compatibility between the *Mode* and *Type* fields for correct CIML annotation

Mode	Type	
	external	internal
DI	Yes	No
DO	Yes	No
OO	Yes	No
GND	Yes	No
None	Yes	Yes

The different terminals described in 5.1 (see Figure 1) are represented in a compact format as shown below:

```
<Lead_definitions>
     <Lead Id="1" Name="T1" Mode="DI"/>
     <Lead Id="2" Name="T2" Mode="DI"/>
     <Lead Id="3" Name="T3" Mode="DO"/>
     <Lead Id="4" Name="T4" Mode="DO"/>
     <Lead Id="5" Name="T5" Mode="DO"/>
     <Lead Id="6" Name="T6" Mode="DO"/>
     <Lead Id="7" Name="GND1" Mode="GND"/>
     <Lead Id="8" Name="GND3" Mode="GND"/>
     <Lead Id="9" Name="T7" Mode="OO"/>
     <Lead Id="10" Name="T8" Mode="OO"/>
     <Lead Id="11" Name="GND2" Mode="GND"/>
</Lead_definitions>
```

The above lines of code represent the ICIM-CI model structure presented in Figure 1. The identities of the pins ("Id") are arbitrarily chosen. Note that these pin definitions are used for example purposes throughout this part of IEC 62433, unless otherwise specified.

6.6 SPICE macro-models

This section describes the various SPICE macro-models in netlist format. These sub-circuits are referenced within the *Pdn* tag under the *Netlist* section as explained in 6.8.3.4 and 6.8.3.5. Each SPICE macro-model in the *Macromodels* section is defined using the *Subckt* tag, whose definition is shown in Table 3. The presence of this section in a CIML file is optional.

Table 3 – *Subckt* definition

Subckt
Name: Name of the SPICE macro-model (required)
Nodes: External Nodes connecting to the main circuit (required)
Kind: SPICE netlist format (optional) default: “SPICE3”
Data_files: SPICE macro-model defined in an external file (optional)

The *Subckt* keyword has two required fields: *Name* and *Nodes*. The *Name* field consists of letters and numbers defined in A.2.5.4. The *Nodes* field defines the external nodes that connect outside the sub-circuit, i.e. the nodes through which the sub-circuit element connects to the main circuit. The different external nodes are defined in sequence separated by a comma (",") and these nodes are strictly local to the SPICE macro-model definition. These nodes can be identified with either numbers or letters.

The optional attribute *Kind* tells the CIM parser that the defined sub-circuit (SPICE macro-model) follows a specific syntax. CIML version 1 supports industry-standard SPICE like netlist syntaxes:

The *Kind* field defaults to generic "SPICE3" if absent. An example *Subckt* element is shown below:

```
<Subckt Name="PDN_pin1" Nodes="Node1,Node2,Node3" Kind="SPICE3">
     C1 Node1 int1 20e-9
L1 int1 int2 9e-9
R1 int2 Node2 230e-3
R2 Node2 Node3 100e-3
</Subckt>
```

For compatibility reasons between several SPICE kinds, "0" is not allowed as an external node. The different sub-circuit elements are listed one after another to form the *Macromodels* section. The following example illustrates the typical representation of the *Macromodels* section:

```
<Macromodels>
<Subckt Name="PDN_pin1" Nodes="Node1,Node2,Node3">
...
</Subckt>
<Subckt Name="PDN_pin2" Nodes="Node1,Node2,Node3">
...
</Subckt>
    ...
</Macromodels>
```

Once defined, the various sub-circuits are usable anywhere within the *Pdn and Ibc* tags using an identifier starting with the character "X". The call shall be made under the *Netlist* section and is referenced using the *Name* field (see 6.8.3.4 and 6.8.3.5). The number of nodes on the call line shall match the number listed in the *Nodes* attribute line of the specific sub-circuit. For example, the above defined "PDN_pin1" can be called:

```
<Pdn>
...
    <Lead Id="1 2 7" Type="Ckt">
...
        <Netlist>
Xpin1 1 2 7 PDN_pin1
        </Netlist>
    </Lead>
...
</Pdn>
```

If one or more sub-circuit models is defined in an external library file, then the file(s) is (are) referenced using the *Data_files* tag. For example:

```
<Macromodels>
<Subckt Kind="SPICE3">
<Data_files>
subckt_pin1.lib
subckt_pin2.lib
...
</Data_files>
</Subckt>
</Macromodels>
```

A typical sub-circuit definition is shown in Figure 6.

```
*Netlist file created on Fri 27 Nov 2012
*Time: 12:01:27
*PDN macro-model model of PIN1 with respect to GND1
.Subckt Pin1_PDN N1 N2
C1 N1 int1 20e-9
L1 int1 int2 9e-9
R1 int2 N2 230e-3
.ends
```

IEC

Figure 6 – Example of a netlist file defining a sub-circuit

To avoid ambiguity, the CIM parses only the data statements defined within the SPICE keywords: ".SUBCKT" and ".ENDS". These keywords are not case sensitive. If multiple ".SUBCKT" sections are found, then they are parsed as independent sub-circuit elements.

Since these definitions share the same namespace within the CIML format, every sub-circuit shall carry a unique name and shall conform to XML rules discussed in A.2.5.4.

6.7 Validity section

6.7.1 General

The *Validity* section is used to represent the conditions in which the ICIM-CI model is defined. This section is strictly informative to the user and independent of all other sections in the CIML file.

Table 4 lists the various recognized keywords in the *Validity* section.

Table 4 – Definition of the *Validity* section

Validity
Power_supply: Power supply range as a string (required)
Frequency_range: Frequency range as a string with units (required)
Temperature_range: Temperature range in which the model is extracted (required). To be specified with units.

This definition is not exhaustive and is open for progress and improvement.

Documentation pertaining to the IC such as datasheets, test reports, and ICIM-CI extraction report shall be specified with the global keyword *Documentation* in the form of a valid string that specifies the path to the corresponding documentation. Many file paths can be listed one below another. It defaults to "None" when absent. See E.4 for more information on the usage of the *Documentation* keyword.

Any other specific details pertaining to the complete ICIM-CI model definition shall be defined with the *Notes* section in the form of a valid string. It defaults to "None" when absent. See E.4 for more information on the usage of the *Notes* keyword.

This section is mandatory and is defined directly under the *CImodel* root element. For example:

```
<CImodel>
     ...
     <Validity>
          <Power_supply>12V</Power_supply>
          <Frequency_range>[1MHz - 1GHz]</Frequency_range>
          <Temperature_range>25Celsius</Temperature_range>
          <Notes>Only LIN network activated</Notes>
     </Validity>
     ...
</CImodel>
```

6.7.2 Attribute definitions

6.7.2.1 Power_supply

The *Power_supply* attribute is used define the supply conditions for which ICIM-CI is valid. This attribute informs the user that the ICIM-CI model is extracted in the specified supply range.

There is no particular format for defining the value for this attribute; it shall be easily comprehensible for proper model usage. The value of this attribute is a data string containing valid text string and/or numerical values with units. See A.2.5.5 for valid units.

This is a required field.

A few examples of the *Power_supply* field are shown in Examples 1 to 3.

EXAMPLE 1 The following syntax specifies that the model is defined for a supply voltage of 5 V.

```
<Power_supply>5V</Power_supply>
```

EXAMPLE 2 The following syntax specifies that the digital blocks of the model data are defined with a supply voltage of 5 V and the analogue blocks are defined for a supply voltage of 12 V.

```
<Power_supply>5V for digital blocks, 12V for analogue blocks</Power_supply>
```

EXAMPLE 3 The following syntaxes specify that the model is defined for supply voltages between 2,5 V and 18 V.

```
<Power_supply>[2.5V-18V]</Power_supply>
```

or

```
<Power_supply>between 2.5V and 18V</Power_supply>
```

6.7.2.2 Frequency_range

The *Frequency_range* attribute is used define the frequency range in which ICIM-CI is valid. This attribute informs the user that the ICIM-CI model is extracted in the specified frequency range and is usable in the same range. The frequency range of validity of the ICIM-CI model shall be the common frequency range of the PDN and IB.

There is no particular format for defining the value for this attribute; it shall be easily comprehensible for proper model usage. The value of this attribute is a data string containing valid text string and/or numerical values with units (see Example 1). See A.2.5.5 for valid units.

This is a required field.

EXAMPLE 1 The following syntaxes specify that the model is valid in the frequency range from 1 MHz to 1 GHz.

```
<Frequency_range>[1MHz-1GHz]</Frequency_range>
```

or

```
<Frequency_range>from 1MHz to 1GHz</Frequency_range>
```

6.7.2.3 Temperature_range

The *Temperature_range* attribute is used define the temperature range in which ICIM-CI is extracted. The temperature range of validity of the ICIM-CI model shall be the common temperature range of the PDN and IB.

There is no particular format for defining the value for this attribute; it shall be easily comprehensible for proper model usage. The value of this attribute is a data string containing valid text string and/or numerical values with units. See A.2.5.5 for valid units.

This is a required field.

Two examples are shown in Example 1 and Example 2.

EXAMPLE 1 The following syntaxes specify that the model is valid in the temperature range between 20 °C and 40 °C.

```
<Temperature_range>[20Celsius-40Celsius]</Temperature_range>
```

or

```
<Temperature_range>from 20Celsius to 40Celsius</Temperature_range>
```

EXAMPLE 2 The following syntax specifies that model is defined only at 298,15 K.

```
<Temperature_range>298.15K</Temperature_range>
```

6.8 PDN

6.8.1 General

The *Pdn* section of the ICIM-CI model contains the PDN data that describes the model. The data shall be defined within the *Pdn* keyword as follows:

```
<Pdn>
    PDN data
</Pdn>
```

Different PDN complexity levels can be considered. The simplest configuration level is the single-ended disturbance input. The differential disturbance input may also be envisaged.

The most complex is the multi-port configuration.

A PDN data is defined for a particular IC pin and thus the definition shall be done within a *Lead* tag. See Figure 5 for the structural hierarchy. Many *Lead* elements can be listed one below another within the *Pdn* section. Table 5 lists the various recognized fields of the *Lead* keyword:

Table 5 – Definition of the *Lead* keyword for *Pdn* section

Lead
Id: pin identity as a valid string (required)
Ground_id: return pin identity as a valid string (required if Type=("S", "Z", "Y", else optional)
Blockname: PDN block name as a valid string
Type: PDN source parameter ("S", "Z", "Y", "Ckt")
Param_order: Order in which PDN parameters are defined
Format: Data format ("RI", "MA", "DB")
Meas_type: Method implemented for performing PDN measurements
Reference_impedance: Reference impedance used in performing PDN measurements
Use: Parameter that is to be specifically used
Netlist: PDN definition using standard netlist format
Unit_freq: Unit definition of the frequency terms
Unit_param: Unit of the PDN parameters
Power_level: Measurement power level during PDN extraction
Data_files: PDN source parameter defined in an external file (required if not List)
List: PDN parameter list (required if not Data_files)

The frequency range of the PDN information shall be specified in the *Validity* section under the *Frequency_range* tag.

NOTE The frequency range of validity of the ICIM-CI model is the common frequency range of the PDN and IB.

Any other relevant information required for correct understanding (and usage) of the PDN shall be optionally defined within the *Notes* and *Documentation* tags. Details such as IC operating mode, decoupling capacitors on supply lines, activated functions, grounding details, datasheets and test reports can be defined.

6.8.2 Attribute definitions

6.8.2.1 Id

The *Lead* Ids used in the PDN definition should have been previously defined in the *Lead_definitions* tag as described in 6.5. Depending on the type of the PDN (single-ended, differential or multi-ended), one or more Ids can be defined together. Both external and internal terminals can be specified. See 6.8.4 and 6.8.5 for more information.

This is a required field.

6.8.2.2 Ground_id

The *Lead* Ground_ids used in the PDN definition should have been previously defined in the *Lead_definitions* tag in GND mode (see 6.5). This lead represents the return signal path for defining the PDN.

This attribute is defined only if network parameters are used for defining the PDN (Type="S" or "Z" or "Y"). *Ground_id* attribute is ignored by the CIM parser if Type="Ckt", that is, if a netlist is used for representing the PDN. See 6.8.2.4 for more information on the *Type* attribute.

When used, only one unique *Ground_id* is permitted per *Lead* definition. This is an optional field and is required if PDN is represented using network parameters.

6.8.2.3 Blockname

The *Blockname* field is used to define the name of the PDN block. This field is optional and is used for representing the PDN as a sub-block. A block-based ICIM-CI macro-model is shown in Figure 4. This field is intended for informational purposes only. The CIM parser does not interpret this field.

6.8.2.4 Type

The *Type* attribute is used to represent the type of the PDN data. Valid types are:

- "S": S-parameter data.
- "Z": Z-parameter data. These parameters are not normalized to the reference impedance.
- "Y": Y-parameter data. These parameters are not normalized to the reference impedance.
- "Ckt": Circuit description using netlists.

This field is optional. When absent, the default value is "S".

6.8.2.5 Param_order

The *Param_order* attribute tells the CIM parser how the data is represented. It is not defined if the PDN is represented as a circuit model as discussed in 6.8.3.4 and 6.8.3.5. The following strings are dedicated for specifying the parameter order:

- "Freq" and "Frequency": Frequency used for parameters' definition
- "Sij": S-parameters, i and j are integers representing measurement ports/pins (example: "S11", "S21", "S31", etc...)

- "Zij": *Z*-parameters, i and j are integers representing measurement ports/pins (example: "Z11", "Z21", "Z31", etc...)
- "Yij": *Y*-parameters, i and j are integers representing measurement ports/pins (example: "Y11", "Y21", "Y31", etc...)

The different terms of *Param_order* shall be separated by a comma character (",").

This field is optional. If absent, the default value is "Freq,S11".

6.8.2.6 Format

The Format attribute decides the data format. It is not defined if the PDN is represented as a circuit model as discussed in 6.8.3.4 and 6.8.3.5. Valid data formats are:

- "RI": real/imaginary format
- "DB": Magnitude in decibel scale with phase angle in degrees
- "MA": Magnitude in linear scale with phase angle in degrees

This field is optional. If absent, the default value is "RI".

6.8.2.7 Meas_type

The *Meas_type* attribute is used by the CIM parser in order to compute the impedance of the specific lead ("Id") when S-parameters are used. Depending on the type of the PDN (single-ended, differential or multi-ended), the *Meas_type* attribute takes multiple definitions. See 6.8.4 and 6.8.5.

This field is defined only when Type="S" and is optional. When absent, it defaults to "0".

6.8.2.8 Reference_impedance

The *Reference_impedance* attribute is used by the CIM parser in order to compute the impedance of the specific lead ("Id") when network parameters are used for PDN definition.

This field is defined only when Type="S" and is optional. When defined, it shall always be specified with a numerical value along with units as described in A.2.5.3 (example: "50ohm"). When absent, it defaults to "50ohm".

6.8.2.9 Use

The *Use* attribute tells the CIM parser to use one of the values in the *Param_order* attribute. When explicitly defined, the corresponding parameter is used as PDN. If undefined, the first Sij or Zij or Yij term is used by default.

6.8.2.10 Netlist

The *Netlist* keyword is used to define the PDN as a SPICE netlist that represents the electrical connectivity of the PDN elements. The electrical connectivity flow shall be as per SPICE specification [2]. A detailed description of the circuit model is presented in 6.8.3.4 and 6.8.3.5.

This field is required if Type="Ckt".

6.8.2.11 Unit_freq and Unit_param

The parameter units are defined under the *Unit_freq* and *Unit_param* tags for frequency and data, respectively. If absent, *Unit_freq* defaults to basic units, "Hz". Table 6 shows the default value of the *Unit_param* attribute as a function of data type and format when undefined.

Table 6 – Valid data formats and their default units in the *Pdn* section

Data type	Data format	Default Unit_param values
S	RI	1
	MA	1
	DB	dB
Z	RI	ohm
	MA	ohm
	DB	dBohm
Y	RI	S
	MA	S
	DB	dBS

See A.2.5.5 for valid units.

These fields are optional.

6.8.2.12 Power_level

The measurement power level used for PDN extraction (see 7.3.2) is specified in the *Power_level* field. For simplicity reasons, the power level along with units should be defined together as discussed in A.2.5.3.

This is an optional field. If absent, it defaults to "0dBm".

6.8.2.13 Data_files and List

The *Data_files* tag is used to differentiate between inline and external data. If the PDN data is defined in an external file, the link to the file shall be specified within the *Data_files* tag. Inline data is directly defined under the top level *Lead* tag within a *List* tag if needed. Files with the extensions given in Table 7 are allowed.

Table 7 – Valid file extensions in the Pdn section

File extension	Common name
dat or DAT	Data file
csv or CSV	Comma separated values
txt or TXT	Text file
snp or SnP	Touchstone, n is an integer (1, 2, …)
cir or CIR	Circuit file (Netlist)
lib or LIB	Library file (Netlist)
net or NET	Netlist file

The *List* tag is not defined if circuit model is used to describe the PDN. *Data_files* tag is defined for network parameters (S or Z or Y) and netlist description.

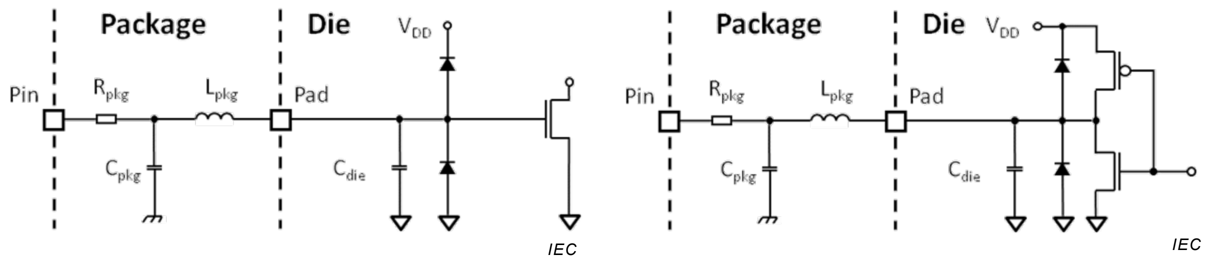
This is a required field; a unique *List* or *Data_files* element shall be used to define the PDN data of the specific lead.

6.8.3 PDN for a single-ended input or output

6.8.3.1 General

A single-ended input or output corresponds to a single pin on the IC. In that case, the signal is carried by one PCB track. The return signal track is the electrical ground of the IC. It is possible that various parts of the PDN have different grounds. These grounds will be connected together either inside the device or by external connections, which will not necessarily be perfect. Care should be taken when extracting the PDN to take into account these connections.

Figure 7 gives typical electrical schematics of single-ended input/output pins.



a) Input PDN electrical schematic **b) Output PDN electrical schematic**

Key

R_{pkg}	Parasitic resistance of package
L_{pkg}	Parasitic inductance of package
C_{pkg}	Parasitic capacitance of package
C_{die}	Parasitic capacitance of die
Pin	IC pin interface at the package level
Pad	IC pin interface at the die level
V_{DD}	IC supply voltage

Figure 7 – PDN electrical schematics

Depending on the simulation tool used, the PDN could be represented with different network parameters such as S-, Z-, Y-parameters, or as a circuit/netlist using physical R, L and C elements.

Figure 8 shows the impedance of the PDN represented by a one-port black-box.

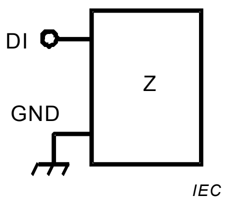


Figure 8 – PDN represented as a one-port black-box

Table 8 lists the valid fields of a *Lead* structure for a single-ended PDN definition and their usage.

Table 8 – Valid fields of the *Lead* keyword for single-ended PDN

Field	Description	Usage	Rules
Id	Identifier or pin number	Required	One unique Id previously defined in the Lead-definitions section
Ground_id	Identifier or pin number of the return signal pin	Required for Type="S" or "Z" or "Y"	One unique Id previously defined as GND in the Lead-definitions section
Blockname	Name of the PDN block component	Optional	Valid string (see 6.8.1)
Type	PDN source parameter (S/Z/Y/Circuit)	Optional	Valid String: "S" (default) or "Z" or "Y" or "Ckt"
Param_order	Order in which parameters are defined	Optional	Valid string (see 6.8.1)
Format	Data format	Optional	"RI" (default) or "DB" or "MA"
Meas_type	Method implemented for performing PDN measurements	Optional	"0" (default) or "1" or "2"
Reference_impedance	Reference impedance used in PDN measurements	Optional	Valid numerical value with units. Default="50ohm"
Use	Parameter that is to be specifically used	Optional	One of the values in Param_order other than the Frequency term. Default: First S or Z or Y term
Netlist	SPICE type netlist	Required if Type="Ckt"	Valid SPICE like data statements. See 6.8.3.4 and 6.8.3.5
Unit_freq	Frequency units	Optional	Valid units (see A.2.5.5). Default="Hz"
Unit_param	Parameter units	Optional	Valid units (see A.2.5.5). See 6.8.2.11 for default values
Power_level	Measurement power level	Optional	Valid numerical value with units (See A.2.5.5). Default="0dBm"
Data_files	PDN source parameter defined in an external file	Required if not List	Valid for external netlist file or external network parameter file.
List	PDN data entries in the form of a list defined inline	Required if not Data_files	Valid numerical values with or without units in the specified order

The compositions of *Id*, *Ground_id*, *Type*, *Param_order* and *Format* fields have been previously discussed in 6.8.2. The CIM parser understands that the PDN definition for a particular pin is single-ended when the *Id* attribute contains a unique value (example Id="1").

Meas_Type field is recognized only when the PDN is defined using S-parameters (Type= "S"). For all other types, this field is ignored. CIML version 1 supports the following *Meas_type* values for single-ended PDN with S-parameters:

- "0" for standard or conventional measurement configuration (default)
- "1" when the DUT is in parallel to the measurement ports (shunt connection)

- "2" when the DUT is in series to the measurement ports (series connection)

The reference impedance used in PDN measurements is defined using the *Reference_impedance* tag. This field is recognized only when the PDN is defined using S-parameters (Type= "S").

The different measurement configurations and set-up for single-ended PDN extraction as defined in CISPR 17 are presented in 7.3. When absent, *Meas_type* defaults to "0" (conventional method).

Data can either be defined inline within the CIML file or can be defined using external data files for both network parameter and circuit (netlist) definition.

6.8.3.2 Inline data – network parameter

If the network parameters (S, Z or Y) are defined for a single frequency, then they can be defined within the *Lead* keyword directly. If the PDN is defined for multiple frequencies (more than one frequency), data shall be written within the *List* keyword. The different DI or DO leads, whose PDN is to be defined, shall be defined using the *Id* attribute and the ground lead (lead with Mode="GND" in *Lead_definitions* section) used as return signal path shall be specified using the *Ground_id* attribute.

The frequency units shall be defined within the *Unit_freq* keyword and data units shall be specified using *Unit_param* keyword. The power level used for measurement shall be defined using *Power_level* tag and the reference impedance using the *Reference_impedance* tag. See 6.8.2 for more information on these attributes and their default values.

The following example illustrates the single-ended PDN of lead "1" defined by S-parameters measured using conventional VNA one-Port method with lead "7" used as ground (return signal pin). By default Use="S11". The PDN is modelled as a block with the *Blockname* field defined as "Block_Pdn1".

```
<Pdn>
   <!-- S Parameters inline data, multi-frequencies -->
   <Validity>9kHz-3GHz</Validity>
   <Lead Id="1";Ground_id="7";Type="S"; Param_order="Freq,S11";
Format="RI";Meas_type= "0">
        <Blockname>Block_Pdn1</Blockname>
        <Unit_freq>Hz</Unit_freq>
        <Power_level>0dBm</Power_level>
        <Reference_impedance>50ohm</Reference_impedance>
        <List>
              9.000000e+003 9.417885e-001 -3.504903e-001
              9.123751e+003 9.379390e-001 -3.540765e-001
              9.249203e+003 9.370850e-001 -3.587080e-001
              9.376381e+003 9.358488e-001 -3.618073e-001
              9.505307e+003 9.335523e-001 -3.676978e-001
              9.636006e+003 9.318579e-001 -3.723437e-001
              9.768502e+003 9.309074e-001 -3.770503e-001
              9.902820e+003 9.291059e-001 -3.815358e-001
              1.003898e+004 9.248903e-001 -3.872907e-001
              ....
        </List>
   </Lead>
</Pdn>
```

6.8.3.3 External file data – network parameter

For directing the CIM parser to use the necessary external data file in ASCII format, definition shall be made using *Data_files* keyword. If the external file has a touchstone extension (*.snp or *.SnP where n is an integer 1, 2, …), *Unit_param*, *Unit_freq*, *Param_order*, *Reference_impedance* and *Type* definitions are not required (ignored by the CIM parser if explicitly defined). For all other file extensions (*.dat, *.csv, *.txt) the defined values are used. If absent, default values are automatically considered. See Table 8 for default properties. Similar to inline definition seen in 6.8.3.2, the *Ground_id* field is required and the *Meas_type* field is optional.

Measurement power level shall be a part of the external file as a comment or shall be defined using the *Power_level* tag. Comment lines in the PDN file shall start with an exclamation symbol ("!") as shown below:

```
!This is a comment line
```

Figure 9 shows an example of the file in Touchstone format with S_{11} parameters in dB format for a single-ended input versus frequency. Note that the measurement power level is included as a comment in the PDN file.

```
!Date: Wed Feb 24 17:02:04 2010
!Data & Calibration Information:
!Freq   S11:SOLT2(ON)
!Power level : -10dBm
# Hz S dB R 50
10000000    -3.729084e+001  7.606495e+001
14990000    -3.380164e+001  7.729963e+001
19980000    -3.153998e+001  7.662747e+001
24970000    -2.994036e+001  7.626312e+001
29960000    -2.839336e+001  7.553269e+001
34950000    -2.717934e+001  7.494058e+001
```

IEC

Figure 9 – PDN represented as S-parameters in Touchstone format

These data can be obtained by a one-port vector network analyzer as explained in 7.3.2. Details are provided in Annex F.

The following is an example to use this file for defining the PDN of lead "1" with respect to lead "7" (used as return signal pin). By default Use="S11" even if unspecified.

```
<Pdn>
    <Lead Id="1" Ground_id="7" Meas_type="0">
        <Data_files>
            Pin1_PDN_S11.s1p
        </Data_files>
    </Lead>
</Pdn>
```

Figure 10 shows an example of the file in Touchstone format with two-port S-parameters in real/imaginary format for a single-ended input versus frequency measured using two-port parallel method.

```
!Date: Wed Feb 24 18:10:35 2010
!Data & Calibration Information:
!Freq   S11:SOLT2(ON)   S21:SOLT2(ON)   S12:SOLT2(ON)   S22:SOLT2(ON)
!Power level: 10dBm
# Hz S RI R 50
100000  -1.036458e-001  -2.813728e-001  8.962133e-001  -2.812879e-001  8.968058e-001  -2.810997e-001  -1.035877e-001  -2.808048e-001
100679  -1.047647e-001  -2.827956e-001  8.950628e-001  -2.827016e-001  8.956069e-001  -2.825874e-001  -1.047446e-001  -2.822436e-001
101359  -1.059933e-001  -2.843089e-001  8.938606e-001  -2.841587e-001  8.944253e-001  -2.840167e-001  -1.059335e-001  -2.836677e-001
102038  -1.070761e-001  -2.857621e-001  8.927390e-001  -2.856093e-001  8.932514e-001  -2.854702e-001  -1.071706e-001  -2.850955e-001
102717  -1.082844e-001  -2.871706e-001  8.915527e-001  -2.870721e-001  8.921174e-001  -2.869190e-001  -1.082758e-001  -2.865788e-001
103396  -1.094305e-001  -2.886304e-001  8.904199e-001  -2.885258e-001  8.910204e-001  -2.883397e-001  -1.094611e-001  -2.879343e-001
104076  -1.105872e-001  -2.900029e-001  8.892567e-001  -2.898991e-001  8.898156e-001  -2.898370e-001  -1.105748e-001  -2.895200e-001
104755  -1.117609e-001  -2.914495e-001  8.880716e-001  -2.913276e-001  8.886742e-001  -2.911542e-001  -1.117679e-001  -2.907723e-001
105434  -1.129686e-001  -2.928305e-001  8.869238e-001  -2.927147e-001  8.875063e-001  -2.926166e-001  -1.129574e-001  -2.922262e-001
106113  -1.141046e-001  -2.943295e-001  8.857913e-001  -2.941380e-001  8.863739e-001  -2.940393e-001  -1.140602e-001  -2.936681e-001
106793  -1.153434e-001  -2.957321e-001  8.846137e-001  -2.955797e-001  8.851491e-001  -2.954778e-001  -1.152589e-001  -2.950926e-001
107472  -1.164054e-001  -2.971754e-001  8.834974e-001  -2.970460e-001  8.840123e-001  -2.968765e-001  -1.164158e-001  -2.965406e-001
108151  -1.176255e-001  -2.985017e-001  8.822543e-001  -2.983617e-001  8.828818e-001  -2.982495e-001  -1.175782e-001  -2.978422e-001
108830  -1.188660e-001  -2.998882e-001  8.810909e-001  -2.997076e-001  8.816448e-001  -2.996442e-001  -1.188061e-001  -2.992442e-001
109510  -1.200334e-001  -3.012986e-001  8.799533e-001  -3.011631e-001  8.805157e-001  -3.009885e-001  -1.199358e-001  -3.006307e-001
110189  -1.211291e-001  -3.026314e-001  8.787928e-001  -3.025275e-001  8.793571e-001  -3.023668e-001  -1.211662e-001  -3.019719e-001
```

IEC

Figure 10 – PDN represented as two-port S-parameters in Touchstone format

This data can be obtained by a two-port vector network analyzer as explained in Annex F.

The following is an example to use S_{21} parameter from this file for defining the single-ended PDN of lead "2" with lead "8" used as return signal pin.

```
<Pdn>
    <Lead Id="2" Ground_id="8" Meas_type="1" Use="S21">
        <Data_files>
            Pin2_Parallel_PDN.s2p
        </Data_files>
    </Lead>
</Pdn>
```

6.8.3.4 Inline circuit definition

Another way to define the PDN is in the form of a SPICE like netlist [2]. CIM parser understands that the PDN has a circuit definition when the *Type* attribute of a particular lead is set to "Ckt". The circuit definition shall be directly declared within the *Netlist* tag under the *Lead* section. The *Netlist* section shall contain the following definitions:

- *Power_level* definition
- Data statements defining the electrical connectivity of components

All SPICE recognized elements can be defined in this section and the representation shall follow SPICE syntax. The data statements have a free format and consist of fields separated by a blank. If one wants to continue a statement to the next line, one uses a "+" sign (continuation sign) at the beginning of the next line. Numbers can be integers, or floating points. For example, a resistor "R1" with a value of 1 kΩ connecting nodes "In" and "Out" can be represented as:

```
R1 In Out 1e3
```

All nodes used in the data statements share the same namespace with the lead Ids defined in the *Lead_definitions* section. The *Ground_id* field is ignored by the CIM parser when defining the PDN using a netlist. The *Id* attribute of the *Lead* keyword shall carry the Id information of the DI, DO and GND (ground) pins (as defined in the *Lead_definitions* section).

Within the several data statements used to define the netlist, at least one node shall correspond to the lead defined as DI or DO and at least one node shall be GND in the *Lead_definitions* section. All other nodes used for circuit definition shall not carry the lead Ids defined in the *Lead_definitions* section. For compatibility reasons between several SPICE kinds, "0" is not allowed as node number.

The *Netlist* keyword definition is shown in Table 9.

Table 9 – *Netlist* definition

Netlist
Kind: SPICE netlist format (optional) default: "SPICE3"
Data_files: SPICE netlist in external file (optional)

The *Kind* field tells the CIM parser that the defined netlist follows a specific syntax. CIML version 1 supports the industry-standard SPICE like netlist syntaxes [2].

The *Kind* field defaults to generic "SPICE3" if absent.

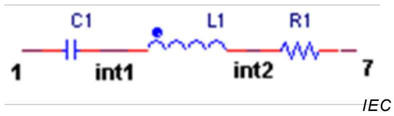


Figure 11 – Example structure for defining the PDN using circuit elements

The following example illustrates the PDN of the structure shown in Figure 11. The different circuit elements of lead "1" with respect to GND1 (lead "7") are represented using *Netlist* definition. The PDN is defined from measurements made with a power level of 10 dBm.

```
<Pdn>
     <!-- General circuit model -->
     <Lead Id="1 7" Type="Ckt">
          <Power_level>10dBm</Power_level>
          <Netlist Kind="SPICE3">
               C1 1 int1 20e-9
               L1 int1 int2 9e-9
               R1 int2 7 230e-3
          </Netlist>
     </Lead>
</Pdn>
```

The above example can also be expressed using a SPICE macro-model as illustrated below. It is assumed that "PDN_pin1" is defined in the *Macromodels* section (see 6.6).

```
<Pdn>
     <!-- General circuit model -->
     <Lead Id="1 7" Type="Ckt">
          <Power_level>10dBm</Power_level>
          <Netlist>
               Xpin1 1 7 PDN_pin1
          </Netlist>
     </Lead>
</Pdn>
```

In the above example, Xpin1 is the identifier of the sub-circuit "PDN_pin" in the main circuit.

6.8.3.5 External file containing the netlist

Instead of the inline netlist definition (see 6.8.3.4), it is possible to define the PDN in an external netlist file. The definition is done with the *Data_files* tag under the *Netlist* section. All rules with respect to the node numbers used in the netlist definition are the same as defined in 6.8.3.4. An example netlist file with circuit definition is shown in Figure 12.

```
*Netlist file created on Fri 27 Nov 2012
*Time: 14:09:02
*PDN main circuit model of PIN1 with respect to GND1
C1 1 int1 20e-9
L1 int1 int2 9e-9
R1 int2 7 230e-3
```

IEC

Figure 12 – Example of a single-ended PDN Netlist main circuit definition

In some cases, a netlist file could contain the main circuit definition and sub-circuit definitions together. To avoid ambiguity, the CIM parses only the data statements defined outside the SPICE keywords: ".SUBCKT" and ".ENDS". These keywords are not case sensitive.

An example netlist file containing both sub-circuit and min circuit data is shown in Figure 13. In the *Netlist* section, only the main circuit elements are parsed. For parsing the sub-circuit element, it is mandatory to define the same file within the *Macromodels* section (see 6.6).

```
*Netlist file created on Fri 26 Nov 2012
*Time: 08:39:14
*PDN macro-model model of PIN1 with respect to GND1
.Subckt Pin1_PDN N1 N2
C1 N1 int1 20e-9
L1 int1 int2 9e-9
R1 int2 N2 230e-3
.ends
*Call in main circuit
Xpin1 1 7 Pin1_PDN
```

Sub-circuit part

Main circuit part

IEC

Figure 13 – Example of a single-ended PDN Netlist with both sub-circuit and main circuit definitions

The following example illustrates the PDN of lead "1" with respect to GND1 (lead with Id="7") using *Netlist* definition in an external file ("Pin1_PDN_Ckt.lib") containing both sub-circuit and main circuit definitions (Figure 13). The measurement power level is –10 dBm.

```
<Macromodels>
    <Data_files>
        Pin1_PDN_Ckt.lib
    </Data_files>
</Macromodels>
<Pdn>
    <!-- General circuit model -->
    <Lead Id="1 7" Type="Ckt">
        <Blockname>Block1</Blockname>
        <Power_level>-10dBm</Power_level>
        <Netlist>
            <Data_files>Pin1_PDN_Ckt.lib</Data_files>
        </Netlist>
    </Lead>
</Pdn>
```

In the above example, the sub-circuit definition is parsed within the *Macromodels* section and the main circuit in the *Netlist* section.

It is nevertheless recommended (which is also true in many cases) that a SPICE macro-model of a circuit element exists in a separate library or netlist file and the main circuit defined in another. The corresponding files are defined under the *Macromodels* section and the *Netlist* section as shown below:

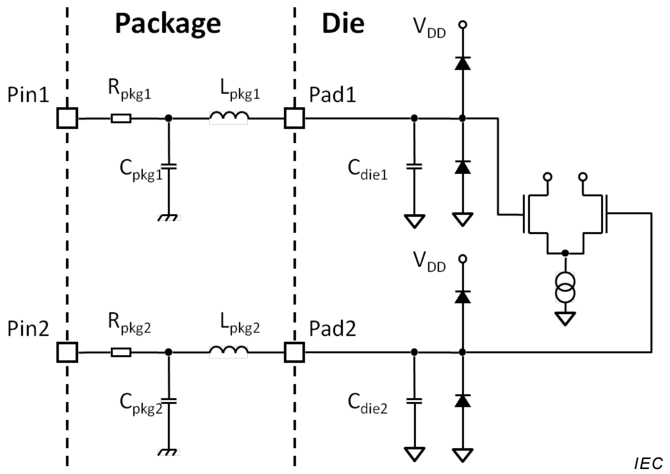
```
<Macromodels>
    <!-- Subcircuit model -->
    <Data_files>
        Pin1_PDN_SubCkt.lib
    </Data_files>
</Macromodels>

<Pdn>
    <Lead Id="1 7" Type="Ckt">
        <Power_level>-10dBm</Power_level>
        <Netlist>
        <!-- Main circuit definition -->
            <Data_files>
                Pin1_PDN_MainCkt.lib
            </Data_files>
        </Netlist>
    </Lead>
</Pdn>
```

6.8.4 PDN for a differential input

A differential input or output corresponds to a pair of pins on the IC. In that case, signal is carried by two PCB tracks. The electrical ground of the IC can be considered as a shielded track or ground plane.

It is possible that various parts of the PDN have different grounds. These grounds will be connected together either inside the device or by external connections, which will not necessarily be perfect. Care should be taken when extracting the PDN to take into account these connections.

Figure 14 gives a typical electrical schematic of a differential input.



Key

Pin1, Pin2	IC pin interface at the package level
R_{pkg1}, R_{pkg2}	Parasitic resistance of package corresponding to pin1 and pin2
L_{pkg1}, L_{pkg2}	Parasitic inductance of package corresponding to pin1 and pin2
C_{pkg1}, C_{pkg2}	Parasitic capacitance of package corresponding to pin1 and pin2
C_{die1}, C_{die2}	Parasitic capacitance of die corresponding to pin1 and pin2
Pad1, Pad2	IC pin interface at the die level corresponding to pin1 and pin2
VDD	IC supply voltage

Figure 14 – Differential input schematic

Figure 15 shows the impedance of the PDN represented by a two-port black-box.

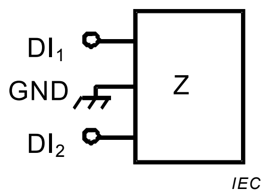


Figure 15 – PDN represented as a two-port black-box

Figure 16 shows an example of a file in Touchstone format with S-parameters for a differential input versus frequency. The measurement power level is included as a comment in the PDN file.

```
!Date: Wed Feb 24 16:59:43 2010
!Data & Calibration Information:
!Freq   S11:SOLT2(ON)   S21:SOLT2(ON)   S12:SOLT2(ON)   S22:SOLT2(ON)
!Power level : -10dBm
# Hz S dB R 50
10000000   -3.600368e+001  7.685763e+001   -2.980386e-002  -2.381251e+000  -2.825661e-002  -2.368914e+000
14990000   -3.247939e+001  7.772459e+001   -3.569744e-002  -3.511269e+000  -3.624313e-002  -3.507569e+000
19980000   -3.005455e+001  7.789619e+001   -4.466566e-002  -4.640308e+000  -4.369846e-002  -4.655575e+000
24970000   -2.839623e+001  7.768869e+001   -5.491686e-002  -5.775656e+000  -5.325215e-002  -5.776176e+000
29960000   -2.681729e+001  7.683536e+001   -5.999875e-002  -6.889885e+000  -6.091786e-002  -6.914319e+000
34950000   -2.558788e+001  7.569970e+001   -6.945887e-002  -8.025029e+000  -6.760100e-002  -8.027510e+000
```

IEC

Figure 16 – PDN data format for differential input or output

This data can be obtained by a two-port vector network analyzer as explained in 7.3.2. For differential inputs, CIML version 1 supports only conventional measurement method. Annex C gives more details on the conversion between S-, Z- and Y-parameters.

The PDN data of differential pins can also be represented using a SPICE-like netlist that describes the interaction between the two differential input pins [2].

Table 10 lists the valid fields of a *Lead* structure for a differential PDN definition and their usage.

Table 10 – Valid fields of the *Lead* keyword for differential PDN

Field	Description	Usage	Rules
Id	Identifier or pin number	Required	Two Ids previously defined in the Lead-definitions section (DI's,DO's and internal terminals)
Ground_id	Identifier or pin number of the return signal pin	Required for Type="S" or "Z" or "Y"	One unique Id previously defined as GND in the Lead-definitions section
Blockname	Name of the PDN block component	Optional	Valid string (see 6.8.1)
Type	PDN source parameter (S/Z/Y/Circuit)	Optional	Valid String: "S" (default) or "Z" or "Y" or "Ckt"
Param_order	Order in which parameters are defined	Optional	Valid string (see 6.8.1)
Format	Data format	Optional	"RI" (default) or "DB" or "MA"
Meas_type	Method implemented for performing PDN measurements	Optional	"0" (default)
Reference_impedance	Reference impedance used in PDN measurements	Optional	Valid numerical value with units. Default="50ohm"
Use	Parameter that is to be specifically used	Optional	One of the values in Param_order other than the Frequency term. Default: First S or Z or Y term
Netlist	SPICE type netlist	Optional	Valid SPICE like data statements. See 6.8.3.4 and 6.8.3.5
Unit_freq	Frequency units	Optional	Valid units (see A.2.5.5). Default="Hz"
Unit_param	Parameter units	Optional	Valid units (see A.2.5.5). See 6.8.2.11 for default values
Power_level	Measurement power level	Optional	Valid numerical value with units (See A.2.5.5). Default="0dBm"
Data_files	PDN source parameter defined in an external file	Required if not List	Valid for external netlist file or external network parameter file.
List	PDN data entries in the form of a list defined inline	Required if not Data_files	Valid numerical values with or without units in the specified order

CIM parser detects that the PDN definition is for differential input or output when at least two DIs or DOs are specified in the "Id" attribute as shown:

```
<Lead Id="1,2"/>
```

A maximum of two DI (or DO or internal) terminals, previously defined in the *Lead_definitions* section, shall be referenced together separated by a comma (",") character.

NOTE When using network parameters for PDN description, the lead *Ids*' value need not be coherent with the measurement port numbers. The values are matched with the port numbers in sequence, from left to right.

An example of the differential inputs of an operational amplifier is shown in Figure 17.

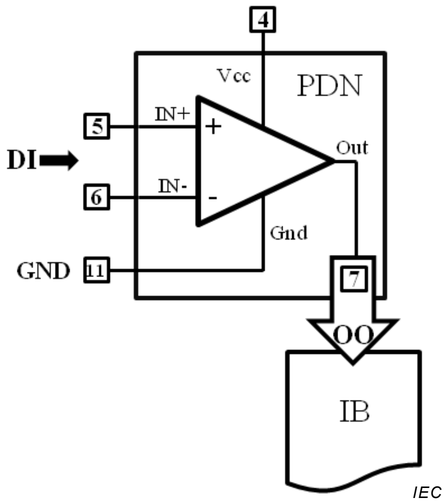


Figure 17 – Differential inputs of an operational amplifier example

The *Lead_definitions* section, showing only the pins of interest, is shown below:

```
<Lead_definitions>
    <Lead Id="5" Name="IN2+" Mode="DI"/>
    <Lead Id="6" Name="IN2-" Mode="DI"/>
    <Lead Id="4" Name="Vcc" Mode="None"/>
    <Lead Id="11" Name="Gnd" Mode="GND"/>
    <Lead Id="7" Name="Out" Mode="OO"/>
</Lead_definitions>
```

The PDN description, corresponding to the differential input pins, is:

```
<Pdn>
    <Lead Id="5,6" Ground_id="11" Type="S">
        <Data_files>Pins5_6.s2p</Data_files>
    </Lead>
</Pdn>
```

Correlating the touchstone file "Pins5_6.s2p" (shown in Figure 16) to the PDN description, lead Id="5" corresponds to Port 1 and lead Id="6" corresponds to Port 2 when using a two-port VNA. The details of measuring S-parameters using a VNA are provided in Annex F.

6.8.5 PDN multi-port description

The multi-port PDN concerns any kind of IC having several pins that need to be considered for the model. These pins can be DI, DO or internal terminals.

The PDN is then based on a full *S*- or *Z*- or *Y*-parameter matrix or an electrical netlist, describing the interactions between the different pins considered in the model. The file structure is the same as on Figure 16 but includes more ports.

NOTE When using network parameters for PDN description, the lead *Ids*' value need not be coherent with the measurement port numbers. The values are matched with the port numbers in sequence, from left to right.

Figure 18 shows an example of an ICIM-CI black box model for a 74HC08 circuit. Several pins are considered:

- "1A", "1Y" and "VCC" pins are assumed to be DI terminals in a given application,
- "1Y" is also an OO terminal that is monitored,
- "1B" is considered as a DO terminal.

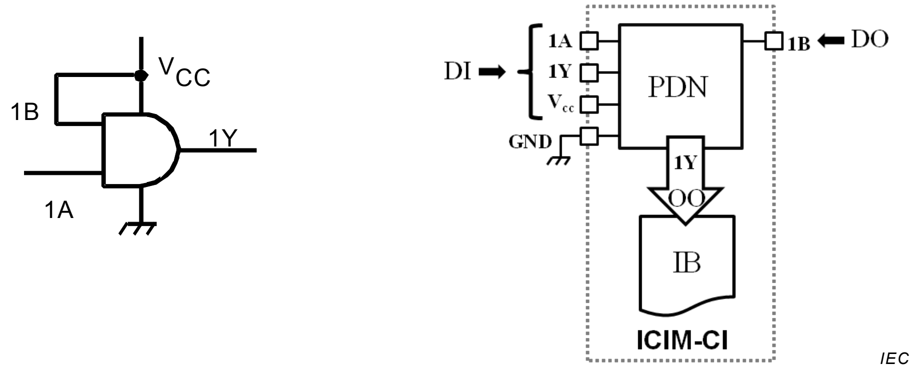


Figure 18 – ICIM-CI Model for a 74HC08 component

The CIML attributes that were defined in Table 10 for differential pins are also valid for multi-port definition except that the Id attribute can take more than two identities as its value. A three-port S-parameter matrix is used to describe the PDN corresponding to the three DI terminals.

The *Lead_definitions* and *Pdn* section, corresponding to the ICIM-CI macro-model, of the structure described in Figure 18 can be represented as:

```
<!--Lead_definitions section -->
<Lead_definitions>
    <Lead Id="1" Name="1A" Mode="DI"/>
    <Lead Id="2" Name="1B" Mode="DO"/>
    <Lead Id="3" Name="1Y" Mode="DI,OO"/>
    <Lead Id="14" Name="VCC" Mode="DI"/>
    <Lead Id="7" Name="GND" Mode="GND"/>
</Lead_definitions>

<!--Pdn section -->
<Pdn>
    <Lead Id="1,14,3" Ground_id="7" Type="S">
        <Data_files>Pins1_14_3.s3p</Data_files>
    </Lead>
</Pdn>
```

In the above example, if a three-port *S*-parameter measurement is made using the VNA Ports 1, 2 and 3, then "S11" corresponds to the reflection coefficient of pin with Id="1", "S22" to that of pin with Id="14", "S33" to that of pin with Id="3", "S21" is the transmission coefficient between pins "14" and "1"and so on.

6.9 IBC

6.9.1 General

Similar to the PDN, different IBC complexity levels can be considered. The simplest configuration level is modelling the IBC with two internal terminals linking two internal terminals of different PDN blocks. IBC networks that interface many PDN blocks with many internal terminals can become very complex.

The *Ibc* section of the ICIM-CI macro-model contains the IBC data that describes the ICIM-CI PDN. The data shall be defined within the *Ibc* keyword as follows:

```
<Ibc>
    IBC data
</Ibc>
```

An IBC data is defined for interfacing different PDN blocks and thus the definition shall be done within a *Lead* tag (similar to the PDN). See Figure 5 for the structural hierarchy. Many *Lead* elements can be listed one below another within the *Ibc* section.

6.9.2 Attribute definitions

The general structure of the *Lead* keyword is coherent with that listed in Table 5. However, some attribute specifications are different for the IBC network. These differences are tabulated in Table 11. All other fields in Table 5 remain unchanged.

Table 11 – Differences between the *Pdn* and *Ibc* section fields

Field	Description	Usage		Rules	
		Pdn	***Ibc***	***Pdn***	***Ibc***
Id	Identifier or pin number	Required	Required	One or more Ids previously defined in the Lead-definitions section as external or internal terminals	Two or more Ids previously defined in the Lead-definitions section as internal terminals
Ground_id	Identifier or pin number of the return signal pin	Required for Type="S" or "Z" or "Y"	Not applicable	One unique Id previously defined as GND in the Lead-definitions section	Not applicable

Table 12 lists the valid fields of a *Lead* structure for an IBC definition and their usage.

Table 12 – Valid fields of the *Lead* keyword for IBC definition

Field	Description	Usage	Rules
Id	Identifier or pin number	Required	Two or more Ids previously defined in the Lead-definitions section as internal terminals
Blockname	Name of the IBC component	Optional	Valid string (see 6.8.1)
Type	IBC source parameter (S/Z/Y/Circuit)	Optional	Valid String: "S" (default) or "Z" or "Y" or "Ckt"
Param_order	Order in which IBC parameters are defined	Optional	Valid string (see 6.8.1)
Format	Data format	Optional	"RI" (default) or "DB" or "MA"
Meas_type	Method implemented for performing IBC measurements	Optional	"0"
Reference_impedance	Reference impedance used in IBC measurements	Optional	Valid numerical value with units: "50ohm"
Use	Parameter that is to be specifically used	Optional	One of the values in Param_order other than the Frequency term. Default: First S or Z or Y term
Netlist	SPICE type netlist	Optional	Valid SPICE like data statements. See 6.8.3.4 and 6.8.3.5
Unit_freq	Frequency units	Optional	Valid units. See A.2.5.5 Default="Hz"
Unit_param	Parameter units	Optional	Valid units (see A.2.5.5). See 6.8.2.11 for default values
Power_level	Measurement power level	Optional	Valid numerical value with units (see A.2.5.5). Default="0dBm"
Data_files	IBC source parameter defined in an external file	Required if not List	Valid for external netlist file or external network parameter file.
List	IBC data entries in the form of a list defined inline	Required if not Data_files	Valid numerical values with or without units in the specified order

Any relevant information that is required for correct understanding (and usage) of the IBC shall be optionally defined within the *Notes* and *Documentation* tags.

6.10 IB

6.10.1 General

The *Ib* section of the ICIM-CI macro-model contains the IB data that describes the model. The data shall be defined within the *Ib* keyword as follows:

```
<Ib>
    IB data
</Ib>
```

Similar to the PDN definition, IB data is defined for a particular IC pin and thus the definition shall be done within a *Lead* tag (see Figure 5 for the structural hierarchy). Several *Lead* elements can be listed one below another in the *Ib* section to represent the IB data to the different pins of the IC. Table 13 lists the various recognized fields of the Lead keyword in the *Ib* section:

Table 13 – Definition of the *Lead* keyword in *Ib* section

Lead
Id: pin identity as a valid string (required)
Ground_id: return signal path as a valid string (required)
Blockname: IB block name as a valid string
Type: IB source parameter -"DPI" (required)
Max_power_level: Maximum injected power
Voltage: IB data defined as a voltage quantity (required if not Current or Power)
Current: IB data defined as a current quantity (required if not Voltage or Power)
Power: IB data defined as transmitted power quantity (required if not Voltage or Current)

The frequency range of the IB information shall be specified in the *Validity* section under the *Frequency_range* tag.

NOTE The frequency range of validity of the ICIM-CI macro-model is the common frequency range of the PDN and IB.

Any other relevant information that is required for correct understanding (and usage) of the IB shall be optionally defined within the *Notes* and *Documentation* tags. Details such as IC operating mode, decoupling capacitors on supply lines, activated functions, grounding details, datasheets and test reports can be defined.

6.10.2 Attribute definitions

6.10.2.1 Id

The *Lead* Ids used in this IB definition should have been previously defined as DI pins in the *Lead_definitions* tag as described in 6.5. One or more lead Ids are permitted.

This is a required field.

6.10.2.2 Ground_id

The *Lead* Ground_ids used in this IB definition should have been previously defined as GND in the *Lead_definitions* tag in 6.5. Only one unique *Ground_id* is permitted per *Lead* definition.

This is a required field.

6.10.2.3 Blockname

The *Blockname* field is used to define the name of the IB block.

This field is optional and is used for representing the IB as a sub-block. This field is intended for informational purposes only. The CIM parser does not interpret this field.

6.10.2.4 Type

The *Type* attribute is used to represent the type of the IB data. CIML version 1 supports only one type: "DPI" in the frequency domain.

This attribute is open for progress and improvement. It may be reusable for time domain immunity modelling at a later stage.

This is a required field.

6.10.2.5 Max_power_level

This optional field specifies the maximum injected power on the specific DI pin (lead Id). The *Max_power_level* attribute definition is shown in Table 14.

Table 14 – *Max_power_level* definition

Max_power_level
Value: Value of the maximum power level along with units (required)
Start_freq: Start frequency (optional)
Stop_freq: Stop frequency (optional)

If defined, it has one required attribute, *Value*, which carries the value of the maximum injected power. For simplicity reasons the value defined for the *Value* attribute shall be defined along with units as discussed in A.2.5.3 (for example, Value="35dBm"). By default, this value is used for all frequencies in which the main IB data is defined (see Example 1).

If several values need to be defined in specific frequency bands of interest, then multiple *Max_power_level* definitions shall be made one after another by specifying the frequency band values (Start frequency and Stop frequency) within the *Start_freq* and *Stop_freq* keywords (see Example 2).

EXAMPLE 1 The following syntax specifies that the maximum injected power level is 40 dBm in the entire frequency range of validity.

```
<Max_power_level Value="40dBm"/>
```

EXAMPLE 2 The following syntax specifies that the maximum injected power level is 35 dBm in the frequency band from 1 MHz to 500 MHz, 25 dBm in the frequency band from 510 MHz to 1 GHz.

```
<Max_power_level>
      <Value>"35dBm"</Value>
      <Start_freq>1MHz</Start_freq>
      <Stop_freq>500MHz</Stop_freq>
</Max_power_level>

<Max_power_level>
      <Value>"25dBm"</Value>
      <Start_freq>510MHz</Start_freq>
      <Stop_freq>1GHz</Stop_freq>
</Max_power_level>
```

6.10.2.6 Voltage, Current and Power

The main IB data is defined under the *Voltage*, *Current* and/or *Power* sections.

At least one definition is required. The voltage data is defined within the *Voltage* keyword and the current data is defined within the *Current* keyword. The *Power* section is used to define the transmitted power on to the IC pin (lead *Id*).

The common definition of the *Voltage*, *Current* and *Power* sections is shown in Table 15.

Table 15 – *Voltage*, *Current* and *Power* definition

Voltage / Current / Power
Test_criteria: Details on test conditions (required)
Param_order: Order in which IB parameters are defined (optional)
Format: IB Data format (optional)
Unit_voltage: Unit of the voltage terms (optional)
Unit_current: Unit of the current terms (optional)
Unit_power: Unit of the power terms (optional)
Unit_freq: Unit of the frequency terms (optional)
Data_files: IB source parameter defined in an external file (required if not List)
List: IB parameter list (required if not Data_files)

These sections have two required child elements: *Test_criteria* and *List* (or *Data_files)*. All other attributes and elements in Table 15 are optional.

6.10.2.7 Test_criteria

The test conditions shall be defined within the *Test_criteria* keyword, which is a required field. These test conditions correspond to the particular IB definition. Its attributes are shown in Table 16.

Table 16 – *Test_criteria* definition

Test_criteria
Id: identity of the OO pin (required)
Ground_id: return signal identity for the OO pin tested (optional)
Type: Type of test performed – "PF" for pass/fail, "NPF" for non pass/fail (required)
Level: Susceptibility level set on the OO pin (optional)
Parameter: The parameter in which the test is performed (optional)

The *Test_criteria* has two required attributes: *Id* and *Type*. The *Id* attribute is one of the OO pins defined in the *Lead_definitions* section (see 6.5). It informs the user that the test is conducted based on monitoring the specified OO pin. Non OO pins are not accepted.

The optional *Ground_id* field represents the return signal path for the OO pin defined in the *Id* field. If absent, the *Ground_id* defined in the top level IB lead definition is considered by the CIM parser. If explicitly defined, the value of the *Ground_id* field shall correspond to one of the GND pins defined in the *Lead_definitions* section (see 6.5).

The *Type* attribute can either be "PF" for pass/fail tests or "NPF" for non pass/fail tests.

The *Level* attribute defines the tolerance level set during the test with respect the nominal OO signal. For simplicity reasons the value of the *Level* attribute shall be defined along with units as discussed in A.2.5.3 (for example, Level="+200mV"). If multiple tolerance levels need to be defined, they shall be represented as single values separated by a comma (",") character. For example, to set a tolerance limit of ± 200 mV, one shall define:

```
Level="+200mV,-200mV"
```

If absent, it defaults to "None".

The value of the *Parameter* attribute represents the parameter on which the pass/fail or non pass/fail test has been carried out. In CIML version 1, the *Parameter* attribute accepts the following values:

- "Amplitude" – The test level is set on the amplitude of the OO pin's signal
- "Mean" – The test level is set on the mean of the OO pin's signal
- "Time" – The test level is set as jitter
- "Duty" – The test level is set on the duty cycle of the OO pin's signal
- "Period" – The test level is set on the period of the OO pin's signal
- "BER" – The test level is set on the Bit Error Rate of the OO pin's signal
- "SNR" – The test level is set on the Signal-to-Noise Ratio of the OO pin's signal
- "None" – No parameter is defined or none of the above (default)

This definition is not exhaustive and is open for progress and improvement. Newer values could be accepted in the future CIML versions. If absent, the default value is "None".

Multiple test criteria for the same OO pin can be defined one after other. Nevertheless, it is not realistic to define multiple OO pins under the same parent section (*Voltage*, *Current* or *Power*), i.e. the following is not permitted:

```
<Lead Id="1" Ground_id="7" Type="DPI">
    <Voltage Param_order ="Freq,Volt" Format="MA">
        <Test_criteria Id="9" Ground_id="8" Type="PF" .../>
        <Test_criteria Id="10" Ground_id="8" Type="PF" .../>
        ...
    </Voltage>
</Lead>
```

Whereas the following is permitted:

```
<Lead Id="1" Ground_id="7" Type="DPI">
    <Voltage Param_order ="Freq,Volt" Format="MA">
        <Test_criteria Id="9" Ground_id="8" Type="PF"
           Parameter="Amplitude"/>
        <Test_criteria Id="9" Ground_id="8" Type="PF"
           Parameter="Time"/>
        ...
    </Voltage>
    <Voltage Param_order ="Freq,Volt" Format="MA">
        <Test_criteria Id="10" Ground_id="8" Type="PF"
           Parameter="Amplitude"/>
        <Test_criteria Id="10" Ground_id="8" Type="PF"
           Parameter="Time"/>
        ...
    </Voltage>
</Lead>
```

In the above example, two IB data for pin "1" with respect to pin "7" (ground reference) are defined using two different *Voltage* sections, with lead "9" used as OO for the first and lead "10" for the second. Both the data are represented as *Voltage* quantities and represented with respect to lead "8" as ground reference. The same namespace with the *Lead_definitions* section is to be followed (see 6.5).

If the different *Voltage*, *Current* or *Power* sections, defined under the same top-level *Lead* tag, have the same *Id* in their *Test_criteria* field (same OO pin reference), then they are considered to be measured together.

EXAMPLE

```
<Lead Id="1" Ground_id="7" Type="DPI">
<Voltage Param_order ="Freq,Volt" Format="MA">
         <Test_criteria Id="9" Ground_id="8" Type="PF"
         Parameter="Amplitude"/>
         <Test_criteria Id="9" Ground_id="8" Type="PF"
         Parameter="Time"/>
         ...
    </Voltage>
    <Voltage Param_order ="Freq,Volt" Format="MA">
         <Test_criteria Id="10" Ground_id="8" Type="PF"
         Parameter="Amplitude"/>
         <Test_criteria Id="10" Ground_id="8" Type="PF"
         Parameter="Time"/>
         ...
    </Voltage>

    <Current Param_order ="Freq,Current" Format="MA">
         <Test_criteria Id="10" Ground_id="8" Type="PF"
         Parameter="Amplitude"/>
         <Test_criteria Id="10" Ground_id="8" Type="PF"
         Parameter="Time"/>
         ...
    </Current>
</Lead>
```

In the above example, the *Voltage* and *Current* sections, representing the IB data obtained by monitoring the OO lead "10" are regrouped together by the CIM parser. In contrast, the *Voltage* section with monitoring on OO lead "9" is considered to be another IB data for the same parent lead Id="1".

Any other specific details pertaining to the test conditions shall be defined with the *Notes* and *Documentation* sections. See E.4 for more information.

6.10.2.8 Param_order

The *Param_order* attribute tells the CIM parser how the IB data is represented. The following strings are dedicated for specifying the parameter order:

- "Freq" and "Frequency": Frequency values used for parameters’ definition
- "Volt" and "Voltage": Voltage values used for parameters’ definition
- "Curr" and "Current": Current values used for parameters’ definition
- "Pwr" and "Power": Power values used for parameters’ definition

If absent, it defaults to "Freq,Volt" in the *Voltage* section, "Freq,Curr" in the *Current* section and "Freq,Pwr" in the *Power* section.

6.10.2.9 Format

The *Format* attribute decides the data format. Valid data formats for IB are:

- "RI": real/imaginary format
- "DB": Magnitude in decibel scale with phase angle in degrees
- "MA": Magnitude in linear scale with phase angle in degrees
- "DBMAG": Magnitude in decibel scale without phase information
- "MAG": Magnitude in linear scale without phase information

This field is optional. If absent, the default value is "RI".

6.10.2.10 Unit_freq, Unit_voltage, Unit_current and Unit_power

The parameter units are defined under the *Unit_freq*, *Unit_voltage*, *Unit_current* and *Unit_power* tags for frequency, voltage, current and power quantities, respectively. Depending on the parent element, only the corresponding units are considered, i.e. *Unit_voltage* is allowed under the *Voltage* section and so on. Only *Unit_freq* attribute is defined for multiple sections.

If absent, *Unit_freq* defaults to "Hz". See Table 17 for default values of *Unit_voltage*, *Unit_current* and *Unit_power* tags as a function of data format.

Table 17 – Default values of *Unit_voltage*, *Unit_current* and *Unit_power* tags as a function of data format

Parameter	Data format	Default Unit_voltage values	Default Unit_current values	Default Unit_power values
Voltage	RI	V	–	–
	MA or MAG	V	–	–
	DB or DBMAG	dBV	–	–
Current	RI	–	A	–
	MA or MAG	–	A	–
	DB or DBMAG	–	dBA	–
Power	RI	–	–	W
	MA or MAG	–	–	W
	DB or DBMAG	–	–	dBW

6.10.2.11 Data_files and List

The definitions of the *Data_files* and *List* keywords are similar to that seen with the PDN definition (see 6.8.2.13). The *Data_files* tag is used to differentiate between inline and external data. If the PDN data is defined in one or more external files, the link to the file(s) shall be specified within the *Data_files* tag. Inline data is directly defined under the top level *Voltage* or *Current* or *Power* tag within a *List* tag if needed. Files with the extensions given in Table 18 are allowed for describing the IB data.

Table 18 – Valid file extensions in the *Ib* section

File extension	Common name
dat or DAT	Data file
csv or CSV	Comma separated values
txt or TXT	Text file

6.10.3 Description

6.10.3.1 Inline data

If the IB data (voltage, current or power) are defined for a single frequency, then they can be defined within the corresponding section (*Voltage*, *Current* or *Power*) keyword directly. If the IB data are defined for multiple frequencies (more than one frequency), data shall be written within the *List* keyword under each section. The frequency units shall be defined within the *Unit_freq* keyword, voltage units shall be specified using the *Unit_voltage* keyword, that of current using the *Unit_current* keyword and power units using the *Unit_power* keyword. When absent, default values are used (see 6.10.2.10). Refer to A.2.5 for valid values and units.

The following example illustrates the IB data, obtained through a DPI test, representing the transmitted power on lead "1" with the following test conditions: Pin with Id="9" is monitored with pass/fail criteria with a tolerance level of ±2,5 V with respect to the nominal output voltage amplitude and ±5 µs with respect to the nominal output voltage distortion in time. The test is carried out with a maximum power level of 35 dBm (in all tested frequencies) injected on lead "1". Only the magnitude of the output power in watts (W) is represented.

```
<Ib>
    <Lead Id="1" Ground_id="7" Type="DPI">
    <Max_power_level Value="35dBm"/>
        <Power Param_order ="Freq,Power" Format="DBMAG">
            <Test_criteria Id="9" Type="PF" Level="+2.5V,-2.5V"
                Parameter="Amplitude"/>
            <Test_criteria Id="9" Type="PF" Level="+5us,-5us"
                Parameter="Time"/>
            <Blockname>Block_OOPin1</Blockname>
            <Unit_freq>MHz</Unit_freq>
            <Unit_power>W</Unit_power>
            <List>
                1 1.536571142
                2 0.8327052017
                3 0.9596036832
                4 0.8646181202
                5 0.7045024392
                ...
            </List>
        </Power>
    </Lead>
</Ib>
```

The IB data can be obtained through DPI or RFIP measurements as explained in 7.4.

6.10.3.2 External file data

As stated in 6.10.2.11, for directing the CIM parser to use the necessary external data file in ASCII format, the definition shall be made using the *Data_files* keyword under the *Voltage*, *Current* or *Power* sections. All other rules are the same as those seen with inline data definition in 6.10.3.1. An example of an IB file is shown in Figure 19. Note that all comment lines, if present, are indicated by the exclamation ("!") symbol at the beginning, but they not parsed by the CIM parser.

```
!f(Hz)      Pt(W)
!Monitoring on LIN
1000000    0.01210474359
2000000    0.004227117987
3000000    0.002897663639
4000000    0.002649712504
5000000    0.00250762503
6000000    0.002345954784
7000000    0.002308431188
8000000    0.002346253032
9000000    0.002633505446
10000000   0.00246788178
15000000   0.008718441842
20000000   0.01087608427
25000000   0.007527113401
30000000   0.007196132914
35000000   0.007041186572
40000000   0.006978506095
45000000   0.007011565952
50000000   0.009056521981
...
```

IEC

Figure 19 – Example IB file obtained from DPI measurement

This information can be obtained through DPI or RFIP measurement methods as explained in 7.4. An example of the *Ib* section, defined using IB data in an external file, is shown below:

```
<Ib>
    <Lead Id="1" Ground_id="7" Type="DPI">
        <Max_power_level Value="35dBm"/>
        <Power Param_order ="Freq,Power" Format="DBMAG">
            <Test_criteria Id="9" Ground_id="7" Type="PF"
            Level="+2.5,-2.5V" Parameter="Amplitude"/>
            <Test_criteria Id="9" Ground_id="7" Type="PF"
            Level="+5us,-5us" Parameter="Time"/>
            <Unit_freq>MHz</Unit_freq>
            <Unit_power>W</Unit_power>
            <Data_files>
                IB_DPI_Injection9.txt
            </Data_files>
        </Power>
    </Lead>
</Ib>
```

7 Extraction

7.1 General

ICIM-CI macro-model parameters can be extracted from either design information or measurements. Detailed methodology for model parameter extractions are not the purpose of this part of IEC 62433. Clause 7 gives basic information for obtaining the model parameters from measurements.

7.2 Environmental extraction constraints

The ICIM-CI macro-model parameter extractions have to be performed under normal room temperature conditions: 23 °C ± 5 °C. There are no additional requirements on air pressure and humidity.

When open silicon is used, the lights shall be dimmed or switched off in order not to generate photonic effects.

NOTE Some substrate materials are hydroscopic which might affect the permittivity of the material and its loss tangent.

7.3 PDN extraction

7.3.1 General

The PDN impedance is extracted using different configurations proposed in CISPR 17. As per the standard, impedance of a DUT is measured using impedance-measuring equipment and a test fixture.

An appropriate combination of the measuring equipment and test fixture shall be selected according to the DUT configuration and the test frequency. As the PDN impedance may vary with bias, extraction of PDN elements shall be performed with the DUT "powered" in order to be close to normal operating conditions. Care shall be taken not to over bias the DUT.

The measurement system shall be traceable to a national standards organization. The measuring system and the test fixture shall be properly calibrated as specified in the equipment's instruction manuals.

There are several methods to extract these PDN parameters. They are described briefly in 7.3.2 and 7.3.3.

7.3.2 *S*-/*Z*-/*Y*-parameter measurement

One method to measure the DUT's network parameters (*S*- or *Z*- or *Y*-parameters) consists of using impedance-measuring equipment. As per CISPR 17, impedance measurement of a DUT is carried out by one of two methods: the direct method or the indirect method.

In the direct method, impedance shall be measured by inserting the DUT into the test fixture and by sweeping the measurement frequency with the impedance-measuring equipment. The relationship between the impedance and the frequency shall be recorded within the required frequency range.

In the indirect method, the impedance of a DUT can be evaluated from its *S*-parameters. In this case, the *S*-parameters are measured using a vector network analyzer within the required frequency range. Modern VNAs typically include a function for calculating the impedances.

Measurement setup may vary depending on whether the test-pin is single-ended or differential. These methods are described in Annex F.

Conversion between different network parameters is provided in Annex C.

7.3.3 RFIP technique

The PDN elements can be extracted with a measurement method based on a DPI test setup (IEC 62132-4).

Probes can be passive (R, L, C elements) or active (R, L, C and transistors). Therefore, calibration of these probes is required. Pin impedance is extracted from voltage and current measurements.

One probe allows to measure impedance of one-pin (one-port). For several port measurements (multi-pin), several probes are required.

Detailed description of RFIP technique is available in Annex G.

7.4 IB extraction

7.4.1 General

As discussed in 5.4, the IB component of the ICIM-CI macro-model describes how the IC reacts to the applied disturbances. The disturbance may be injected in one or many IC leads simultaneously. The IB is defined in the frequency domain by representing transmitted power (P_T) on to the DI pin(s) as a function of frequency, as well as the variations on one or more OO. The transmitted power threshold is the intrinsic power which induces a malfunction. The variation of the signal at OO is considered to depend on the transmitted power entering in the device.

There are several methods to extract these IB parameters. Two of them are described in 7.4.2 and 7.4.3.

7.4.2 Direct RF power injection test method

The direct RF power injection (DPI) measurement method is an internationally accepted technique to verify the robustness of an IC against an injected RF signal. The requirements of this measurement method are defined in IEC 62132-4. The test setup is shown in Figure 20.

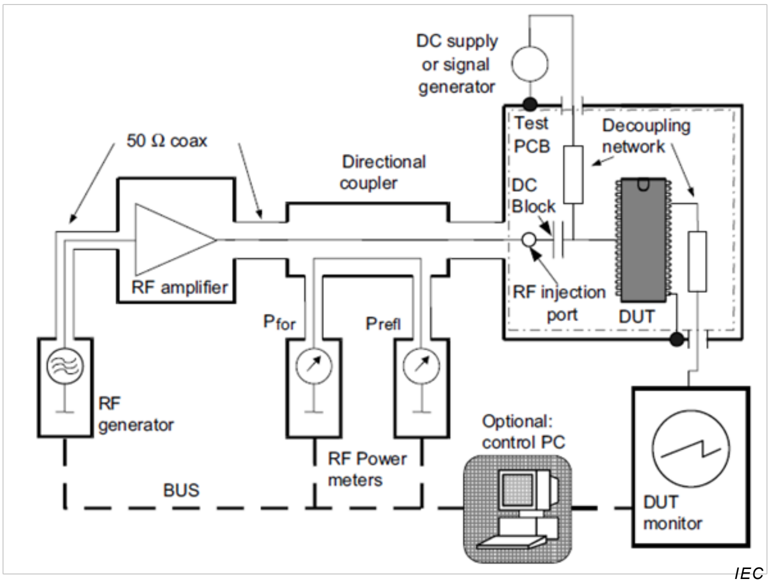


Figure 20 – Test setup of the DPI immunity measurement method as specified in IEC 62132-4

The continuous wave (CW) RF disturbance signal is generated by the RF generator which is connected to the RF amplifier. The signal is injected into the test board carrying the test IC through an optional directional coupler. The use of the directional coupler is to measure the injected and reflected power if needed with the use of RF power-meters. At the reference port on the test board (RF injection port), the RF disturbance signal is connected to one or more pins of the IC. A DC block capacitor is used to avoid supplying DC to the output of the RF amplifier. On the other side, a decoupling network is used so as to prevent DC supply from receiving the RF power. Single and multi-pin injection is illustrated in Figure 21.

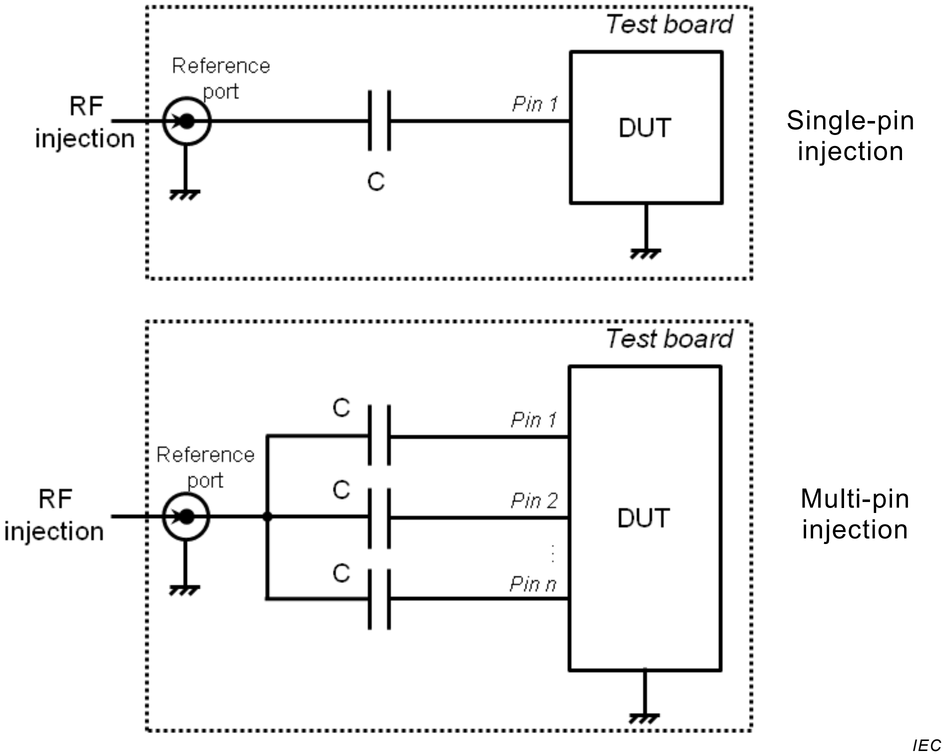


Figure 21 – Principle of single and multi-pin DPI

The test procedure is as follows:

- The power of the disturbance signal is increased stepwise at each frequency of interest, until the DUT shows a malfunction on the OO pin.
- Sufficient dwell time is chosen so that the DUT is allowed to react to the disturbance signal.
- A maximum injection power level may also be set during the tests.
- At each frequency, the power level at which a malfunction is induced is measured with a power meter across the coupler ports when used. If needed, both injected power and reflected power can be measured simultaneously. When the coupler is not used, then the RF power level is directly measured at the output of the RF amplifier.

Depending on the measured quantities, the method for extracting the transmitted power on to the test lead varies. Refer to IEC 62132-4 for more information on the DPI test method.

When both injected power (P_i) and reflected power (P_r) are measured across the dual directional coupler, it is possible to calculate the transmitted power (P_Tref) on to the reference port using:

$$P_\text{Tref} = P_\text{i} - P_\text{r}$$

This power corresponds to the power transmitted at the reference port on the test board. To calculate the actual transmitted injected on the lead pin, electrical simulations shall be performed so as to take into account the traces and other elements connected to the reference port. This is illustrated in Figure 22.

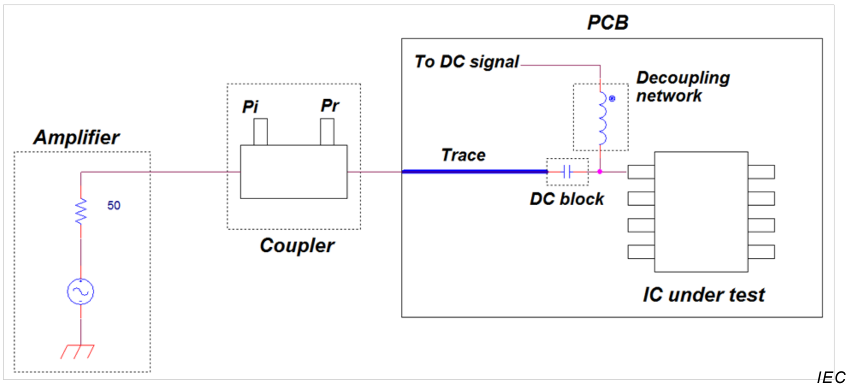


Figure 22 – Electrical representation of the DPI test setup

The traces on the PCB and other passive components such as the DC block capacitor and the decoupling network shall be modelled accurately with their respective high-frequency models. The DI pin under test is represented by its PDN measured using one of the methods explained in 7.3. Since P_i is measured, the equivalent injection voltage (e) can be calculated using:

$$P_i = \frac{e^2}{4Z_0}$$

with Z_0 = 50 Ω. The transmitted power to the DI pin (P_T) can be calculated from the voltage (V_{DUT}) and current simulated (I_{DUT}) at the reference port by using:

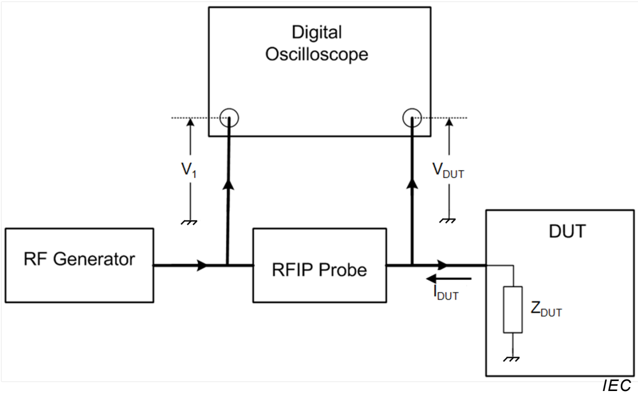
$$P_T = \frac{1}{2}\mathrm{Re}\left[V_{DUT}\, I_{DUT}^{\ *} + V_{DUT}^{\ *}\, I_{DUT}\right]$$

If the coupler is not used, the same technique can be applied, except that the injected power (P_i) is the RF power at the amplifier stage.

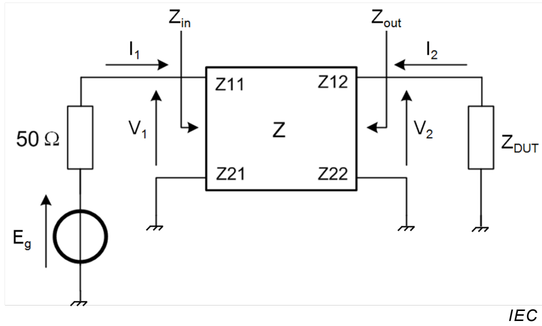
If the extraction of IB is based on the use of measurements (for example IEC 62132-4), then the valid frequency range of the IB corresponds to the corresponding standard.

7.4.3 RF Injection probe test method

The RF injection probe (RFIP) method is derived from the DPI immunity test method. The probe applies the disturbance and measures the voltage across the DUT (V_1 and V_{DUT}). The I_{DUT}, P_{DUT} and Z_{DUT} parameters are then computed. An oscilloscope is used to measure V_1 and V_{DUT} in the time domain. All computation is performed in the frequency domain thanks to a processing performed with a software tool.



a) Test setup



b) RFIP probe representation

Figure 23 – Test setup of the RFIP measurement method derived from the DPI method

This method is based on the current and voltage measurements. Thus, obtaining the immunity parameters is reasonably straightforward in this method.

The RF injection probe is defined by the *Z*-matrix characterized by two-port S-parameter measurements (see Figure 23). All the key electrical parameters, namely I_{DUT}, Z_{DUT} and P_{DUT} can be computed based on the measuring the voltages V_{DUT} and V_1.

It shall be noted that Z_{DUT} of the particular DI pin is defined in the PDN part of the ICIM-CI macro-model. Based on these fundamentals, the RFIP allows measurement of the power transmitted into the DUT (P_{T}). The measurement method is explained in detail in Annex G. The transmitted power is calculated from the following equations:

$$P_{\text{T}} = \frac{1}{2}\text{Re}\left[\frac{V_{\text{DUT}}V_{\text{DUT}}^{*}}{Z_{\text{DUT}}}\right] = \frac{1}{2}\text{Re}\left[I_{\text{DUT}}I_{\text{DUT}}^{*}Z_{\text{DUT}}\right]$$

Though IB is always termed as the transmitted power in the frequency domain, it is possible to represent IB as a voltage or current quantity due to the inherent relation between V_{DUT}, I_{DUT} and P_{T}.

If the IB data is represented using the complex voltage V_{DUT} or complex current I_{DUT}, P_{T} is computed with the use of Z_{DUT} available in the PDN. In these cases, it is mandatory to define V_{DUT} and I_{DUT} as a complex quantity. If P_{T} is defined as IB, then it is directly used and can be represented in any format (real or complex).

If the RFIP test method is used, then the valid frequency range of the ICIM-CI macro-model's IB extracted using RFIP is the same as that of the measurement data.

7.4.4 IB data table

In the simplest case, a table summarizes the transmitted power corresponding to the level at which the failure occurs. The example IB data of a voltage regulator, obtained from DPI measurement, is illustrated in Table 19. The injected power causing the malfunction on a chosen OO lead is used to calculate the transmitted power (see 7.4.2). User set immunity criteria have been applied on the OO lead and a binary pass/fail test is performed. More details on the test setup and criteria are discussed in Clause 9.

Table 19 – Example of IB table pass/fail criteria

Frequency (MHz)	P_T (dBm)
1	18,11
2	23,15
3	22,10
4	21,13
5	18,04
10	10,82
50	9,25
100	16,88
200	7,95
500	12,34
980	31,40
NOTE Only some immunity values have been listed for illustrative purposes.	

Table 19 can also be represented by including all tested frequencies, irrespective of the whether the malfunction has occurred or not.

It is also possible to represent the IB data using a non pass/fail test type. In such cases, the IB table shall contain the maximum transmitted power (versus frequency) before any variation on the OO is induced. Example data are shown in Figure H.1 (see Annex I).

7.5 IBC

The IBC impedance can be derived from the power-supply pin (V_{DD} – V_{SS}) impedance by subtracting the impedance part that belongs to the PDN. A detailed method should be elaborated in future.

8 Validation of ICIM-CI hypotheses

8.1 General

The model structure is based on hypotheses that need to be verified in order to validate the model and justify its capability to predict the EMC behaviour in other conditions than the one used to extract the model.

The first hypothesis is linked to the use of network parameters (S or Z or Y) to describe the PDN of the component, or more generally to the description without considering non-linear effects.

The second hypothesis is on the use of the transmitted power criterion as a relevant parameter for defining and expressing the immunity of the device.

Both these hypotheses are validated using a transistor (a non-linear device) as an example. The test setup is shown in Figure 24. The base and the emitter of the transistor are grounded (connected to 0 V reference) and the collector is biased with a 5 V supply. The base is the DI terminal and the collector is the OO terminal that is monitored for defect, with tolerance of ±200 mV on amplitude.

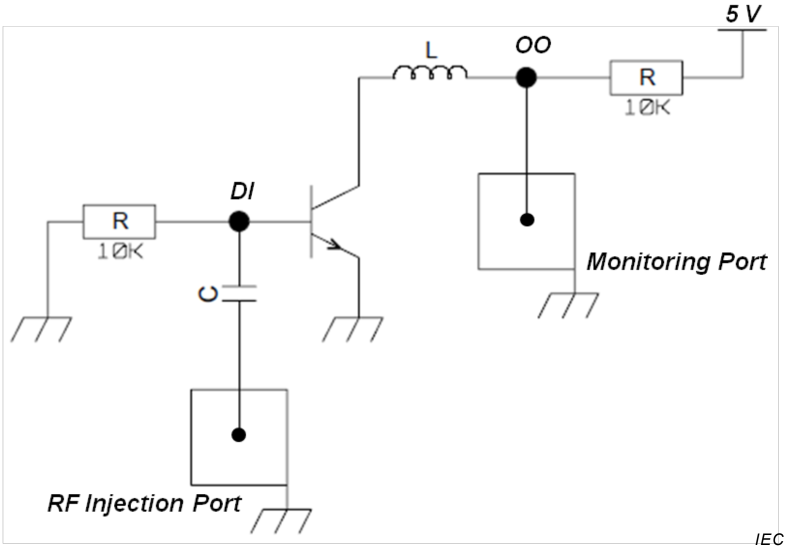


Figure 24 – Example setup used for illustrating ICIM-CI hypotheses

8.2 Linearity

It is evident that a disturbance of an integrated circuit could also be caused by a non-linear effect. Nevertheless, in our approach, we suppose that this non-linear behaviour can be neglected in the PDN description, until the malfunction appears. This hypothesis shall be verified to validate the model.

This can be validated by measuring transfer functions with a network analyzer, for incident power close to the disturbance level identified during the DPI test (if it is the method used to characterize the device). The level is usually set at 6 dB below the susceptibility threshold to perform the measurement. This result can then be compared to a simulation result being based on linear models (such as S-parameters).

If there is no more than 3 dB deviation between both results we can conclude that the linearity hypothesis is verified, and that the model is validated for this aspect. Figure 25 provides an example of comparison between measurement and simulation for a $|S_{21}|$ coefficient, corresponding to the transmission coefficient between the base and the collector of the transistor shown in Figure 24.

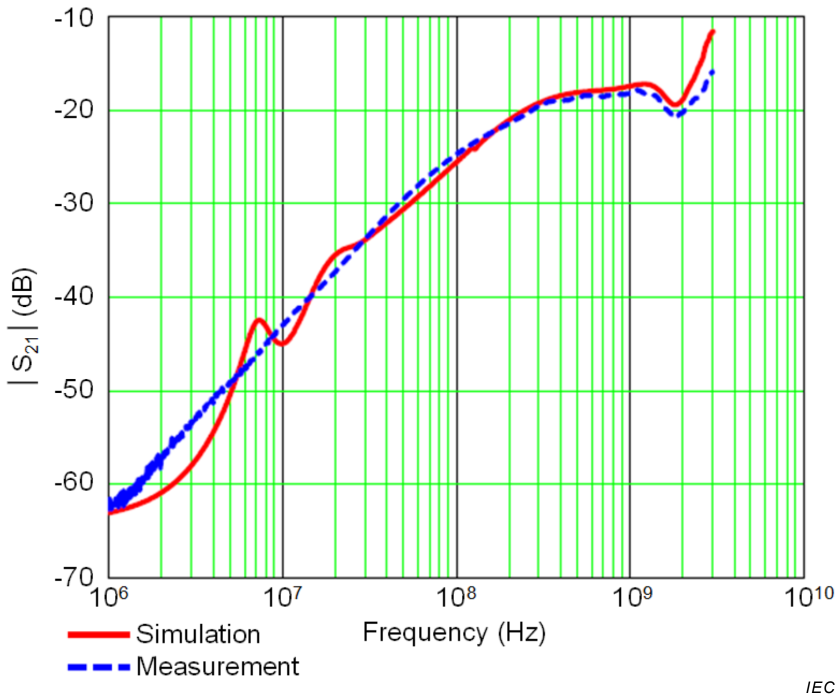


Figure 25 – Example of linearity assumption validation

8.3 Immunity criteria versus transmitted power

The second hypothesis is to consider that an integrated circuit will be disturbed for a given transmitted power on a pin, and that this can be considered as an intrinsic data for the component. This means that the environment (filtering, PCB layout, etc.) will only act in the transfer function of disturbances until the IC inputs, but not on the transmitted power threshold causing a malfunction.

In order to validate this, it is recommended to perform DPI tests (if it is the method used to characterize the immunity of the device) in two configurations. The first one will be used to extract the transmitted power threshold. The second one can consist in adding typical filters such as those envisaged in the application. Based on the established model, one can predict the performance in this second configuration and compare its prediction with the experiment. The correlation allows to validate the predictive performance of the model, and to validate the use of the transmitted power as a relevant criterion to describe the immunity of a device.

An example of prediction is provided in Figure 26, allowing the validation of this second hypothesis on the setup shown in Figure 24. The immunity level in Figure 26 corresponds to the injected power on the base of the transistor (DI) for which a defect has been observed on the collector pin (OO) for an amplitude tolerance of ±200 mV.

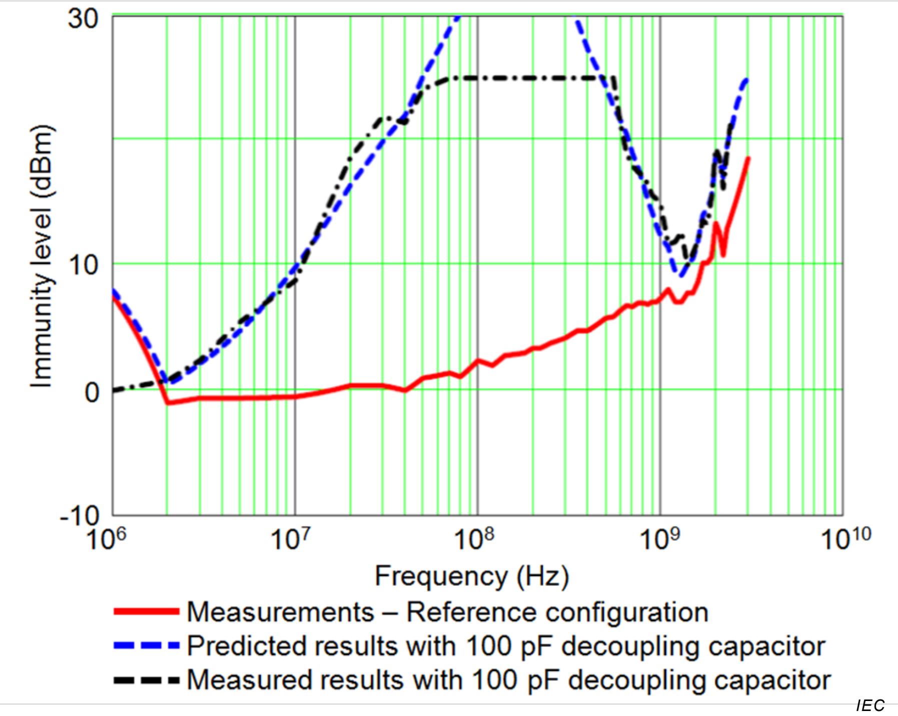


Figure 26 – Example of transmitted power criterion validation

In Figure 26, it should be noted that the predicted results correlate well with the measured results with 100 pF decoupling capacitor. From about 50 MHz to 500 MHz the measured results have reached the maximum allowed power level (25 dBm in this case), whereas the predicted results can exceed this level.

9 Model usage

As previously stated, ICIM-CI macro-model's PDN and IB sub-models are valid in the conditions in which they have been established. Nevertheless, ICIM-CI macro-model can be used at application level simulation in SPICE like simulators, incorporating external components (environment models) such as decoupling capacitors, filter components, and PCB trace parasitics. An example use of an ICIM-CI macro-model is shown in Figure 27.

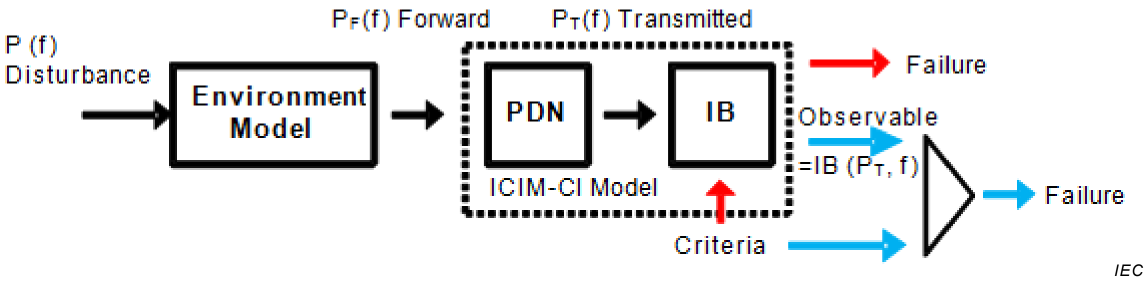


Figure 27 – Use of the ICIM-CI macro-model for simulation

Failure prediction output by simulation is dependent on the IB block itself. If the IB has been determined using binary pass/fail method (immunity criteria is already incorporated in the IB), then the simulations can directly estimate failure. The simulation flow is represented using red arrows in Figure 27. An application example, based on pass/fail test, to predict IC immunity behaviour (failure) is illustrated in Annex H.

However, failure detection cannot not be performed by the IB block directly if it has been extracted using a non pass/fail test. The failure detection has to be done by monitoring the simulated transmitted power and the behavioural data supplied by the IB block; the simulation result is analogue data and not binary data. Immunity criteria shall be applied at this stage to predict the IC failure. The simulation flow for such cases is represented using blue arrows in Figure 27. An example of using a non pass/fail test result to predict IC failure is illustrated in Annex I.

Annex A
(normative)

Preliminary definitions for XML representation

A.1 XML basics

A.1.1 XML declaration

Although the XML declaration is optional in an XML file, the ICIM-CI macro-model file shall include an XML declaration, dedicated to basic XML parsers.

```
<?xml version="1.0" encoding="UTF-8" ?>
```

The XML declaration shall be the first line of the file.

A.1.2 Basic elements

All information is saved in the form of XML elements. Each element starts with a start-tag and ends with an end-tag. The start-tag consists of a keyword enclosed in triangular brackets, <Keyword>. The end-tag consists of the same keyword prefixed by the character "/" and enclosed in brackets, </Keyword>. Content in the form of text is enclosed by a start-tag and an end-tag.

An example of an element is given below:

```
<Keyword>          <!-- start-tag -->
    text           <!-- content -->
</Keyword>         <!-- end-tag -->
```

It is also allowed to write an element on the same line, for example, to include short content:

```
<Keyword>text</Keyword>
```

The contents of an element may consist of one or more elements or a value (numerical, or alphanumerical). For clarity, tab characters may be used for indenting. Except when used for surrounding keywords, triangular brackets "<" and ">" shall not be part of content.

The text shall use characters from the UTF-8 set (space " ", "<", ">", "&" are not included).

An empty element may be included to indicate that a particular keyword exists, but has no content:

```
<empty_element/>
```

A.1.3 Root element

The XML file shall contain one, and only one, root element. It encloses all the other elements and is therefore the sole parent element to all the other elements. The start-tag of the root element is placed at the beginning of the file or after the XML declaration when present. The end-tag of the root element is at the last entry of the file.

The root element keyword shall not be used for any other purposes in the XML file

A.1.4 Comments

Comments may be inserted into the file between "<!--" and "-->". An example is given below:

```
<!-- this line is a comment -->
```

Comments can be inserted anywhere in the file, except inside start- and end-tags, and written on a single line or on several lines. All text enclosed by comment brackets is considered as a comment and may be ignored.

A.1.5 Line terminations

In order to facilitate readability, it is usual to organize the file into lines. The line termination sequence shall be either a linefeed character or a carriage return character followed by a linefeed character.

A.1.6 Element hierarchy

The order of the elements is not important, but their hierarchy shall be respected. A layout example is shown below:

```
<Keyword1> ... </Keyword1>
<Keyword2>
     <Keyword21> ... </Keyword21>
     <Keyword22> ... </Keyword22>
</Keyword2>
<Keyword3> ... </Keyword3>
```

A.1.7 Element attributes

XML keyword elements can have attributes. Attributes provide additional information about elements that are not a part of the data. Attribute values shall always be quoted. Either single or double quotes can be used. Multiple attributes are either separated by a space or by a semi-colon (";") character. In contrast to elements, attributes usually cannot contain multiple values and tree structures, except for certain exceptions in the XML. An example of attribute definition is shown below:

```
<Parent Type="example"; Format="string"/>
```

In the above syntax *Type* and *Format* are attributes to the keyword *Parent*. The same terms can be defined as elements as shown below:

```
<Parent>
     <Type>example</Type>
     <Format>string<Format>
</Parent>
```

A.2 Keyword requirements

A.2.1 General

Keywords, placed in start- and end-tags, are used to introduce descriptions, values and sections that are specific to the file. Some keywords, such as Unit, List, etc, may be present in several sections. A parent keyword is required whenever a child keyword is present. The rules below ensure that the file can be correctly parsed by a specific XML parser.

A.2.2 Keyword characters

ASCII characters, as defined in ISO/IEC 646: 1991, shall be used in the files The use of characters with codes greater than hexadecimal 07E is not allowed. Also, ASCII control characters (those numerically less than hexadecimal 20) are not allowed, except for tabs or in a line termination sequence.

Only alphabetical or numerical characters can be used to write keywords. Spaces are not permitted. If needed, the underscore "_" character can separate the parts of a multi-word keyword.

A.2.3 Keyword syntax

The content of the files is case sensitive. All keywords shall be written in lower case starting with an upper case letter.

A.2.4 File structure

A.2.4.1 General

The information to be exchanged may be stored in a single file or in several and data files. The following rules and guidelines ensure that the files can be correctly located by an XML parser.

A.2.4.2 File names

To facilitate portability between operating systems, file names should have a base name of no more than forty characters followed by a period ".", followed by a filename extension of no more than four characters. The file name and extension shall use characters from the set (space " ", 0x20 is not included) seen previously in A.1.2. File name shall be defined within the *Filename* keyword as shown below:

```
<Filename>ExampleXML_file.xml</Filename>
```

A.2.4.3 File Paths

In order to ensure portability and compressibility, only relative paths can be used to define a path name. An absolute path is not exportable and is not permitted. The relative path shall start with "./" to indicate that the path name of the file will be appended to the path of the current XML file. It is not permitted to browse to a higher level from the current XML path (e.g. by using "../"). A file name without "./" is assumed to be located in the same directory as the current XML file.

A.2.4.4 Single XML file

When the information is contained in a single XML file, it shall conform to the rules and guidelines applicable to XML files as described previously.

Data is included in the PDN or IB section of the file within the XML element using the keyword "List" whenever required.

A.2.4.5 Multiple XML files

The XML document is divided into several sections having the root element as parent. The model’s information is then defined under the root section using keywords such as PDN, IB, etc. Each XML file may contain one or more sections and shall conform to the rules and guidelines applicable to XML files as described previously. A section shall be present in only one of the XML files.

In order to ensure portability and compressibility, all the XML files shall be placed in the same directory, as shown in Figure A.1. The XML parser shall parse all the files that are in the main directory.

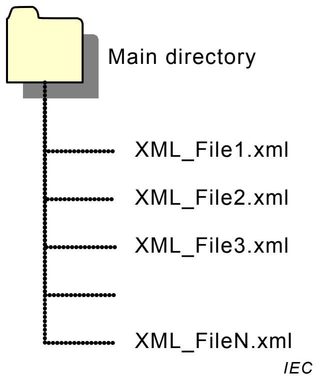
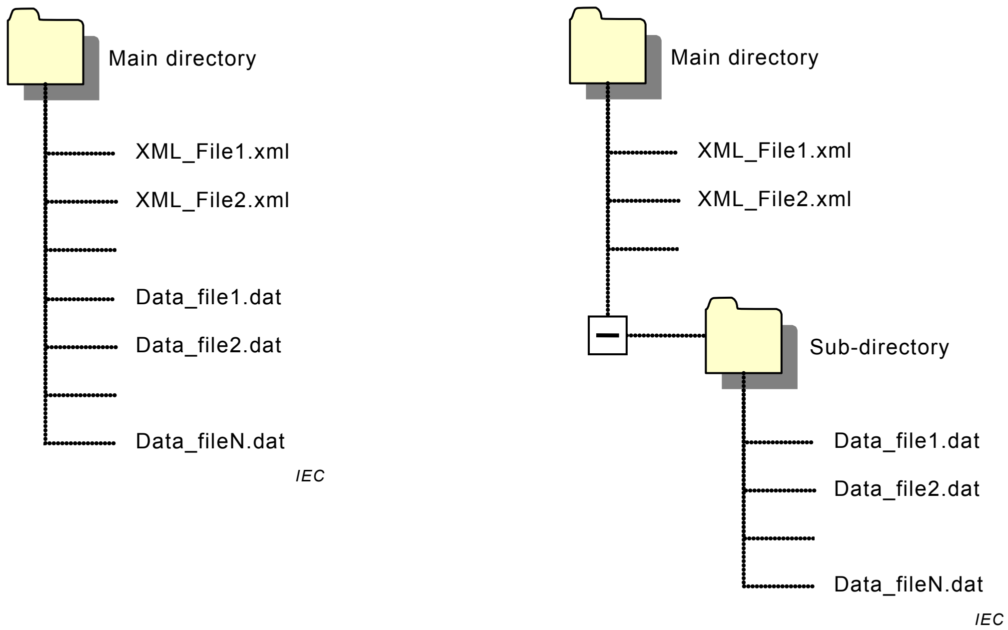


Figure A.1 – Multiple XML (CIML) files

A.2.4.6 Separate data files

The information may be contained in a single or in multiple XML files and the data contained in one or more additional data files. The XML files shall conform to the rules and guidelines applicable to XML files as described above. The data files can contain lines of data and header information shall be specified with explanation character ("!") as the first character of each header line (non-data line). As an exception, for data files with a touchstone extension (*.snp, n = 1,2,…) used for PDN definition, the line starting with a hash character ("#") is treated as the "option line" that specifies data format and units pertaining to touchstone data. Only one "option line" is allowed per touchstone data file. The names and paths of the data files are defined by the keyword *Data_files* and shall conform to A.2.4.2 and A.2.4.3.

In order to ensure portability and compressibility, the data files shall be placed either in the same directory as the XML files or in a sub-directory located at the same level as the XML files or at a lower level, as shown in Figure A.2. It is not permitted to locate the additional files at a higher level than the XML files.

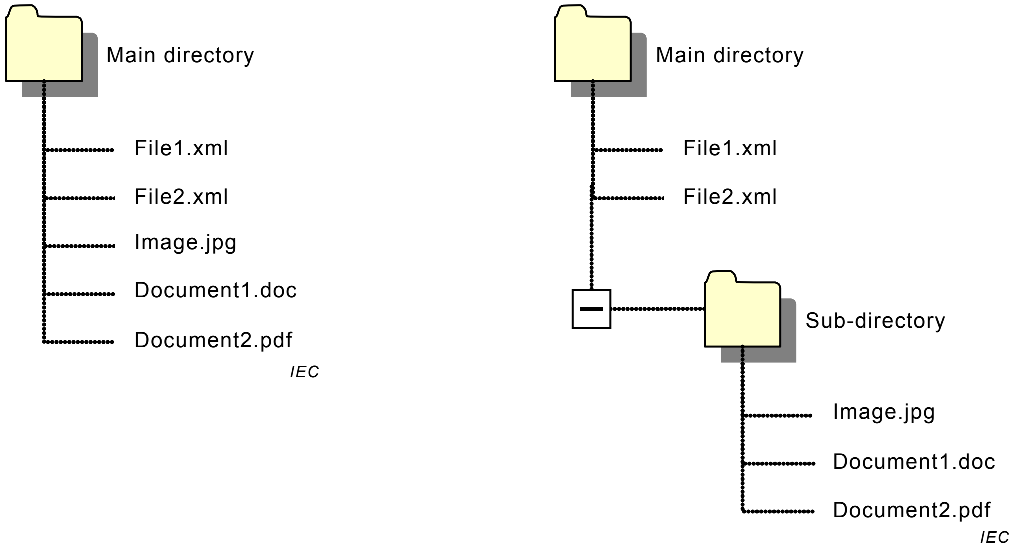


a) Data files in the same directory **b) Data files in a sub-directory**

Figure A.2 – XML files with data files (*.dat)

A.2.4.7 Additional files

A XML file may contain references to other files such as document files (Keyword: *Documentation*). In order to ensure portability and compressibility, these additional files shall be placed either in the same directory as the single XML file or in a sub-directory located at the same level as the XML files or at a lower level, as shown in Figure A.3. It is not permitted to locate the additional files at a higher level than the XML files.



a) Additional files in the same directory **b) Additional files in a sub-directory**

Figure A.3 – XML files with additional files

A.2.4.8 File compression

When compressing the file system, care shall be taken to include the paths of the various XML and data files in the compressed file. This ensures that, when decompressed, the file structure is conserved. The paths are not required when all files are stored in the same directory.

A.2.5 Values

A.2.5.1 General

When an element contains a value, this may be a numerical value (e.g. 123,45), or a numerical value with units (e.g. 123,45 MHz).

A.2.5.2 Numerical syntax

Numerical values may be expressed in decimal form with the period as the decimal separator (e.g. 123.45) or in scientific form (e.g. 1.2345e2). Spaces " " and commas ",", which are often used as thousand separators, and other characters are not allowed.

In cases where several numerical values are required, they shall be separated by spaces " " or tab characters.

A.2.5.3 Numerical with units syntax

The numerical value (see A.2.5.2) is followed by valid units, as described in A.2.5.5 (e.g. 123,45 MHz). Spaces are not allowed between the numerical value and the units.

A.2.5.4 Text string

A text string may represent a word recognized by the XML parser or it may be a file name, a description, etc. A text string may contain any of the alphanumerical characters given in A.1.2.

A.2.5.5 Valid units

Units shall be expressed in SI units or derived SI units. Valid units are:

V for volt	ohm for ohm	S for siemens =1/ohm
A for ampere	Hz for hertz	m for metre
W for watt	s for second	H for henry
F for farad	ohm.m for ohm metre	Celsius for degree Celsius
K for kelvin	1 for dimensionless quantity	

Units are case sensitive.

Angles are expressed in degrees. The symbol "°" is not required. Percentage is expressed as "%".

Valid scaling factors are:

T = tera: 10^{12}	c = centi: 10^{-2}	p = pico: 10^{-12}
G = giga: 10^{9}	m = milli: 10^{-3}	f = femto: 10^{-15}
M = mega: 10^{6}	u = micro: 10^{-6}	a = atto: 10^{-18}
k = kilo: 10^{3}	n = nano: 10^{-9}	

When no scaling factors are specified, the appropriate base units are assumed. These are volts, amperes, watts, ohms, siemens, hertz, metres, seconds, henry, farads, ohm.m, Celsius and kelvin. Abbreviations for the units (for example, pV, nA, ms, MHz) shall be used, except ohm, Celsius and resistivity, which shall be written in full. A list of valid logarithmic units is given in Table A.1.

Table A.1 – Valid logarithmic units

Usage	Symbol	Unit	Reference
Ratio	dB	decibel	1
Power	dBW	decibel watt	1W
Power	dBmW	decibel milli-watt	1mW
Power	dBuW	decibel micro-watt	1μW
Voltage	dBV	decibel volt	1V
Voltage	dBmV	decibel milli-volt	1mV
Voltage	dBuV	decibel micro-volt	1μV
Ampere	dBA	decibel ampere	1A
Ampere	dBmA	decibel milli-ampere	1mA
Ampere	dBuA	decibel micro-ampere	1μA
Impedance	dBohm	decibel ohm	1ohm
Admittance	dBS	decibel siemens	1S

Unit definitions can be made in any section and with the *Unit* keyword. A typical unit description is shown below:

```
<Unit>
     kHz
</Unit>
```

Annex B
(informative)

ICIM-CI example with disturbance load

Figure B.1 shows an example of DPI setup for extracting the IB data of an oscillator. The DI is the supply line (V_{CC}) and the OO is the jitter of the clock output.

The DO1 is the input of the IC where the Cx1 capacitor is connected. The DO2 is the output of the IC where the Cx2 is connected. Both of them receive a part of the jitter applied on the DI and they can influence the jitter level. The OO is where the jitter is monitored.

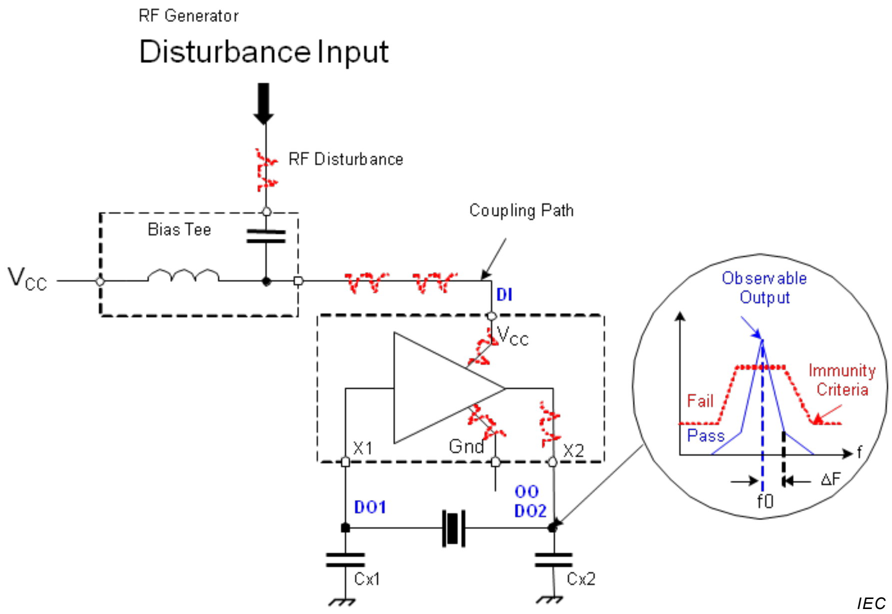


Figure B.1 – ICIM-CI description applied to an oscillator stage for extracting IB

Annex C
(informative)

Conversions between parameter types

C.1 General

As described in Clause 5, the power transmitted into a DI shall be determined from the forward power and the impedance. Obtaining this quantity is straightforward when the impedance of the DI is characterized by S-parameters, whereas conversion of the parameters is required when Z- or Y-parameters are used. This conversion also depends on whether the input or output is single-ended or differential.

C.2 Single-ended input or output

The configuration for a single-ended DI, is shown in Figure C.1

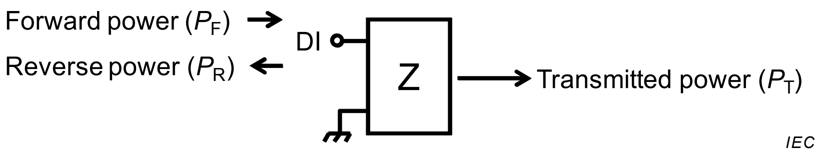


Figure C.1 – Single-ended DI

The single-ended DI is considered to be a one-port network. In this case, the relationship between the transmitted power (P_T) and the forward power (P_F) is given by:

- S-parameters

$$P_T = P_F\left(1 - |S_{11}|^2\right)$$

- Z-parameters

$$P_T = P_F\left(1 - \left|\frac{Z_{11} - Z_0}{Z_{11} + Z_0}\right|^2\right)$$

- Y-parameters

$$P_T = P_F\left(1 - \left|\frac{Y_0 - Y_{11}}{Y_0 + Y_{11}}\right|^2\right)$$

In the above equations, S_{11}, Z_{11} and Y_{11} are complex values.

Table C.1 shows the relationships to convert between S_{11}, Z_{11} and Y_{11} for a one-port network.

Table C.1 – Single-ended parameter conversion

		To		
		S-parameters	**Z-parameters**	**Y-parameters**
From	**S-parameters**		$Z_{11} = Z_0 \dfrac{1+S_{11}}{1-S_{11}}$	$Y_{11} = Y_0 \dfrac{1-S_{11}}{1+S_{11}}$
	Z-parameters	$S_{11} = \dfrac{Z_{11}-Z_0}{Z_{11}+Z_0}$		$Y_{11} = \dfrac{1}{Z_{11}}$
	Y-parameters	$S_{11} = \dfrac{Y_0-Y_{11}}{Y_0+Y_{11}}$	$Z_{11} = \dfrac{1}{Y_{11}}$	
Z_0 is the characteristic impedance and Y_0 is the characteristic admittance used as the reference for the S-parameters (Z_0 is typically 50 Ω).				

C.3 Differential input or output

The configuration for a differential DI is shown in Figure C.2.

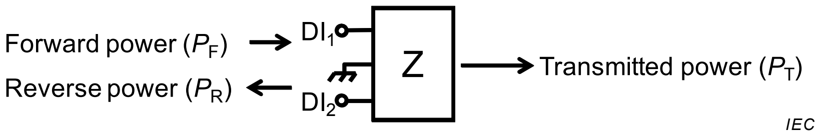


Figure C.2 – Differential DI

A differential DI is considered to be a two-port network as shown in Figure C.3.

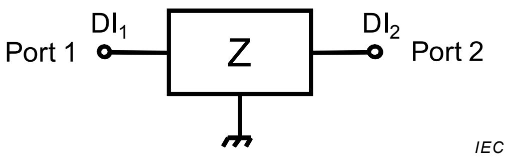


Figure C.3 – Two-port representation of a differential DI

The differential DI can be described by two-port S-parameters, two-port Z-parameters or two-port Y-parameters. These may be obtained either by measurements using a two-port vector network analyzer or by voltage and current measurements at the two ports. The resulting parameter file may then be used for simulation.

Table C.2 shows the relationships between S-, Z- and Y-parameters for a two-port network [3].

Table C.2 – Differential parameter conversion

		To		
		S-parameters	**Z-parameters**	**Y-parameters**
From	**S-parameters**		$Z_{11}=Z_0\dfrac{(1+S_{11})(1-S_{22})+S_{12}\,S_{21}}{(1-S_{11})(1-S_{22})-S_{12}\,S_{21}}$ $Z_{12}=Z_0\dfrac{2\,S_{12}}{(1-S_{11})(1-S_{22})-S_{12}\,S_{21}}$ $Z_{21}=Z_0\dfrac{2\,S_{21}}{(1-S_{11})(1-S_{22})-S_{12}\,S_{21}}$ $Z_{22}=Z_0\dfrac{(1-S_{11})(1+S_{22})+S_{12}\,S_{21}}{(1-S_{11})(1-S_{22})-S_{12}\,S_{21}}$	$Y_{11}=Y_0\dfrac{(1-S_{11})(1+S_{22})+S_{12}\,S_{21}}{(1+S_{11})(1+S_{22})-S_{12}\,S_{21}}$ $Y_{12}=Y_0\dfrac{-2\,S_{12}}{(1+S_{11})(1+S_{22})-S_{12}\,S_{21}}$ $Y_{21}=Y_0\dfrac{-2\,S_{21}}{(1+S_{11})(1+S_{22})-S_{12}\,S_{21}}$ $Y_{22}=Y_{00}\dfrac{(1+S_{11})(1-S_{22})+S_{12}\,S_{21}}{(1+S_{11})(1+S_{22})-S_{12}\,S_{21}}$
	Z-parameters	$S_{11}=\dfrac{(Z_{11}-Z_0)(Z_{22}+Z_0)-Z_{12}\,Z_{21}}{(Z_{11}+Z_0)\,(Z_{22}+Z_0)-Z_{12}\,Z_{21}}$ $S_{12}=\dfrac{2\,Z_0\,Z_{12}}{(Z_{11}+Z_0)\,(Z_{22}+Z_0)-Z_{12}\,Z_{21}}$ $S_{21}=\dfrac{2\,Z_0\,Z_{21}}{(Z_{11}+Z_0)(Z_{22}+Z_0)-Z_{12}\,Z_{21}}$ $S_{22}=\dfrac{(Z_{11}+Z_0)(Z_{22}-Z_0)-Z_{12}\,Z_{21}}{(Z_{11}+Z_0)\,(Z_{22}+Z_0)-Z_{12}\,Z_{21}}$		$Y_{11}=\dfrac{Z_{22}}{Z_{11}\,Z_{22}-Z_{12}\,Z_{21}}$ $Y_{12}=\dfrac{-Z_{12}}{Z_{11}\,Z_{22}-Z_{12}\,Z_{21}}$ $Y_{21}=\dfrac{-Z_{11}}{Z_{11}\,Z_{22}-Z_{12}\,Z_{21}}$ $Y_{22}=\dfrac{Z_{11}}{Z_{11}\,Z_{22}-Z_{12}\,Z_{21}}$
	Y-parameters	$S_{11}=\dfrac{(Y_0-Y_{11})(Y_0+Y_{22})+Y_{12}\,Y_{21}}{(Y_0+Y_{11})(Y_0+Y_{22})-Y_{12}\,Y_{21}}$ $S_{12}=\dfrac{-2\,Y_0\,Y_{12}}{(Y_0+Y_{11})(Y_0+Y_{22})-Y_{12}\,Y_{21}}$ $S_{21}=\dfrac{-2\,Y_0\,Y_{21}}{(Y_0+Y_{11})(Y_0+Y_{22})-Y_{12}\,Y_{21}}$ $S_{22}=\dfrac{(Y_0+Y_{11})\,(Y_0-Y_{22})+Y_{12}\,Y_{21}}{(Y_0+Y_{11})\,(Y_0+Y_{22})-Y_{12}\,Y_{21}}$	$Z_{11}=\dfrac{Y_{22}}{Y_{11}\,Y_{22}-Y_{12}\,Y_{21}}$ $Z_{12}=\dfrac{-Y_{12}}{Y_{11}\,Y_{22}-Y_{12}\,Y_{21}}$ $Z_{21}=\dfrac{-Y_{21}}{Y_{11}\,Y_{22}-Y_{12}\,Y_{21}}$ $Z_{22}=\dfrac{Y_{11}}{Y_{11}\,Y_{22}-Y_{12}\,Y_{21}}$	
Z_0 is the characteristic impedance and Y_0 is the characteristic admittance used as the reference for the S-parameters (Z_0 is typically 50 Ω).				

It is possible to deduce common-mode and differential-mode parameters from the two-port parameters. Common-mode parameters consider that the two ports (DI_1 and DI_2) are connected together directly without any additional components. However, their use is not suited to immunity simulations based on, for example, DPI measurements according to IEC 62132-4. In this case the disturbing signal is fed from a single signal generator to each DI via a coupling network, typically a coupling capacitor. This capacitor, as well as any other passive components, PCB tracks, etc., shall be included in the simulation as shown in Figure C.4.

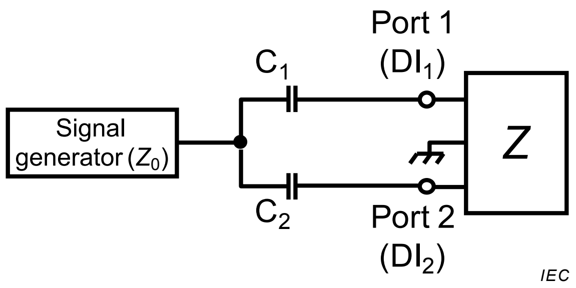


Figure C.4 – Simulation of common-mode injection on a differential DI based on DPI

In the case where the coupling networks are considered to have a negligible effect on the signals (loss and mismatching), the two DIs can be considered to be directly connected together. The equivalent common-mode impedance (Z_E) of the two DIs connected together is shown in Figure C.5 and is given by:

$$Z_E = \frac{Z_{11}\,Z_{22} - Z_{12}\,Z_{21}}{Z_{11} - Z_{12} - Z_{21} + Z_{22}}$$

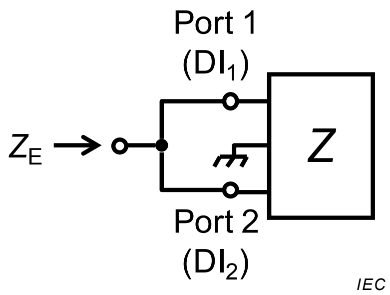


Figure C.5 – Equivalent common-mode input impedance of a differential DI

The transmitted power can then be calculated using the method described above for a single-ended DI, replacing Z_{11} by Z_E.

Other parameters can be used with the conversions given in Tables C.2 and C.3.

In the case where the coupling network is lossy or introduces a significant mismatch, the contribution to the transmitted power of each DI and its associated coupling network shall be determined. This can be carried out by simulation when the coupling networks have been suitably modelled (discrete RLC or file-based). A typical simulation setup using a file-based two-port element is shown in Figure C.6. The currents I_1 and I_2 and the voltages V_1 and V_2 have complex values.

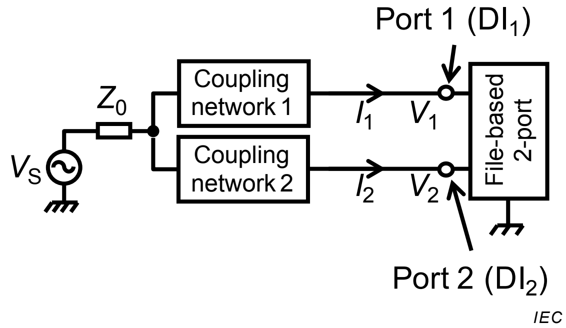


Figure C.6 – Determination of transmitted power for a differential DI

The total transmitted power P_T is the sum of the transmitted powers at each DI given by the complex conjugate product of the voltage and current (both are peak and complex values):

$$P_T = P_{T1} + P_{T2}$$

where

$$P_{T1} = \frac{\mathrm{Re}\left[V_1\, I_1^*\right]}{2}$$

$$P_{T2} = \frac{\mathrm{Re}\left[V_2\, I_2^*\right]}{2}$$

Therefore,

$$P_T = \frac{\mathrm{Re}\left[V_1\, I_1^*\right]}{2} + \frac{\mathrm{Re}\left[V_2\, I_2^*\right]}{2}$$

Table C.3 shows other possible formulations for the calculation of power.

Table C.3 – Power calculation

Scalar product	$P = \frac{V \times I}{2} = \frac{\lvert V\rvert \lvert I\rvert \cos\varphi}{2}$
Conjugate product	$P = \frac{\mathrm{Re}\left[V\, I^*\right]}{2} = \frac{\mathrm{Re}\left[V^*\, I\right]}{2}$
Sum of conjugate products	$P = \frac{V\, I^* + V^*\, I}{4}$

NOTE The power is always the absolute value of P. V and I are peak values.

The corresponding forward power at the summing point P_F is

$$P_F = \frac{V_S}{8Z_0}$$

The forward and transmitted powers can then be scaled as required.

Annex D
(informative)

Example of ICIM-CI macro-model in CIML format

An example ICIM-CI macro-model of a LIN transceiver is illustrated. The test setup is shown in Figure D.1.

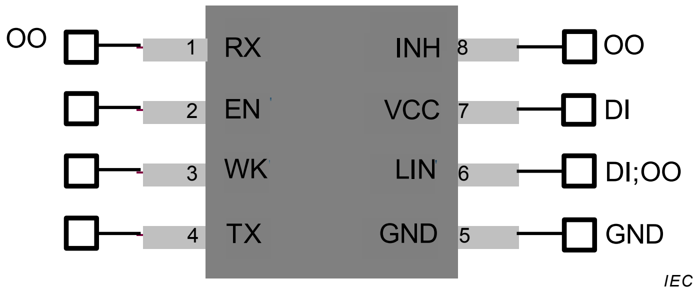


Figure D.1 – Test setup on an example LIN transceiver

The leads VCC and LIN are the DI points and the leads RX, INH and LIN are monitored (OO pins). The PDN of the VCC and LIN pins with respect to the ground (GND) are extracted using conventional two-port *S*-parameter measurements using a power level of –10 dBm. The data is stored in touchstone format (s2p file). Standard pass/fail test is carried out on all OO leads with the following test conditions:

- LIN: ±2,5 V on amplitude and ±5 μs on time
- RX: ±1 V on amplitude and ± 5μs on time
- INH: ±2 V on amplitude

The DPI test is carried out in the frequency band from 1 MHz to 1 GHz, with a maximum power level of 35 dBm.

```
<?xml version="1.0" encoding="UTF-8" ?>
<!-- root element -->
<CImodel>
    <!-- Header section -->
    <Header>
        <Cim_ver>1.0</Cim_ver>
        <Filename>ExampleICIMCI_LINTRCV.ciml</Filename>
        <File_ver>1.0</File_ver>
        <Author>AR,JLL</Author>
        <Dut>LINTRCV</Dut>
        <Date>March 1, 2013</Date>
        <Meas_method>DPI for IB,S for PDN</Meas_method>
    </Header>
    <!-- Lead definitions section -->
    <Lead_definitions>
        <Lead Id="1" Name="RX" Mode="OO"/>
        <Lead Id="2" Name="EN" Mode="None"/>
        <Lead Id="3" Name="WK" Mode="None"/>
        <Lead Id="4" Name="TX" Mode="None"/>
        <Lead Id="5" Name="GND" Mode="GND"/>
        <Lead Id="6" Name="LIN" Mode="DI,OO"/>
        <Lead Id="7" Name="VCC" Mode="DI"/>
        <Lead Id="8" Name="INH" Mode="OO"/>
    </Lead_definitions>
```

```
<!-- Validity section -->
<Validity>
    <Power_supply>12V</Power_supply>
    <Frequency_range>[1MHz - 1GHz]</Frequency_range>
    <Temperature_range>25Celsius</Temperature_range>
    <Notes>WK pin not used</Notes>
</Validity>
<!-- Pdn section -->
<Pdn>
    <!-- PDN of VCC lead, lead 7 and lead 6 -->
    <Lead Id="7,6" Ground_id="5" Meas_type="0">
        <Data_files>
            LINTRCV_VCC_LIN_PDN_S11.s2p
        </Data_files>
    </Lead>
</Pdn>
<!-- Ib section -->
<Ib>
    <!-- IB with injection on VCC lead, id=7 -->
    <Lead Id="7" Ground_id="5" Type="DPI">
        <Max_power_level Value="35dBm"/>
        <!-- Pt section with RX pin id=1 monitoring -->
        <Power Param_order ="Freq,Power" Format="DBMAG">
            <Test_criteria Id="1" Type="PF" Level="+1,-1V"
              Parameter="Amplitude"/>
            <Test_criteria Id="1" Type="PF" Level="+5us,-5us"
              Parameter="Time"/>
            <Unit_power>dBm</Unit_power>
            <Data_files>
                Pt_injVCC_monRX.txt
            </Data_files>
        </Power>
        <!-- Pt section with LIN pin id=6 monitoring -->
        <Power Param_order ="Freq,Power" Format="DBMAG">
            <Test_criteria Id="6" Type="PF" Level="+2.5,-2.5V"
              Parameter="Amplitude"/>
            <Test_criteria Id="6" Type="PF" Level="+5us,-5us"
              Parameter="Time"/>
            <Unit_power>dBm</Unit_power>
            <Data_files>
                Pt_injVCC_monLIN.txt
            </Data_files>
        </Power>
        <!-- Pt section with INH pin id=8 monitoring -->
        <Power Param_order ="Freq,Power" Format="DBMAG">
            <Test_criteria Id="8" Type="PF" Level="+2,-2V"
              Parameter="Amplitude"/>
            <Unit_power>dBm</Unit_power>
            <Data_files>
                Pt_inVCC_monINH.txt
            </Data_files>
        </Power>
    </Lead>
    <!-- IB with injection on LIN lead, id=6 -->
    <Lead Id="6" Ground_id="5" Type="DPI">
        <Max_power_level Value="35dBm"/>
        <!-- Pt section with RX pin id=1 monitoring -->
```

```
            <Power Param_order ="Freq,Power" Format="DBMAG">
                <Test_criteria Id="1" Type="PF" Level="+1,-1V"
                  Parameter="Amplitude"/>
                <Test_criteria Id="1" Type="PF" Level="+5us,-5us"
                  Parameter="Time"/>
                <Unit_power>dBm</Unit_power>
                <Data_files>
                    Pt_injLIN_monRX.txt
                </Data_files>
            </Power>
            <!-- Pt section with LIN pin id=6 monitoring -->
            <Power Param_order ="Freq,Power" Format="DBMAG">
                <Test_criteria Id="6" Type="PF" Level="+2.5,-2.5V"
                  Parameter="Amplitude"/>
                <Test_criteria Id="6" Type="PF" Level="+5us,-5us"
                  Parameter="Time"/>
                <Unit_power>dBm</Unit_power>
                <Data_files>
                    Pt_injLIN_monLIN.txt
                </Data_files>
            </Power>
            <!-- Pt section with INH pin id=8 monitoring -->
            <Power Param_order ="Freq,Power" Format="DBMAG">
                <Test_criteria Id="8" Type="PF" Level="+2,-2V"
                  Parameter="Amplitude"/>
                <Unit_power>dBm</Unit_power>
                <Data_files>
                    Pt_injLIN_monINH.txt
                </Data_files>
            </Power>
        </Lead>
    </Ib>
</CImodel>
```

The S-parameter file (s2p) of the PDN of leads 6 (LIN) and 7 (VCC) with respect to lead 5 (GND) is shown in Figure D.2. The data are plotted in Figure D.3.

```
!Agilent Technologies,E5071C,MY46100659,A.07.02
!Date: Sat Mar 02 18:32:12 2013
!Data & Calibration Information:
!Freq S11:SOLT2(ON)     S21:SOLT2(ON)     S12:SOLT2(ON)     S22:SOLT2(ON)
!Power level = -10dBm
# Hz S RI R 50
1000000   9.088826e-001   2.175112e-001   4.959825e-004   6.047383e-004   6.574008e-004   4.707964e-004   9.970238e-001   -1.280453e-002
1005883   9.100319e-001   2.160977e-001   3.667523e-004   4.291529e-004   4.692485e-004   5.038933e-004   9.965288e-001   -1.213697e-002
1011765   9.110942e-001   2.149672e-001   5.001453e-004   4.813022e-004   5.115158e-004   4.671811e-004   9.963682e-001   -1.206233e-002
1017648   9.118667e-001   2.136258e-001   5.186386e-004   4.979755e-004   4.097934e-004   5.014781e-004   9.962916e-001   -1.233104e-002
1023530   9.126281e-001   2.121370e-001   4.007370e-004   4.883603e-004   4.595826e-004   4.363021e-004   9.961206e-001   -1.215509e-002
1029413   9.129750e-001   2.106546e-001   5.138685e-004   5.250810e-004   4.561012e-004   5.159894e-004   9.959874e-001   -1.183065e-002
1035296   9.137162e-001   2.090587e-001   5.119438e-004   3.894194e-004   5.101221e-004   5.492821e-004   9.954820e-001   -1.179400e-002
1041178   9.144078e-001   2.082734e-001   4.905224e-004   4.767893e-004   3.994730e-004   4.847313e-004   9.958518e-001   -1.173345e-002
1047061   9.151246e-001   2.070623e-001   4.589706e-004   4.264606e-004   5.030998e-004   3.821361e-004   9.958136e-001   -1.195698e-002
1052943   9.160557e-001   2.053582e-001   4.300851e-004   4.108949e-004   5.804027e-004   4.982899e-004   9.953038e-001   -1.160832e-002
1058826   9.166562e-001   2.041133e-001   4.445418e-004   5.454105e-004   4.359303e-004   4.643183e-004   9.956318e-001   -1.149447e-002
1064708   9.173392e-001   2.024838e-001   4.862480e-004   4.914565e-004   4.025683e-004   3.986934e-004   9.954431e-001   -1.174636e-002
1070591   9.179662e-001   2.013367e-001   5.705889e-004   4.615389e-004   4.437831e-004   4.206510e-004   9.954250e-001   -1.153634e-002
1076474   9.187746e-001   2.007750e-001   4.743255e-004   4.577823e-004   4.815595e-004   4.542247e-004   9.953506e-001   -1.164343e-002
1082356   9.197041e-001   1.991275e-001   4.467896e-004   4.437902e-004   5.396881e-004   4.823456e-004   9.949610e-001   -1.182305e-002
1088239   9.199772e-001   1.981008e-001   5.117492e-004   4.715610e-004   5.386433e-004   5.815802e-004   9.952103e-001   -1.154153e-002
1094121   9.202774e-001   1.968339e-001   4.872734e-004   5.007612e-004   4.675922e-004   4.311077e-004   9.949859e-001   -1.161092e-002
1100004   9.214074e-001   1.959012e-001   4.741500e-004   3.814384e-004   5.041462e-004   5.543353e-004   9.952264e-001   -1.154271e-002
1105887   9.217450e-001   1.943473e-001   4.086109e-004   4.633820e-004   4.056057e-004   4.609901e-004   9.949360e-001   -1.147551e-002
...
```

IEC

Figure D.2 – PDN data in touchstone format (s2p), data measured using VNA

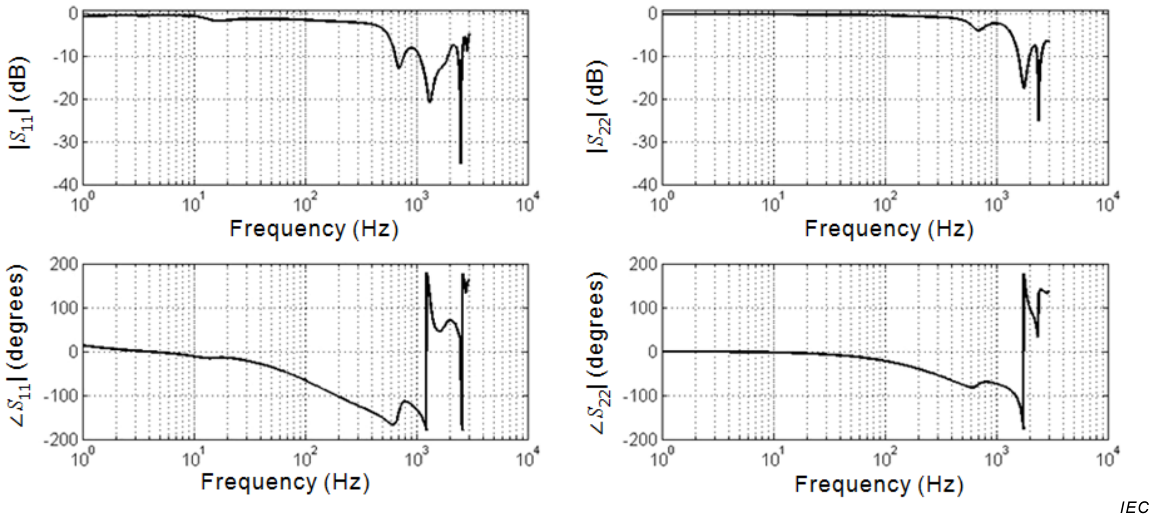


Figure D.3 – PDN data of leads 6 (LIN) and 7 (VCC)

The measured IB data for injection on VCC pin (lead 7), for different OO pins that are monitored, are shown in Figure D.4 and the traces are plotted in Figure D.5.

!f(Hz)	Pt(W)
!Monitoring	on RX
1000000	0.1210474359
2000000	0.004227117987
3000000	0.002897663639
4000000	0.002649712504
5000000	0.00250762503
6000000	0.002345954784
7000000	0.002308431188
8000000	0.002346253032
9000000	0.002633505446
10000000	0.00246788178
15000000	0.008718441842
20000000	0.01087608427
25000000	0.007527113401
30000000	0.007196132914
35000000	0.007041186572
40000000	0.006978506095
45000000	0.007011565952
50000000	0.009056521981
...	

!f(Hz)	Pt(W)
!Monitoring	on LIN
1000000	0.01210474359
2000000	0.004227117987
3000000	0.002897663639
4000000	0.002649712504
5000000	0.00250762503
6000000	0.002345954784
7000000	0.002308431188
8000000	0.002346253032
9000000	0.002633505446
10000000	0.00246788178
15000000	0.008718441842
20000000	0.01087608427
25000000	0.007527113401
30000000	0.007196132914
35000000	0.007041186572
40000000	0.006978506095
45000000	0.007011565952
50000000	0.009056521981
...	

!f(Hz)	Pt(W)
!Monitoring	on INH
1000000	0.1523896931
2000000	0.04227117987
3000000	0.0364794239
4000000	0.02649712504
5000000	0.0250762503
6000000	0.02345954784
7000000	0.02308431188
8000000	0.02346253032
9000000	0.04173824853
10000000	0.03106879086
15000000	0.1739557845
20000000	0.2170064108
25000000	0.1501856571
30000000	0.1140510207
35000000	0.1115952866
40000000	0.1392395023
45000000	0.1398991331
50000000	0.1435362003
...	

IEC

Figure D.4 – IB data in ASCII format (.txt), data measured using DPI method – Injection on VCC pin

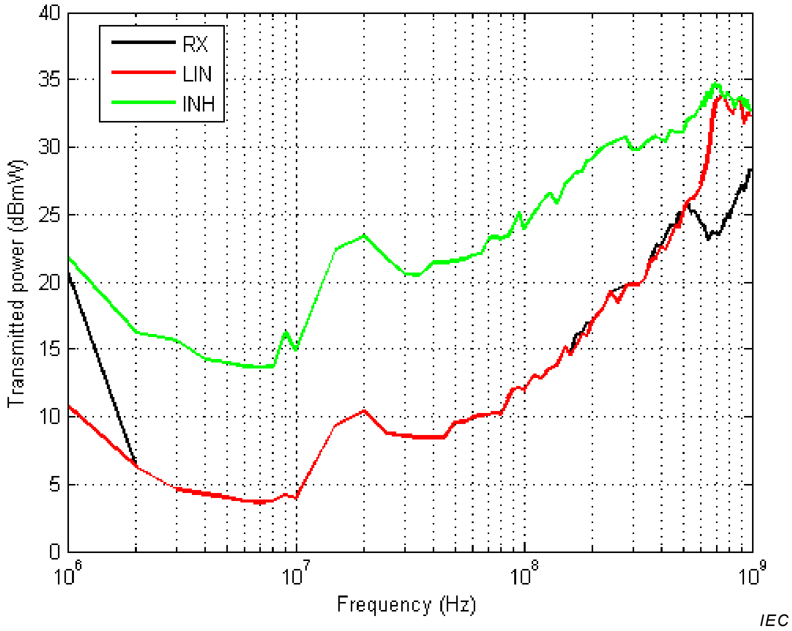


Figure D.5 – IB data for injection on VCC pin

Annex E
(normative)

CIML Valid keywords and usage

E.1 Root element keywords

The keywords shown in Table E.1 are placed at the beginning of the file after the XML definition.

Table E.1 – Root element keywords

Keyword	Parent	Description	Presence	Example
Header	Root element	Specifies a header section.	Required	<Header> … </Header>
Lead_definitions	Root element	Specifies a lead definitions section. The details defined in this section are used for in all other sections.	Required	<Lead_definitions> … </Lead_definitions >
Validity	Root element	Specifies the validity section. The details defined in this section are global to all other sections.	Required	<Validity> … </Validity>
Macromodels	Root element	Specifies a SPICE macro-models section. The details defined in this section can be used in the Pdn section.	Required	<Macromodels> … </Macromodels>
Pdn	Root element	Specifies the PDN data.	Required	<Pdn> … </Pdn>
Ib	Root element	Specifies the IB data.	Required	<Ib> … </Ib>

E.2 File header keywords

The keywords shown in Table E.2 are placed at the beginning of the file after the root element start-tag.

Table E.2 – *Header* section keywords

Keyword	Parent	Description	Presence	Example
Cim_ver	Header element	Specifies the version of file format (1.0). Should follow the header element. Informs parsers of the version of XML exchange format used and allows them to know what keywords to expect.	Required	<Cim_ver>1.0</Cim_ver>
Filename	Header element	Specifies the file name. Normally follows the keyword: Cim_ver.	Required	<Filename> My_file.xml </Filename>
File_ver	Header element	Tracks the revision level of a particular .xml file. Revision level is set at the discretion of the originator of the file.	Required	<File_ver>1.0</File_ver>
Date	Header element	The value can contain blanks, be of any format, but should be limited to a maximum of 20 characters. The month should be spelled out for clarity. The parser considers this information as a data string and does not interpret it.	Optional	<Date> January 1, 2013 </Date>
Author	Header element	The value can contain blanks and be of any format. The parser considers this information as a data string and does not interpret it.	Optional	<Author> Name 1 Name2 </Author>
Dut	Header element	The value can contain blanks and be of any format. The parser considers this information as a data string and does not interpret it.	Optional	<Dut> 32-bit microcontroller </Dut>
Meas_method	Header element	The value can contain blanks and be of any format. The parser considers this information as a data string and does not interpret it.	Optional	<Meas_method> DPI method </Meas_method>
Disclaimer	Header element	The value can contain blanks and be of any format. The parser considers this information as a data string and does not interpret it.	Optional	<Disclaimer> This file contains results of DPI. Other use is not guaranteed </Disclaimer>
Copyright	Header element	The value can contain blanks and be of any format. The parser considers this information as a data string and does not interpret it.	Optional	<Copyright> Copyright 2013, XYZ Corp., All Rights Reserved </Copyright>

E.3 *Validity* section keywords

The keywords shown in Table E.3 are placed in the root element start-tag.

Table E.3 – *Validity* section keywords

Keyword	Parent	Description	Presence	Example
Power_supply	Validity element	Specifies the power supply conditions in which ICIM-CI macro-model is extracted and defined. Should follow the validity element. Informs the user of the ICIM-CI validity criteria. A valid numerical value with units is allowed. See A.2.5.3 for more information.	Required	<Power_supply> 9V </Power_supply>
Frequency_range	Validity element	Specifies the valid frequency range in which ICIM-CI macro-model is extracted and defined. Should follow the validity element. Informs the user of the ICIM-CI validity criteria. A valid numerical value with units is allowed. See A.2.5.3 for more information.	Required	<Frequency_range> [10kHz-100MHz] </Frequency_range>
Temperature_range	Validity element	Specifies the valid temperature range in which ICIM-CI macro-model is extracted and defined. Should follow the validity element. Informs the user of the ICIM-CI validity criteria. A valid numerical value with units is allowed. See A.2.5.3 for more information.	Required	<Temperature_range> 25Celsius </Temperature_range>

E.4 Global keywords

The keywords shown in Table E.4 may be placed anywhere in the file, except within an XML element containing a value.

Table E.4 – Global keywords

Keyword	Parent	Description	Presence	Example
Notes	Any element except those containing a value.	Optionally adds information about the setup, data, etc. The value can contain blanks, and be of any format. A notes section can be inserted anywhere in the file and the number of notes sections in the file is not limited. The parser considers this information as a data string and it does not interpret it.	Optional	<Notes> Use this section for any special notes </Notes>
Documentation	Any element except those containing a value.	Optionally adds the paths to files containing documentation on the project.	Optional	<Documentation> Project doc.pdf Model_descr.doc </Documentation>
Unit	Any element except those containing a value.	Specifies the units of the respective quantity or element.	Optional	<Unit>mm</Unit>

E.5 *Lead* keyword

The keywords shown in Table E.5 may be placed in the *Lead_definitions*, *Pdn* and *Ib* sections as the parent element.

Table E.5 – *Lead* element definition

Keyword	Parent	Description	Presence	Example
Lead	Any element: Lead_definitions, Pdn and Ib	Specifies the Lead element. The accepted attributes could vary from section to section.	Required	<Lead> … </Lead>

E.6 *Lead_definitions* section attributes

The *Lead* keyword in the *Lead_definitions* section has the following valid attributes (see Table E.6):

Table E.6 – *Lead_definitions* section keywords

Keyword	Parent	Description	Presence	Example
Id	Lead element	Specifies the identity or number of the Lead element. Only one value is allowed.	Required	<Lead Id="1"> … </Lead>
Name	Lead element	Specifies the name of the lead element. Can be any valid string.	Optional	<Lead Id="1" Name="VCC"> … </Lead>
Mode	Lead element	Specifies the mode in which a particular pin is used: DI, DO, OO, GND. Multiple modes are separated by a "," character.	Optional	<Lead Id="1" Name="VCC" Mode="DI"> … </Lead>
Type	Lead element	Specifies the type in which a particular pin is used: internal, external.	Optional	<Lead Id="1" Name="VCC" Mode="DI" Type="external"> … </Lead>

E.7 *Macromodels* section attributes

The *Subckt* keyword in the *Macromodels* section has the following valid attributes (see Table E.7):

Table E.7 – *Macromodels* section keywords

Keyword	Parent	Description	Presence	Example
Name	Subckt element	Specifies the name of the SPICE like macro-model.	Required	<Subckt Name="MD1" …> … </Subckt>
Nodes	Subckt element	Specifies the external nodes of the SPICE like macro-model through which the sub-circuit connects to the main circuit.	Required	<Subckt Name="MD1" Nodes="N1,N2,N3"> … </Subckt>
Kind	Subckt element	Specifies the kind of netlist used for defining the SPICE like sub-circuit. See 6.6 for more information.	Optional	< Subckt Name="MD1" Nodes="N1,N2,N3" Kind="SPICE3"> … </Subckt>
Data_files	Subckt element	Specifies the path names of the files containing a sub-circuit netlist. The path names are separated by a space character (" ") or a line termination. The file names and paths shall conform to A.2.4.2 and A.2.4.3.	Optional	< Subckt Kind="SPICE3"> … <Data_files> PDN_Pin1_macro.lib </Data_files> … </Subckt>

E.8 *Pdn* section keywords

E.8.1 *Lead* element keywords

The PDN data of each tested lead are defined within the *Lead* tag. The *Lead* keyword in the *Pdn* section has the following valid attributes (see Table E.8):

Table E.8 – *Lead* element keywords in the *Pdn* section

Keyword	Parent	Description	Presence	Example
Id	Lead element	Specifies the identity or number of the Lead element. One or many Ids are allowed for differentiating between single, differential or multi-ended pins. For differential or multi-ended pins, Ids shall be separated by a "," character.	Required	<Lead Id="1"…> … </Lead> <Lead Id="1,2,3"…> … </Lead>
Ground_id	Lead element	Specifies the identity or number of the return signal lead. Only one id is allowed.	Required for Type="S" or "Z" or "Y"	<Lead Id="1" Ground_id="7" …> … </Lead> <Lead Id="1,2,3" Ground_id="7" …> … </Lead>
Blockname	Lead element	Specifies the name of the PDN block.	Optional	<Blockname> Block1_PDN </Blockname>
Type	Lead element	Specifies the type of PDN data: "S" for S-parameters, "Z" for Z-parameters, "Y" for Y-parameters, "Ckt" for circuit definition. See 6.8.2.4.	Optional	<Lead Id="1" Type="Z"> … </Lead>
Param_order	Lead element	Specifies the order in which the PDN parameters are defined. See 6.8.2.5 for detailed information. Undefined if using Data_files in touchstone format and netlist based PDN description.	Optional Undefined if Type="Ckt"	<Lead Id="1" Type="Z" Param_order="Freq,Z11"> … </Lead>
Format	Lead element	Specifies the PDN data format. See 6.8.2.6. Undefined if using Data_files in touchstone format and netlist based PDN description.	Optional	<Lead Id="1" Type="Z" Param_order="Freq,Z11" Format="MA"> … </Lead>

Keyword	Parent	Description	Presence	Example
Meas_type	Lead element	Specifies the method implemented for performing PDN measurements. See 6.8.2.7 and 7.3.2. Undefined if using netlist for describing the PDN.	Optional	<Lead Id="1" Type="S" Param_order="Freq,S21" Format="MA" Meas_type="1"> … </Lead>
Reference_impedance	Lead element	Specifies the reference impedance used in performing PDN measurements. Undefined if using netlist for describing the PDN.	Optional	<Lead Id="1" Type="S" Param_order="Freq,S11" Format="MA" Reference_impedance="50ohm"> … </Lead>
Use	Lead element	Specifies one of the parameters defined in Param_order, except the frequency term, which is to be specifically used. See 6.8.2.9. Undefined if using netlist for describing the PDN.	Optional	<Lead Id="1" Type="S" Param_order="Freq,S21" Format="MA" Meas_type="1" Use="S21"> … </Lead>
Netlist	Lead element	Specifies the electrical connectivity of the PDN elements in circuit form using SPICE type data statements.	Required if Type="Ckt"	<Lead Id="1" Type="Ckt"> … <Netlist> …. </Netlist> … </Lead>
Unit_freq	Lead element	Specifies the units of the frequencies used for specifying the PDN. The value shall conform to A.2.5.5. If this keyword is omitted, the units are assumed to be SI units. Undefined if using netlist for describing the PDN and Data_files in touchstone format.	Optional	<Lead Id="1" Type="S"> <Unit_freq> MHz </Unit_freq> … </Lead>
Unit_param	Lead element	Specifies the units of the parameters used for specifying the PDN. The value shall conform to A.2.5.5. If this keyword is omitted, the units are assumed to be SI units. Undefined if using netlist for describing the PDN and Data_files in touchstone format.	Optional Undefined if Type="Ckt"	<Lead Id="1" Type="S"> <Unit_param> dB </Unit_param> … </Lead>

Keyword	Parent	Description	Presence	Example
Power_level	Lead element	Specifies the power level used for obtaining the PDN data. The value shall conform to A.2.5.3 and should carry both the value and units together. If no units are found, SI units are assumed. Undefined if using netlist for describing the PDN and Data_files.	Required	<Lead Id="1" Type="S"> <Power_level> -10dBm </Power_level> … </Lead>
Data_files	Lead element	Specifies the path names of the files containing a list of PDN data. The path names are separated by a space character (" ") or a line termination. The file names and paths shall conform to A.2.4.2 and A.2.4.3. Only one Data_files keyword or one List keyword shall be included in the Pdn section.	Required if not List	<Lead Id="1" Type="S"> … <Data_files> Pdn_pin1_S11.txt </Data_files> … </Lead>
List	Lead element	Specifies a list of PDN data entries in the model.	Required if not Data_files	<Lead Id="1" Type="S"> … <List> … </List> … </Lead>

E.8.2 *Netlist* section keywords

The keywords shown in Table E.9 may be placed in the *Netlist* section under the *Pdn* tag as the parent element.

Table E.9 – Netlist section keywords

Keyword	Parent	Description	Presence	Example
Kind	Netlist element	Specifies the kind of netlist used for defining the PDN. See 6.8.3.4 for more information.	Optional	<Netlist Kind="SPICE3"> R1 1 10 1e3 … </Netlist>
Data_files	Netlist element	Specifies the path names of the files containing a netlist. The path names are separated by a space character (" ") or a line termination. The file names and paths shall conform to A.2.4.2 and A.2.4.3. Only one Data_files keyword shall be used.	Optional	< Netlist Kind="SPICE3"> … <Data_files> PDN_Pin1.net </Data_files> … </Netlist>

E.9 *Ibc* section keywords

E.9.1 *Lead* element keywords

The IBC data of each tested lead are defined within the *Lead* tag, similar to the *PDN*. The *Lead* keyword in the *Ibc* section has the following valid attributes (see Table E.10):

Table E.10 – *Lead* element keywords in the *Ibc* section

Keyword	Parent	Description	Presence	Example
Id	Lead element	Specifies the identity or number of the Lead element. One or many Ids are allowed for differentiating between single, differential or multi-ended pins. For differential or multi-ended pins, Ids shall be separated by a "," character.	Required	<Lead Id="1 2"…> … </Lead> <Lead Id="1,2,3"…> … </Lead>
Blockname	Lead element	Specifies the name of the IBC block.	Optional	<Blockname> Block1_IBC </Blockname>
Type	Lead element	Specifies the type of IBC data: "S" for S-parameters, "Z" for Z-parameters, "Y" for Y-parameters, "Ckt" for circuit definition. See 6.8.2.4.	Optional	<Lead Id="1 2" Type="Z"> … </Lead>

Keyword	Parent	Description	Presence	Example
Param_order	Lead element	Specifies the order in which the IBC parameters are defined. See 6.8.2.5 for detailed information. Undefined if using Data_files in touchstone format and netlist based IBC description.	Optional Undefined if Type="Ckt"	<Lead Id="1 2" Type="Z" Param_order="Freq,Z11"> … </Lead>
Format	Lead element	Specifies the IBC data format. See 6.8.2.6. Undefined if using Data_files in touchstone format and netlist based IBC description.	Optional	<Lead Id="1 2" Type="Z" Param_order="Freq,Z11" Format="MA"> … </Lead>
Meas_type	Lead element	Specifies the method implemented for performing IBC measurements. See 6.8.2.7 and 7.3.2. Undefined if using netlist for describing the IBC.	Optional	<Lead Id="1 2" Type="S" Param_order="Freq,S21" Format="MA" Meas_type="1"> … </Lead>
Reference_impedance	Lead element	Specifies the reference impedance used in performing PDN measurements. Undefined if using netlist for describing the IBC.	Optional	<Lead Id="1 2" Type="S" Param_order="Freq,S11" Format="MA" Reference_impedance="50 ohm"> … </Lead>
Use	Lead element	Specifies one of the parameters defined in Param_order, except the frequency term, that is to be specifically used. See 6.8.2.9. Undefined if using netlist for describing the IBC.	Optional	<Lead Id="1 2" Type="S" Param_order="Freq,S21" Format="MA" Meas_type="1" Use="S21"> … </Lead>
Netlist	Lead element	Specifies the electrical connectivity of the IBC elements in circuit form using SPICE type data statements.	Required if Type="Ckt"	<Lead Id="1 2" Type="Ckt"> … <Netlist> …. </Netlist> … </Lead>
Unit_freq	Lead element	Specifies the units of the frequencies used for specifying the IBC. The value shall conform to A.2.5.5. If this keyword is omitted, the units are assumed to be SI units. Undefined if using netlist for describing the IBC and Data_files in touchstone format.	Optional	<Lead Id="1 2" Type="S"> <Unit_freq> MHz </Unit_freq> … </Lead>

Keyword	Parent	Description	Presence	Example
Unit_param	Lead element	Specifies the units of the parameters used for specifying the IBC. The value shall conform to A.2.5.5. If this keyword is omitted, the units are assumed to be SI units. Undefined if using netlist for describing the IBC and Data_files in touchstone format.	Optional Undefined if Type="Ckt"	<Lead Id="1 2" Type="S"> <Unit_param> dB </Unit_param> … </Lead>
Power_level	Lead element	Specifies the power level used for obtaining the IBC data. The value shall conform to A.2.5.5 and should carry both the value and units together. If no units are found, SI units are assumed. Undefined if using netlist for describing the IBC and Data_files.	Required	<Lead Id="1 2" Type="S"> <Power_level> -10dBm </Power_level> … </Lead>
Data_files	Lead element	Specifies the path names of the files containing a list of IBC data corresponding to the IBC section. The path names are separated by a space character (" ") or a line termination. The file names and paths shall conform to A.2.4.2 and A.2.4.3. Only one Data_files keyword shall be included in the Ibc section.	Required if not List	<Lead Id="1 2" Type="S"> … <Data_files> Pdn_pin1_S11.txt </Data_files> … </Lead>
List	Lead element	Specifies a list of IBC data entries in the model.	Required if not Data_files	<Lead Id="1 2" Type="S"> … <List> … </List> … </Lead>

E.9.2 *Netlist* section keywords

The keywords defined in Table E.9 may be placed in the *Netlist* section under the *Ibc* tag as the parent element.

E.10 *Ib* section keywords

E.10.1 *Lead* element keywords

The IB data of each tested lead defined within the *Lead* tag. The *Lead* keyword in the *Ib* section has the following valid attributes (see Table E.11):

Table E.11 – *Lead* element keywords in the *Ib* section

Keyword	Parent	Description	Presence	Example
Id	Lead element	Specifies the identity or number of the Lead element. One or many Ids are allowed for differentiating between single, differential or multi-ended pins. For differential or multi-ended pins, Ids shall be separated by a "," character.	Required	<Lead Id="1"…> … </Lead> <Lead Id="1,2,3"…> … </Lead>
Ground_id	Lead element	Specifies the identity or number of the return signal lead. Only one id is allowed.	Required	<Lead Id="1" Ground_id="7" …> … </Lead> <Lead Id="1,2,3" Ground_id="7" …> … </Lead>
Blockname	Lead element	Specifies the name of the IB block.	Optional	<Blockname> Block1 </Blockname>
Type	Lead element	Specifies the type of IB data: "DPI" for DPI based measurements.	Required	<Lead Id="1" Type="DPI"> … </Lead>
Max_power_level	Lead element	Specifies the maximum injected power on to the lead id of interest. See E.10.2 for more details.	Optional	<Lead Id="1" Type="DPI" > <Max_power_level> … </Max_power_level> … </Lead>
Voltage	Lead element	Specifies the IB data as a voltage quantity. See E.10.3.	Required if not Current, Power	<Lead Id="1" Type="DPI" > <Voltage…> … </Voltage> … </Lead>
Current	Lead element	Specifies the IB data as a current quantity. See E.10.4.	Required if not Voltage, Power	<Lead Id="1" Type="DPI" > <Current…> … </Current> … </Lead>

Keyword	Parent	Description	Presence	Example
Power	Lead element	Specifies the IB data as a transmission power quantity. See E.10.5.	Required if not Voltage, Current	<Lead Id="1" Type="DPI" > <Power…> … </Power> … </Lead>

E.10.2 *Max_power_level* section keywords

The keywords shown in Table E.12 may be placed in the *Max_power_level* section under the *Lead* tag as the parent element (within the *Ib* section).

Table E.12 – *Max_power_level* section keywords

Keyword	Parent	Description	Presence	Example
Value	Max_power_level element	Specifies the power level used for obtaining the PDN data. The value shall conform to A.2.5.5 and should carry both the value and units together. If no units are found, SI units are assumed.	Required	<Max_power_level> <Value>35dBm</Value> </Max_power_level> or <Max_power_level Value="35dBm"/>
Start_freq	Max_power_level element	Specifies the start frequency of the band in which the maximum power level is defined. The value shall conform to A.2.5.5 and should carry both the value and units together. If no units are found, SI units are assumed.	Optional	<Max_power_level Value="35dBm" Start_freq="1MHz" … />
Stop_freq	Max_power_level element	Specifies the stop frequency of the band in which the maximum power level is defined. The value shall conform to A.2.5.5 and should carry both the value and units together. If no units are found, SI units are assumed.	Optional	<Max_power_level Value="35dBm" Start_freq="1MHz" Stop_freq="10MHz" … /> <Max_power_level Value="25dBm" Start_freq="11MHz" Stop_freq="100MHz" … />

E.10.3 *Voltage* section keywords

The keywords shown in Table E.13 may be placed in the *Voltage* section under the *Lead* tag as the parent element (within the *Ib* section).

Table E.13 – *Voltage* section keywords

Keyword	Parent	Description	Presence	Example
Test_criteria	Voltage element	Specifies the test conditions for obtaining the IB data. See E.10.6.	Required	<Voltage> <Test_criteria .../> </Voltage>
Param_order	Voltage element	Specifies the order in which the IB voltage quantity is defined. See 6.10.2.8 for detailed information.	Optional	<Voltage Param_order="Freq,voltage "> … </Voltage>
Format	Voltage element	Specifies the data format for the voltage parameter. See 6.10.2.9.	Optional	<Voltage Param_order="Freq,voltage " Format="MAG"> … </Voltage>
Unit_freq	Voltage element	Specifies the units of the frequencies used for specifying the IB voltage quantity. The value shall conform to A.2.5.5. If this keyword is omitted, the units are assumed to be SI units.	Optional	<Voltage Param_order="Freq,voltage " Format="MAG"> <Unit_freq> kHz </Unit_freq> … </Voltage>
Unit_voltage	Voltage element	Specifies the voltage units of IB data. The value shall conform to A.2.5.5. If this keyword is omitted, the units are assumed to be SI units.	Optional	<Voltage Param_order="Freq,voltage " Format="MAG"> <Unit_voltage> dB </Unit_voltage> … </Voltage>
Data_files	Voltage element	Specifies the path names of the files containing a list of IB data as a voltage quantity. The path names are separated by a space character (" ") or a line termination. The file names and paths shall conform to A.2.4.2 and A.2.4.3. Only one Data_files keyword shall be included in the Voltage section.	Required if not List	<Voltage Param_order="Freq,voltage " Format="MA"> … <Data_files> Ib_voltage_pin1.dat </Data_files> … </Voltage>

Keyword	Parent	Description	Presence	Example
List	Voltage element	Specifies a list of IB voltage data entries in the model. Only one List keyword shall be used.	Required if not Data_files	<Voltage Param_order="Freq,voltage" Format="MA"> … <List> … </List> … </Voltage>

E.10.4 *Current* section keywords

The keywords shown in Table E.14 may be placed in the *Current* section under the *Lead* tag as the parent element (within the *Ib* section).

Table E.14 – *Current* section keywords

Keyword	Parent	Description	Presence	Example
Test_criteria	Current element	Specifies the test conditions for obtaining the IB data. See E.10.6.	Required	<Current> <Test_criteria …/> </Current>
Param_order	Current element	Specifies the order in which the IB current quantity is defined. See 6.10.2.8 for detailed information.	Optional	<Current Param_order="Freq,voltage"> … </Current>
Format	Current element	Specifies the data format for the current parameter. See 6.10.2.9.	Optional	<Current Param_order="Freq,Current" Format="MAG"> … </Current>
Unit_freq	Current element	Specifies the units of the frequencies used for specifying the IB Current quantity. The value shall conform to A.2.5.5. If this keyword is omitted, the units are assumed to be SI units.	Optional	<Current Param_order="Freq,Current" Format="MAG"> <Unit_freq> kHz </Unit_freq> … </Current>
Unit_current	Current element	Specifies the current units of IB data. The value shall conform to A.2.5.5. If this keyword is omitted, the units are assumed to be SI units.	Optional	<Current Param_order="Freq,Current" Format="MAG"> <Unit_current> dB </Unit_current> … </Current>

Keyword	Parent	Description	Presence	Example
Data_files	Current element	Specifies the path names of the files containing a list of IB data as a current quantity. The path names are separated by a space character (" ") or a line termination. The file names and paths shall conform to A.2.4.2 and A.2.4.3. Only one Data_files keyword shall be included in the Current section.	Required if not List	<Current Param_order="Freq,Current " Format="MA"> … <Data_files> Ib_current_pin1.dat </Data_files> … </Current>
List	Current element	Specifies a list of IB current data entries in the model. Only one List keyword shall be used.	Required if not Data_files	<Current Param_order="Freq,Current " Format="MA"> … <List> … </List> … </Current>

E.10.5 *Power* section keywords

The keywords shown in Table E.15 may be placed in the *Power* section under the *Lead* tag as the parent element (within the *Ib* section).

Table E.15 – *Power* section keywords

Keyword	Parent	Description	Presence	Example
Test_criteria	Power element	Specifies the test conditions for obtaining the IB data. See E.10.6.	Required	<Power> <Test_criteria …/> </Power>
Param_order	Power element	Specifies the order in which the IB power quantity is defined. See 6.10.2.8 for detailed information.	Optional	<Power Param_order="Freq,voltage "> … </Power>
Format	Power element	Specifies the data format for the power parameter. See 6.10.2.9.	Optional	<Power Param_order="Freq,Power" Format="MAG"> … </Power>
Unit_freq	Power element	Specifies the units of the frequencies used for specifying the IB Power quantity. The value shall conform to A.2.5.5. If this keyword is omitted, the units are assumed to be SI units.	Optional	<Power Param_order="Freq,Power" Format="MAG"> <Unit_freq> kHz </Unit_freq> … </Power>

Keyword	Parent	Description	Presence	Example
Unit_power	Power element	Specifies the power units of IB data. The value shall conform to A.2.5.5. If this keyword is omitted, the units are assumed to be SI units.	Optional	<Power Param_order="Freq,Power" Format="MAG"> <Unit_power> dB </Unit_power> … </Power>
Data_files	Power element	Specifies the path names of the files containing a list of IB data as a power quantity. The path names are separated by a space character (" ") or a line termination. The file names and paths shall conform to A.2.4.2 and A.2.4.3. Only one Data_files keyword shall be included in the Power section.	Required if not List	<Power Param_order="Freq,Power" Format="MA"> … <Data_files> Ib_power_pin1.dat </Data_files> … </Power>
List	Power element	Specifies a list of IB power data entries in the model. Only one List keyword shall be used.	Required if not Data_files	<Power Param_order="Freq,Power" Format="MA"> … <List> … </List> … </Power>

E.10.6 *Test_criteria* section keywords

The keywords shown in Table E.16 may be placed in the *Voltage*, *Current* and *Power* sections under the *Lead* tag as the parent element (within the *Ib* section).

Table E.16 – *Test_criteria* section keywords

Keyword	Parent	Description	Presence	Example
Id	Test_criteria element	Specifies the identity or number of the monitored Lead element (OO). Only one Id is allowed per definition.	Required	<Test_criteria Id="10"/>
Ground_id	Test_criteria element	Specifies the identity or number of the return signal lead used for referencing the OO. Only one Id is allowed per definition. If absent, the top-level Ground_id in IB section is used.	Optional	< Test_criteria Id="10" Ground_id="7"/>
Type	Test_criteria element	Specifies the type of test conducted: either pass/fail or non pass/fail. See 6.10.2.7 for more information	Required	<Test_criteria Id="10" Type="PF"/>
Level	Test_criteria element	Specifies the tolerance level set on the monitored lead during the tests. The value shall conform to A.2.5.5 and should carry both the value and units together. If no units are found, SI units are used. See 6.10.2.7 for more information. For more than one levels, the values shall be separated by a comma ",".	Optional	<Test_criteria Id="10" Type="PF" Level="100mV"/> or <Test_criteria Id="10" Type="PF" Level="+100mV, -100mV "/>
Parameter	Test_criteria element	Specifies the parameter on which the test condition is set. See 6.10.2.7 for more information.	Optional	<Test_criteria Id="10" Type="PF" Level="100mV" Parameter="Amplitude"/>

Annex F
(informative)

PDN impedance measurement methods using vector network analyzer

F.1 General

When using VNA for S-parameter measurements (and Z- or Y-parameters), certain procedures need to be followed rigorously for obtaining precise results as per CISPR 17. These methods are described briefly below with the use of a two-port VNA. Nevertheless, these methods can be extended to four-port VNA.

F.2 Conventional one-port method

The simplest equivalent circuit model for one-port of a VNA connected to the pin under test (DUT) is shown in Figure F.1.

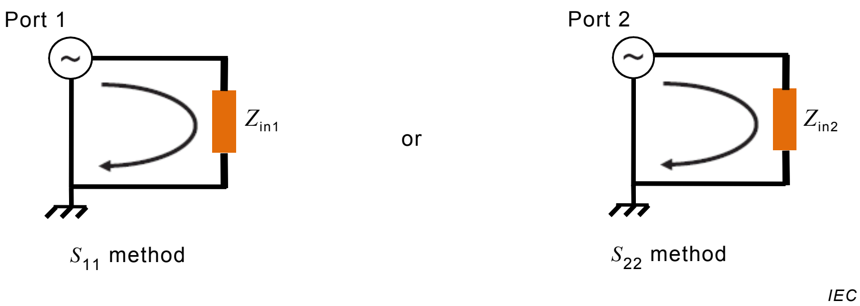


Figure F.1 – Conventional one-port S-parameter measurement

Depending on the exciting port (Port 1 or Port 2), S_{11} or S_{22} represents the impedance of the pin (Z_{in1} or Z_{in2} respectively). For example, Z_{in1} can be obtained from S_{11} using

$$Z_{in1} = Z_0 \frac{1+S_{11}}{1-S_{11}},$$

where Z_0 is the characteristic impedance of Port 1, which is 50 Ω in most cases.

F.3 Two-port method for low impedance measurement

In order to measure low impedance accurately ($Z_{in} << Z_0$), the pin under test shall be placed parallel to the two-VNA ports as shown in Figure F.2. This configuration is called shunt connection.

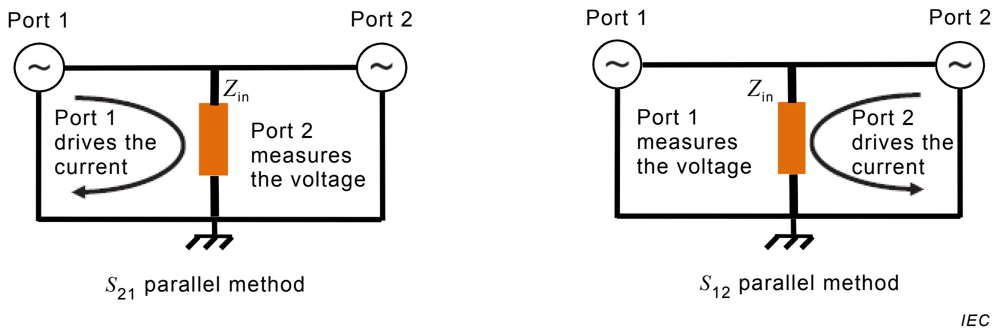


Figure F.2 – Two-port method for low impedance measurement

In this two-port method, S_{11} and S_{22} see the impedance of the pin under test, with a Z_0 impedance shunting across it, from the other port. The information contained in the return loss measurements is clouded by the low impedance of the pin and the additional Z_0 shunt from the other port. However, S_{21} or S_{12} has much more valuable information about the impedance of the pin under test.

For example, Z_{in} can be obtained from S_{21} using

$$Z_{in} = Z_0 \frac{S_{21}}{2(1 - S_{21})}$$

F.4 Two-port method for high impedance measurement

In order to measure high impedance ($Z_{in} >> Z_0$) accurately, the pin under test shall be placed in series to the two-VNA ports as shown in Figure F.3. This is also called series connection.

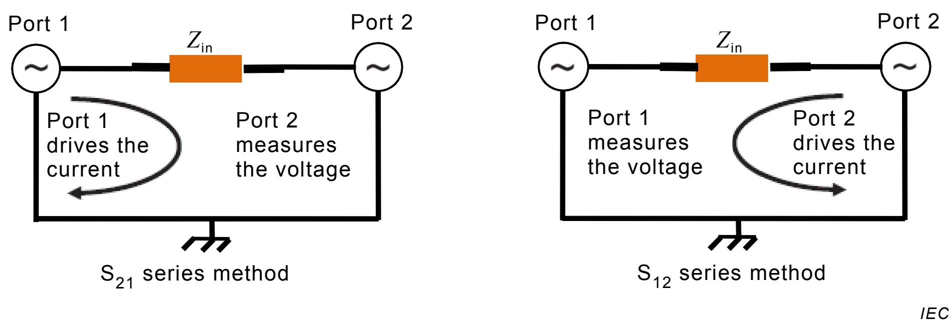


Figure F.3 – Two-port method for high impedance measurement

In this two-port method, S_{11} and S_{22} see the impedance of the DUT, with a Z_0 impedance in series, from the other port. However, S_{21} or S_{12} has much more valuable information about the impedance of the pin under test.

$$Z_{in} = Z_0 \frac{2(1 - S_{21})}{S_{21}}$$

Annex G
(informative)

RFIP measurement method description

G.1 General

The RFIP (RF injection probe) method is derived from the DPI test method. The probe applies the disturbance using an RF generator and measures the voltage across the DUT (V_1 and V_{DUT}). The I_{DUT}, P_{DUT} and Z_{DUT} parameters are then computed. An oscilloscope is used to measure V_1 and V_{DUT} in the time domain. The setup is shown in Figure G.1. All the computation is performed in frequency domain thanks to a processing performed with a software tool.

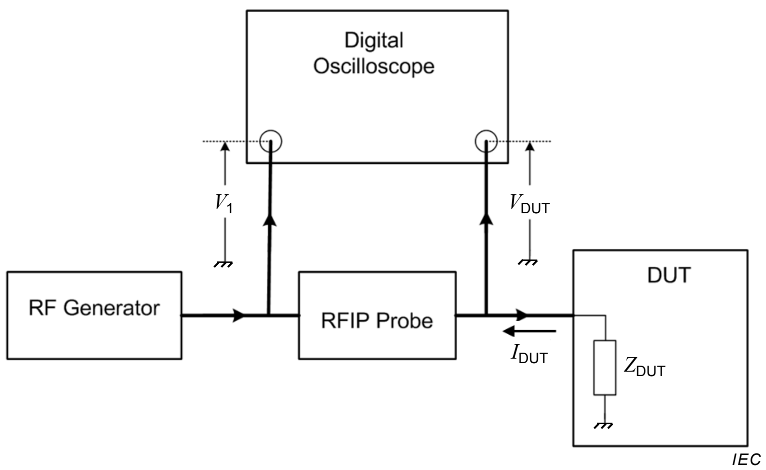


Figure G.1 – Test setup of the RFIP measurement method derived from DPI method

G.2 Obtaining immunity parameters

Obtaining the immunity parameters is very straightforward using the RFIP technique. This method is based on the current and voltage measurements as shown in Figure G.2.

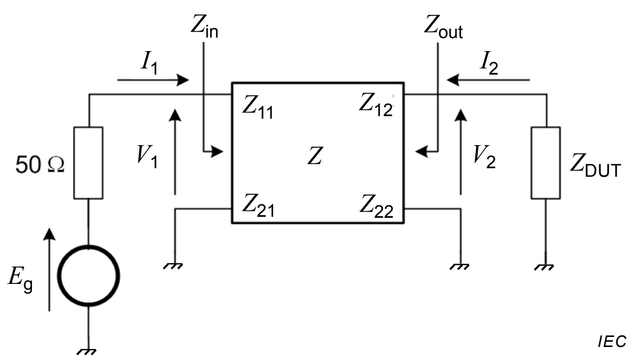


Figure G.2 – Principle of the RFIP measurement method

The RFIP probe is defined by the Z-matrix characterized by two-port measurements. All the key electrical parameters, namely I_{DUT}, P_{DUT} and Z_{DUT} can be computed based on the measurement of the voltages V_{DUT} and V_1.

The general equation of Z_{in} is:

$$Z_{\text{in}} = Z_{11} - \frac{Z_{12}\,Z_{21}}{Z_{22} + Z_{\text{DUT}}}$$

First of all, E_{g}, the amplitude of the noise generator, has to be determined by leaving Z unloaded (Z_{DUT} = ∞):

$$Z_{\text{in}} = Z_{11}$$

E_{g} is then obtained using:

$$E_{\text{g}} = \frac{Z_{11} + 50}{Z_{11}}$$

Z_{DUT} is then computed using:

$$Z_{\text{DUT}} = \frac{Z_{12}\,Z_{21}}{Z_{11} - Z_{\text{in}}} - Z_{22}$$

Then I_{DUT} is computed:

$$I_{\text{DUT}} = \frac{V_{\text{DUT}}}{Z_{\text{DUT}}}$$

And finally the active power is obtained:

$$\text{P}_{\text{T}} = \frac{1}{2}\text{Re}\left[\frac{V_{\text{DUT}} V_{\text{DUT}}^{*}}{Z_{\text{DUT}}}\right] = \frac{1}{2}\text{Re}\left[I_{\text{DUT}}\, I_{\text{DUT}}^{*}\, Z_{\text{DUT}}\right]$$

Annex H
(informative)

Immunity simulation with ICIM model based on pass/fail test

H.1 ICIM-CI macro-model of a voltage regulator IC

H.1.1 General

An application example is illustrated using a voltage regulator IC, with SOIC-8 package. The ICIM-CI macro-model is extracted with the topology shown in Figure H.1; the IC is put in its nominal (stable) operating conditions. In this application, V_{out} is designated as a potential DO pin and is also monitored (OO) while RF injection is done on the V_{CC} pin (DI).

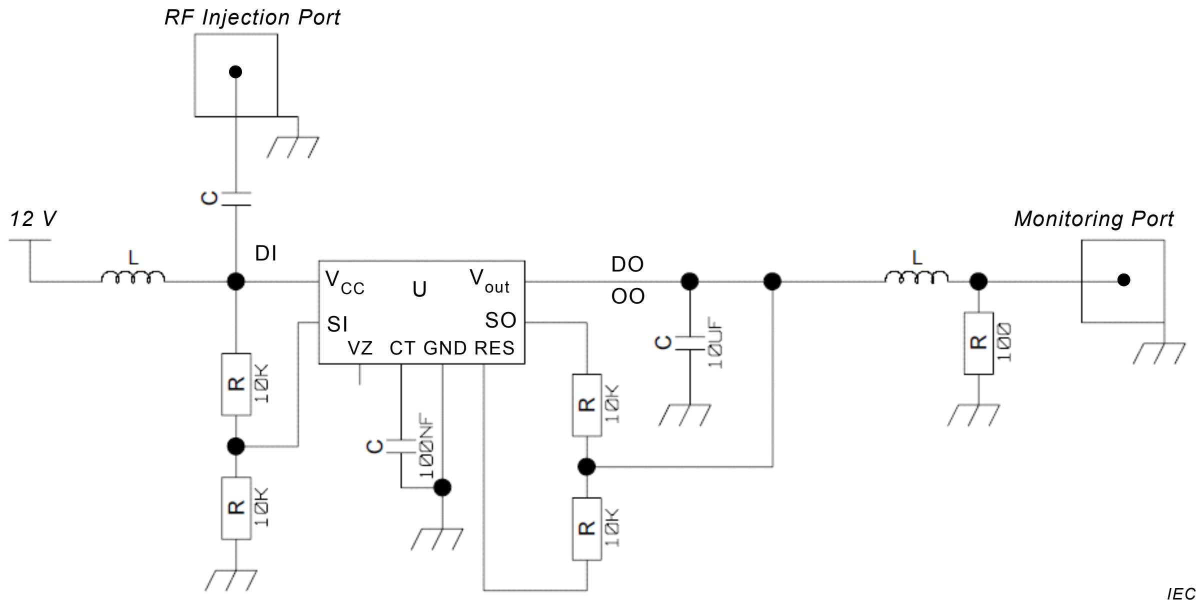


Figure H.1 – Electrical schematic for extracting the voltage regulator's ICIM-CI

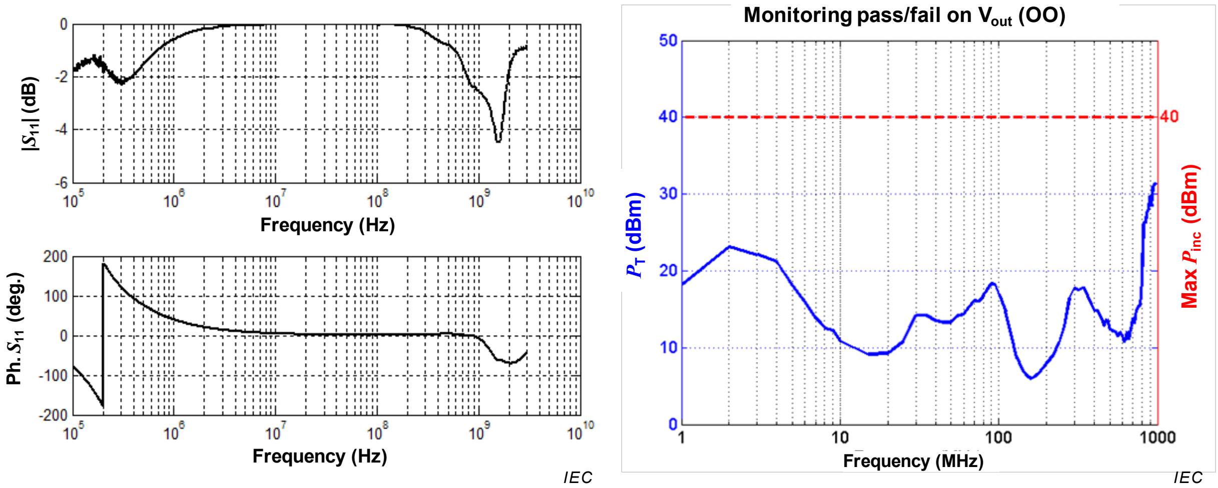
To allow the IC to be biased under RF disturbance, a bias-tee network is used. This is accomplished using a (1 nF and 470 nF in parallel) capacitor network (C) on the RF input and inductor(s) on the DC line. In this application, the following coils (L) were used in series: 47 µH and a ferrite bead of 1 kΩ impedance at 100 MHz.

H.1.2 PDN extraction

The PDN is represented as two-port S-parameter data between V_{CC} (DI), V_{out} (DO) and Ground (GND) terminals. Measurements are made with a VNA at -10 dBm (see Figure H.2a).

H.1.3 IB extraction

The IB is extracted using DPI measurements in the band from 1 MHz to 1 GHz. The maximum injected power on the V_{CC} pin is set to of 40 dBm with a disturbance dwell time of 500 ms. Conventional pass/fail test is carried out on the OO lead (V_{out}) with the following test conditions: ±200 mV tolerance on amplitude, for a nominal voltage of 4,78 V. The incident power causing the malfunction is measured and the transmitted power (P_T) representing the IB is obtained as discussed in 7.4.2 (see Figure H.2b).



a) *S*-Parameter representing the PDN

b) Transmitted power on V_{cc} pin that creates a defect on V_{out}

Figure H.2 – ICIM-CI extraction on the voltage regulator example

H.1.4 SPICE-compatible macro-model

The obtained PDN and IB data are exported in CIML format. A SPICE-compatible ICIM-CI macro-model, shown in Figure H.3 is generated.

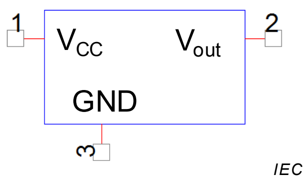


Figure H.3 – Example of a SPICE-compatible ICIM-CI macro-model of the voltage regulator

H.2 Application level simulation and failure prediction

The generated ICIM-CI macro-model is simulated in a SPICE simulator for its immunity performance at application level, in another configuration: a 10 nF capacitor, in 0603 package, is added as a filter between the V_{CC} supply pin and the ground. The simulated schematic is shown in Figure H.4.

For validation purposes, DPI measurement is performed on the application (with filter capacitor), i.e. the setup is same as that in Figure H.1, except that an additional 10 nF capacitor in a 0603 package is added between the V_{CC} pin and ground, close to the IC.

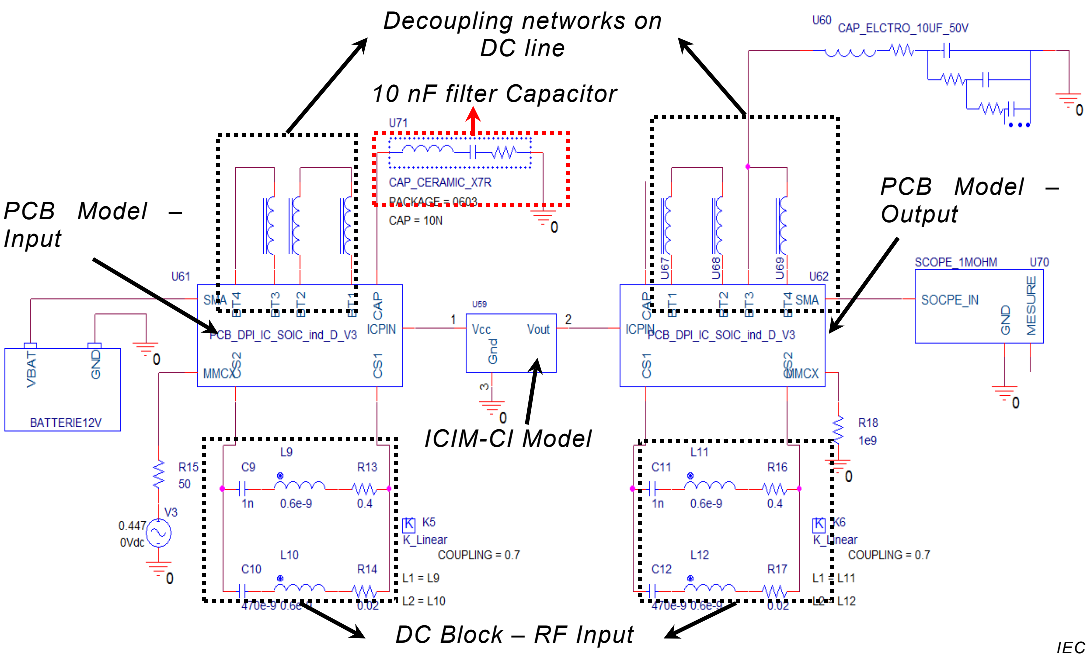


Figure H.4 – Example of a board level simulation on the voltage regulator's ICIM-CI with PCB model and other components including parasitic elements

The estimated (simulation) incident power for causing the defect in the OO lead is compared with the measured values in Figure H.5. In the band from 3 MHz to 100 MHz, the black curve is limited to the maximum injected power (40 dBm). This is coherent with simulations (dotted red curve); the simulated injected power causing the defect in this frequency band is higher than 40 dBm. At all other frequencies, the difference is lower than 6 dB, which is an acceptable tolerance.

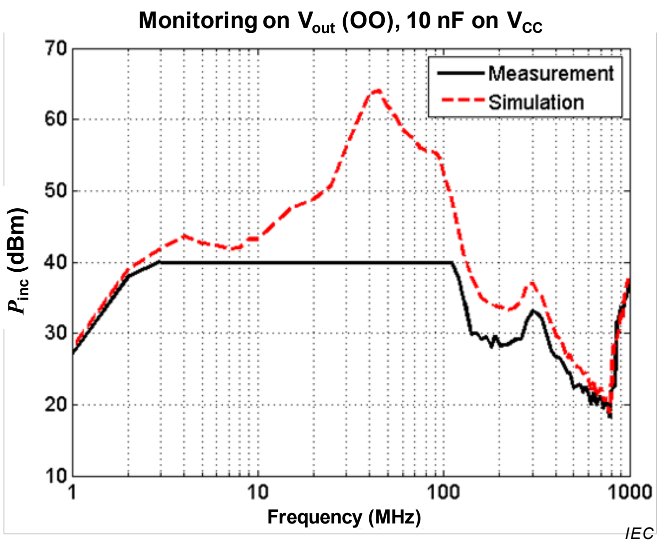


Figure H.5 – Incident power as a function of frequency that is required to create a defect with a 10 nF filter

The fact that the any change in the DI or DO network (PDN) may modify the transmitted power into the device is evident in this application.

Annex I
(informative)

Immunity simulation with ICIM model based on non pass/fail test

Annex I deals with estimating failure using ICIM-CI macro-model when the IB component is extracted using a non pass/fail test on the OOs.

The IB file extracted using the RFIP probe or the DPI test method is shown in Figure I.1. It gives the immunity criterion expressed in transmitted power, i.e. it represents the behavioural aspect of the OO as a function of transmitted power without specified limits. In such cases, the IB data is represented by the maximum power acceptable by the DUT before a change on the OO occurs in the specified frequency range.

The column on the right thus gives the maximum transmitted power before the variation occurs. For example at 1,25 MHz the maximum transmitted power is –27 dBm for guaranteed functioning (no change on the OO is observed).

```
#    Hz          PTr(dBm)
    1250000      -27
    1500000      -26
    1750000      -25.5
    2250000      -24
    2500000      -23
    2750000      -35.5
    3000000      -37.5
    3250000      -22.6
    3500000      -21.6
    3750000      -21
    4250000      -20.5
    4500000      -20
    4750000      -19.8
```

IEC

Figure I.1 – Example of an IB file for a given failure criterion

There is an IB file for each immunity criterion. To determine if a failure occurs, the simulation of the transmitted power applied to the DI terminal is compared to the curve supplied by the IB block. The failure detection has to be done by monitoring the simulated transmitted power and the immunity criteria supplied by the IB block. The simulation result is an analogue data and not a binary data. It gives more details about the behaviour before and after the malfunction.

Figure I.2 plots an example where the simulated transmitted power is compared to measured OO's immunity behaviour. The blue (continuous) curve shows the transmitted power before a variation on the OO is observed. The red (dashed) curve shows the transmitted power obtained by simulation on the DI terminal of the PDN. When the simulated transmitted power is higher than the measured transmitted power for the same susceptibility criterion, the DUT fails. In this example the DUT fails between 2,6 MHz and 3,2 MHz. For example, at 1,25 MHz, the simulation result is –42 dBm and therefore the user can conclude by comparing these values that the test result is "Pass" (–42 dBm < –27 dBm). At 2,75 MHz, the measured transmitted power is –35,5 dBm and the simulation is –25 dBm. The test "fails" because the simulation result is higher (–25 dBm > –35,5 dBm).

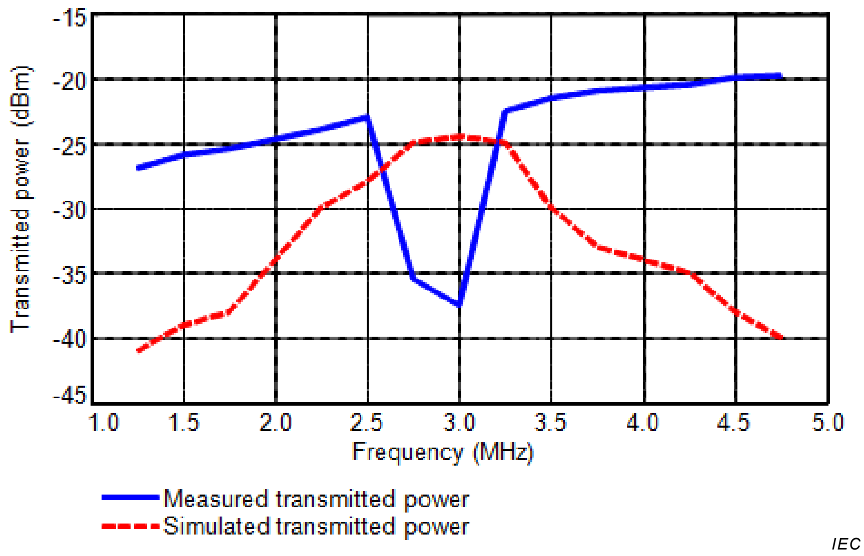


Figure I.2 – Comparison of simulated transmitted power and measured immunity behaviour

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