



BSI Standards Publication

EMC IC modelling

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

National foreword

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

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**EMC IC modelling - Part 4: Models of integrated circuits for RF
immunity behavioural simulation - Conducted immunity
modelling (ICIM-CI)
(IEC 62433-4:2016)**

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

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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

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
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

FOREWORD.....	7
1 Scope.....	9
2 Normative references.....	9
3 Terms, definitions, abbreviations and conventions.....	10
3.1 Terms and definitions.....	10
3.2 Abbreviations.....	11
3.3 Conventions.....	11
4 Philosophy.....	12
5 ICIM-CI model description.....	12
5.1 General.....	12
5.2 PDN description.....	14
5.3 IBC description.....	15
5.4 IB description.....	16
6 CIML format.....	17
6.1 General.....	17
6.2 CIML structure.....	18
6.3 Global keywords.....	19
6.4 Header section.....	19
6.5 Lead definitions.....	20
6.6 SPICE macro-models.....	21
6.7 Validity section.....	23
6.7.1 General.....	23
6.7.2 Attribute definitions.....	23
6.8 PDN.....	25
6.8.1 General.....	25
6.8.2 Attribute definitions.....	26
6.8.3 PDN for a single-ended input or output.....	29
6.8.4 PDN for a differential input.....	36
6.8.5 PDN multi-port description.....	39
6.9 IBC.....	40
6.9.1 General.....	40
6.9.2 Attribute definitions.....	41
6.10 IB.....	42
6.10.1 General.....	42
6.10.2 Attribute definitions.....	43
6.10.3 Description.....	48
7 Extraction.....	50
7.1 General.....	50
7.2 Environmental extraction constraints.....	50
7.3 PDN extraction.....	51
7.3.1 General.....	51
7.3.2 <i>S-/Z-/Y</i> -parameter measurement.....	51
7.3.3 RFIP technique.....	51
7.4 IB extraction.....	52
7.4.1 General.....	52
7.4.2 Direct RF power injection test method.....	52

7.4.3	RF Injection probe test method	54
7.4.4	IB data table	55
7.5	IBC	56
8	Validation of ICIM-CI hypotheses	56
8.1	General	56
8.2	Linearity	57
8.3	Immunity criteria versus transmitted power	58
9	Model usage	59
Annex A (normative)	Preliminary definitions for XML representation	61
A.1	XML basics	61
A.1.1	XML declaration	61
A.1.2	Basic elements	61
A.1.3	Root element	61
A.1.4	Comments	62
A.1.5	Line terminations	62
A.1.6	Element hierarchy	62
A.1.7	Element attributes	62
A.2	Keyword requirements	62
A.2.1	General	62
A.2.2	Keyword characters	63
A.2.3	Keyword syntax	63
A.2.4	File structure	63
A.2.5	Values	65
Annex B (informative)	ICIM-CI example with disturbance load	68
Annex C (informative)	Conversions between parameter types	69
C.1	General	69
C.2	Single-ended input or output	69
C.3	Differential input or output	70
Annex D (informative)	Example of ICIM-CI macro-model in CIML format	74
Annex E (normative)	CIML Valid keywords and usage	79
E.1	Root element keywords	79
E.2	File header keywords	79
E.3	<i>Validity</i> section keywords	81
E.4	Global keywords	81
E.5	<i>Lead</i> keyword	82
E.6	<i>Lead_definitions</i> section attributes	82
E.7	<i>Macromodels</i> section attributes	83
E.8	<i>Pdn</i> section keywords	84
E.8.1	<i>Lead</i> element keywords	84
E.8.2	<i>Netlist</i> section keywords	86
E.9	<i>Ibc</i> section keywords	87
E.9.1	<i>Lead</i> element keywords	87
E.9.2	<i>Netlist</i> section keywords	89
E.10	<i>Ib</i> section keywords	89
E.10.1	<i>Lead</i> element keywords	89
E.10.2	<i>Max_power_level</i> section keywords	91
E.10.3	<i>Voltage</i> section keywords	91
E.10.4	<i>Current</i> section keywords	91

E.10.5	<i>Power</i> section keywords	94
E.10.6	<i>Test_criteria</i> section keywords	95
Annex F (informative)	PDN impedance measurement methods using vector network analyzer	97
F.1	General.....	97
F.2	Conventional one-port method	97
F.3	Two-port method for low impedance measurement.....	97
F.4	Two-port method for high impedance measurement	98
Annex G (informative)	RFIP measurement method description	99
G.1	General.....	99
G.2	Obtaining immunity parameters	99
Annex H (informative)	Immunity simulation with ICIM model based on pass/fail test	101
H.1	ICIM-CI macro-model of a voltage regulator IC	101
H.1.1	General	101
H.1.2	PDN extraction.....	101
H.1.3	IB extraction	101
H.1.4	SPICE-compatible macro-model	102
H.2	Application level simulation and failure prediction	102
Annex I (informative)	Immunity simulation with ICIM model based on non pass/fail test	104
Bibliography		106
Figure 1	– Example of ICIM-CI model structure.....	13
Figure 2	– Example of an ICIM-CI model of an electronic board	14
Figure 3	– Example of an IBC network.....	16
Figure 4	– ICIM-CI model representation with different blocks.....	16
Figure 5	– CIML inheritance hierarchy	18
Figure 6	– Example of a netlist file defining a sub-circuit.....	22
Figure 7	– PDN electrical schematics	29
Figure 8	– PDN represented as a one-port black-box.....	29
Figure 9	– PDN represented as S-parameters in Touchstone format	32
Figure 10	– PDN represented as two-port S-parameters in Touchstone format	33
Figure 11	– Example structure for defining the PDN using circuit elements.....	34
Figure 12	– Example of a single-ended PDN Netlist main circuit definition.....	35
Figure 13	– Example of a single-ended PDN Netlist with both sub-circuit and main circuit definitions.....	35
Figure 14	– Differential input schematic.....	37
Figure 15	– PDN represented as a two-port black-box	37
Figure 16	– PDN data format for differential input or output.....	37
Figure 17	– Differential inputs of an operational amplifier example	39
Figure 18	– ICIM-CI Model for a 74HC08 component	40
Figure 19	– Example IB file obtained from DPI measurement	50
Figure 20	– Test setup of the DPI immunity measurement method as specified in IEC 62132-4	52
Figure 21	– Principle of single and multi-pin DPI.....	53
Figure 22	– Electrical representation of the DPI test setup	54
Figure 23	– Test setup of the RFIP measurement method derived from the DPI method	55

Figure 24 – Example setup used for illustrating ICIM-CI hypotheses	57
Figure 25 – Example of linearity assumption validation	58
Figure 26 – Example of transmitted power criterion validation	59
Figure 27 – Use of the ICIM-CI macro-model for simulation	59
Figure A.1 – Multiple XML (CIML) files	64
Figure A.2 – XML files with data files (*.dat)	64
Figure A.3 – XML files with additional files	65
Figure B.1 – ICIM-CI description applied to an oscillator stage for extracting IB.....	68
Figure C.1 – Single-ended DI	69
Figure C.2 – Differential DI	70
Figure C.3 – Two-port representation of a differential DI	70
Figure C.4 – Simulation of common-mode injection on a differential DI based on DPI	72
Figure C.5 – Equivalent common-mode input impedance of a differential DI	72
Figure C.6 – Determination of transmitted power for a differential DI	72
Figure D.1 – Test setup on an example LIN transceiver	74
Figure D.2 – PDN data in touchstone format (s2p), data measured using VNA	76
Figure D.3 – PDN data of leads 6 (LIN) and 7 (VCC)	77
Figure D.4 – IB data in ASCII format (.txt), data measured using DPI method – Injection on VCC pin	77
Figure D.5 – IB data for injection on VCC pin.....	78
Figure F.1 – Conventional one-port S-parameter measurement.....	97
Figure F.2 – Two-port method for low impedance measurement.....	98
Figure F.3 – Two-port method for high impedance measurement.....	98
Figure G.1 – Test setup of the RFIP measurement method derived from DPI method	99
Figure G.2 – Principle of the RFIP measurement method.....	99
Figure H.1 – Electrical schematic for extracting the voltage regulator's ICIM-CI.....	101
Figure H.2 – ICIM-CI extraction on the voltage regulator example	102
Figure H.3 – Example of a SPICE-compatible ICIM-CI macro-model of the voltage regulator.....	102
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	103
Figure H.5 – Incident power as a function of frequency that is required to create a defect with a 10 nF filter.....	103
Figure I.1 – Example of an IB file for a given failure criterion	104
Figure I.2 – Comparison of simulated transmitted power and measured immunity behaviour	105
Table 1 – Attributes of <i>Lead</i> keyword in the <i>Lead_definitions</i> section	20
Table 2 – Compatibility between the <i>Mode</i> and <i>Type</i> fields for correct CIML annotation.....	20
Table 3 – <i>Subckt</i> definition.....	21
Table 4 – Definition of the <i>Validity</i> section	23
Table 5 – Definition of the <i>Lead</i> keyword for <i>Pdn</i> section	25
Table 6 – Valid data formats and their default units in the <i>Pdn</i> section	28
Table 7 – Valid file extensions in the <i>Pdn</i> section	28
Table 8 – Valid fields of the <i>Lead</i> keyword for single-ended PDN	30

Table 9 – <i>Netlist</i> definition.....	34
Table 10 – Valid fields of the <i>Lead</i> keyword for differential PDN.....	38
Table 11 – Differences between the <i>Pdn</i> and <i>Ibc</i> section fields	41
Table 12 – Valid fields of the <i>Lead</i> keyword for IBC definition	42
Table 13 – Definition of the <i>Lead</i> keyword in <i>Ib</i> section.....	43
Table 14 – <i>Max_power_level</i> definition	44
Table 15 – <i>Voltage</i> , <i>Current</i> and <i>Power</i> definition	45
Table 16 – <i>Test_criteria</i> definition	45
Table 17 – Default values of <i>Unit_voltage</i> , <i>Unit_current</i> and <i>Unit_power</i> tags as a function of data format	48
Table 18 – Valid file extensions in the <i>Ib</i> section.....	48
Table 19 – Example of IB table pass/fail criteria	56
Table A.1 – Valid logarithmic units	66
Table C.1 – Single-ended parameter conversion.....	70
Table C.2 – Differential parameter conversion	71
Table C.3 – Power calculation	73
Table E.1 – Root element keywords	79
Table E.2 – <i>Header</i> section keywords.....	80
Table E.3 – <i>Validity</i> section keywords	81
Table E.4 – Global keywords.....	82
Table E.5 – <i>Lead</i> element definition	82
Table E.6 – <i>Lead_definitions</i> section keywords.....	83
Table E.7 – <i>Macromodels</i> section keywords	83
Table E.8 – <i>Lead</i> element keywords in the <i>Pdn</i> section.....	84
Table E.9 – Netlist section keywords	87
Table E.10 – <i>Lead</i> element keywords in the <i>Ibc</i> section	87
Table E.11 – <i>Lead</i> element keywords in the <i>Ib</i> section.....	90
Table E.12 – <i>Max_power_level</i> section keywords	91
Table E.13 – <i>Voltage</i> section keywords	92
Table E.14 – <i>Current</i> section keywords	93
Table E.15 – <i>Power</i> section keywords	94
Table E.16 – <i>Test_criteria</i> section keywords.....	96

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

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- 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.

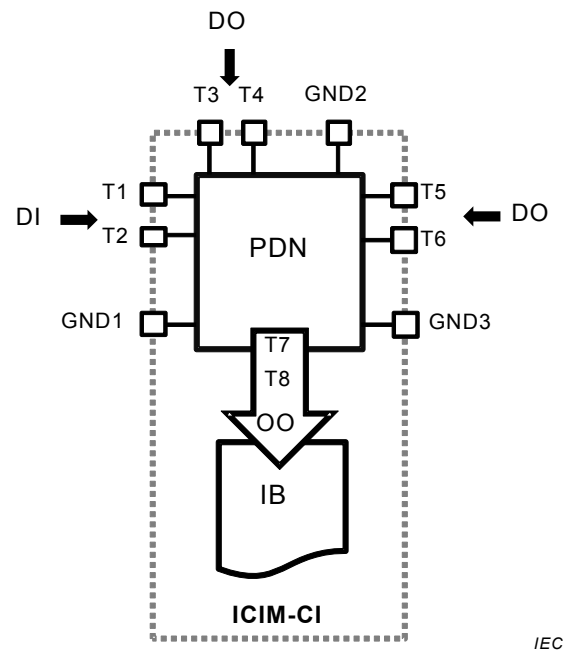


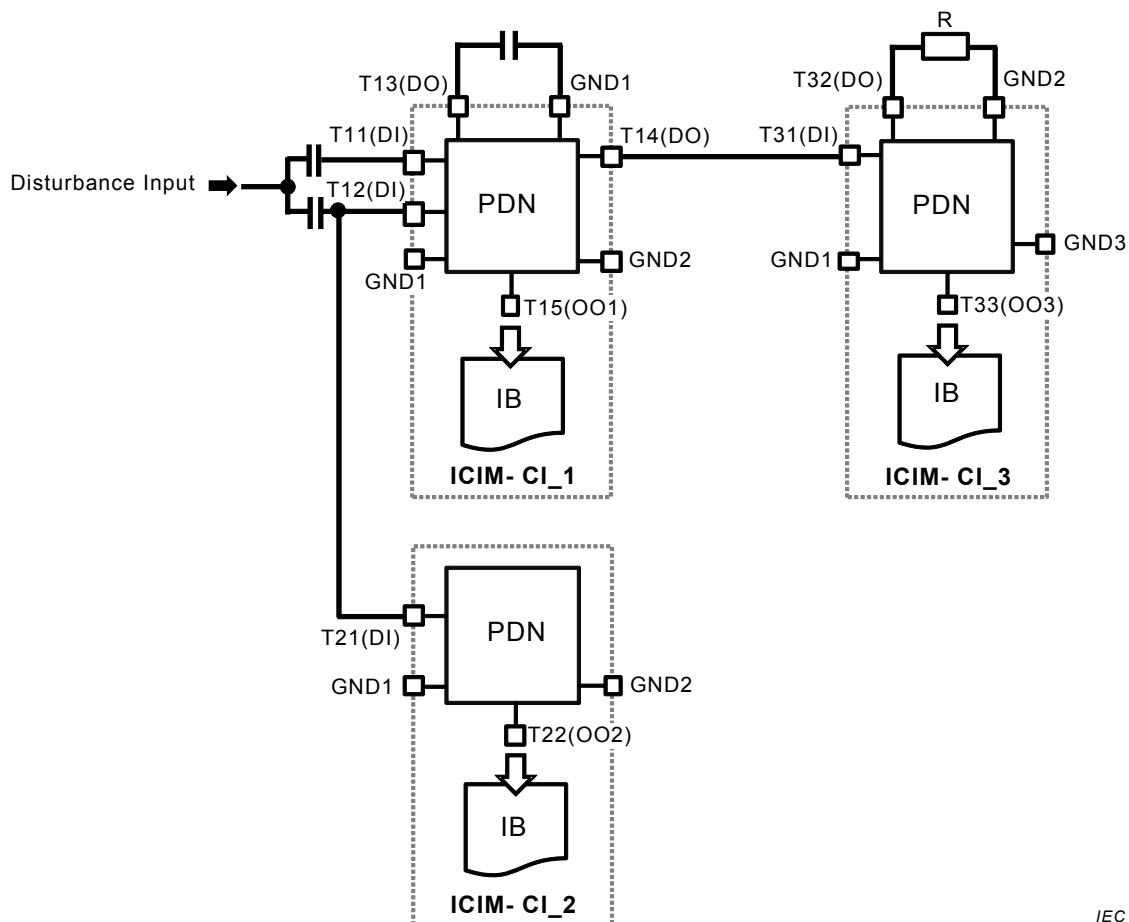
Figure 1 – Example of ICIM-CI model structure

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.



IEC

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:

- $Z(f)$: 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.
- $Y(f)$: 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):

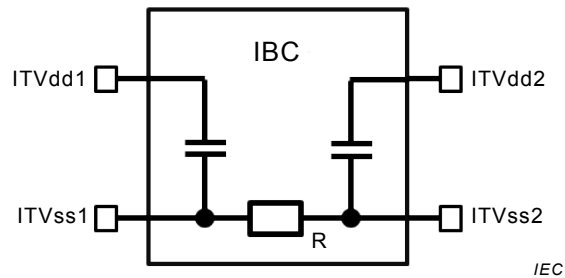
- a) Power supply voltage range
- b) Applicable frequency range
- c) Temperature range
- d) Applicable load conditions on DI and/or DO pins

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.

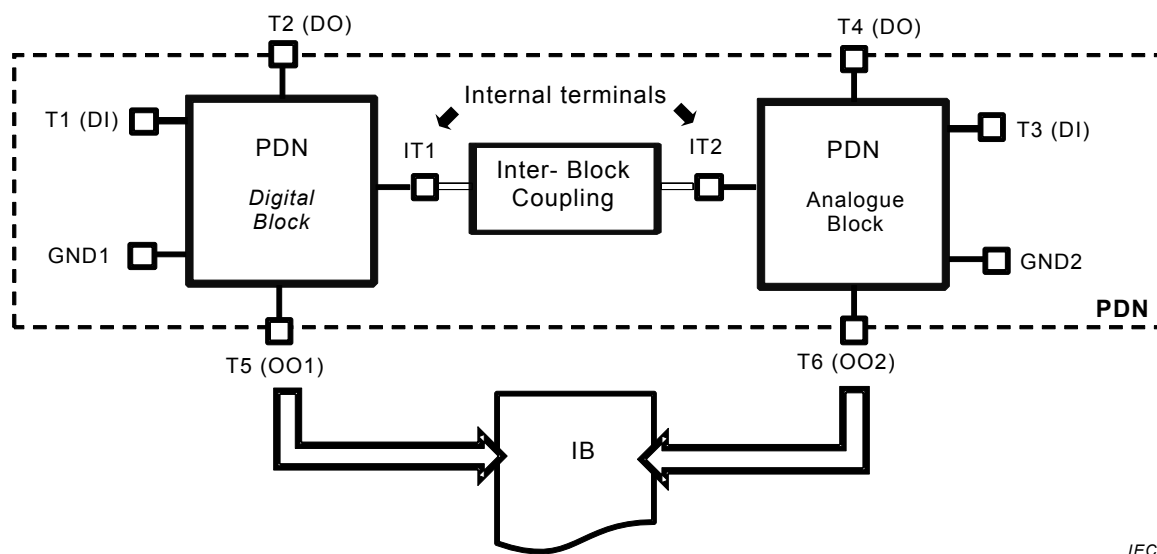


Figure 4 – ICIM-CI model representation with different blocks

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.

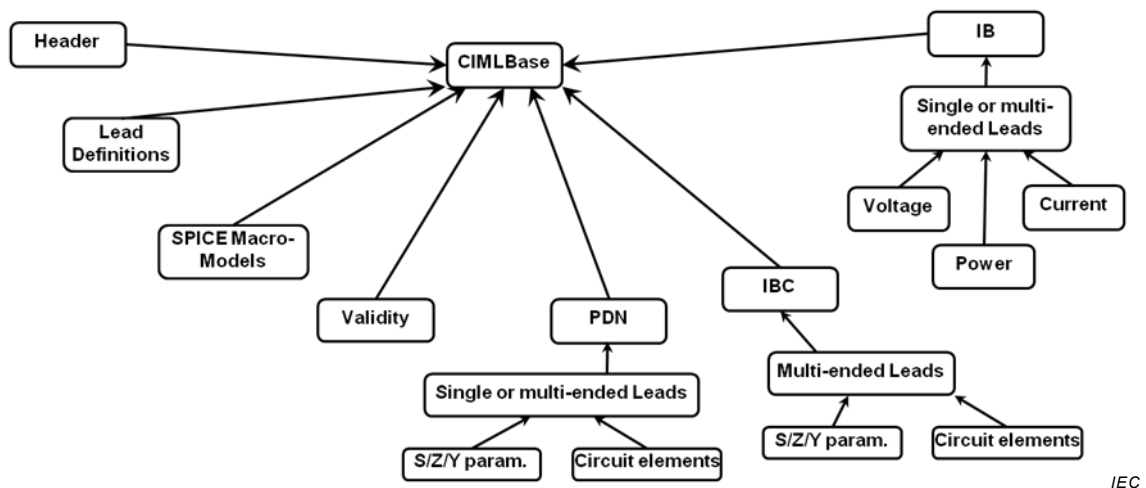
6 CIML format

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.



IEC

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

<i>Lead</i>
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

<i>Subckt</i>
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

<i>Validity</i>
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

<i>Lead</i>
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.

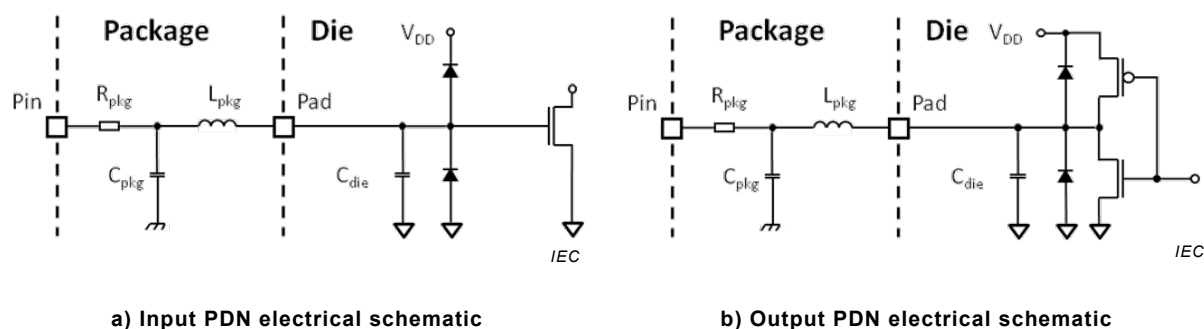
This is a required field; a unique *List* or *Data_files* element shall be used to define the PDN data of the specific lead.

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.



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.

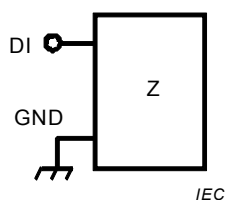


Figure 8 – PDN represented as a one-port black-box

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)