



DPC: 14 / 30310478 DC

BSI Group Headquarters

389 Chiswick High Road London W4 4AL

Tel: + 44 (0)20 8996 9000

Fax: + 44 (0)20 8996 7400

www.bsigroup.com

Date: 17 July 2014

Origin: International

Latest date for receipt of comments: 10 September 2014

Project No. 2014/01908

Responsible committee: EPL/47 Semiconductors

Interested committees:

Title: Draft BS EN 62433-3 EMC IC modelling

Part 3: Models of Integrated Circuits for EMI behavioural simulation - Radiated emissions modelling (ICEM-RE)

Please notify the secretary if you are aware of any keywords that might assist in classifying or identifying the standard or if the content of this standard

- i) has any issues related to 3rd party IPR, patent or copyright
- ii) affects other national standard(s)
- iii) requires additional national guidance or information

**WARNING: THIS IS A DRAFT AND MUST NOT BE REGARDED OR USED AS A BRITISH STANDARD.
THIS DRAFT IS NOT CURRENT BEYOND 10 September 2014**

This draft is issued to allow comments from interested parties; all comments will be given consideration prior to publication. No acknowledgement will normally be sent. **See overleaf for information on the submission of comments.**

No copying is allowed, in any form, without prior written permission from BSI except as permitted under the Copyright, Designs and Patent Act 1988 or for circulation within a nominating organization for briefing purposes. Electronic circulation is limited to dissemination by e-mail within such an organization by committee members.

Further copies of this draft may be purchased from BSI Shop <http://shop.bsigroup.com> or from BSI Customer Services, Tel: + 44(0) 20 8996 9001 or email cservices@bsigroup.com. British, International and foreign standards are also available from BSI Customer Services.

Information on the co-operating organizations represented on the committees referenced above may be obtained from <http://standardsdevelopment.bsigroup.com>

Responsible Committee Secretary: **Committee Service Centre (BSI)**
Direct tel: **020 8996 7009**
E-mail: **csc@bsigroup.com**

AVA Documents
Document Sharing Hub

Introduction

This draft standard is based on international discussions in which the UK has taken an active part. Your comments on this draft are welcome and will assist in the preparation of the consequent standard. There is a high probability that this text could be adopted by CENELEC as a reference document for harmonization or as a European Standard. Recipients of this draft are requested to comment on the text bearing in mind this possibility.

UK Vote

Please indicate whether you consider the UK should submit a negative (with reasons) or positive vote on this draft.

Submission of Comments

- The guidance given below is intended to ensure that all comments receive efficient and appropriate attention by the responsible BSI committee. **Annotated drafts are not acceptable and will be rejected.**
- All comments must be submitted, preferably electronically, to the Responsible Committee Secretary at the address given on the front cover. Comments should be compatible with version 6.0 or version 97 of Microsoft Word for Windows, if possible; otherwise comments in ASCII text format are acceptable. **Any comments not submitted electronically should still adhere to these format requirements.**
- All comments submitted should be presented as given in the example below. Further information on submitting comments and how to obtain a blank electronic version of a comment form are available from the BSI website at: <http://drafts.bsigroup.com/>

Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
------------------	-------------------------------

1	2	(3)	4	5	(6)	(7)
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/ Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



47A/941/CDV

COMMITTEE DRAFT (CD)

IEC/TC or SC: SC47A		Project number IEC 62433-3 Ed.1	
Title of TC/SC: Integrated circuits		Date of circulation 2014-07-11	Closing date for comments 2014-10-17
Also of interest to the following committees		Supersedes document 47A/927/NP, 47A/933A/RVN	
Proposed horizontal standard ☐ Other TC/SCs are requested to indicate their interest, if any, in this CD to the TC/SC secretary			
Functions concerned: ☐ Safety ☒ EMC ☐ Environment ☐ Quality assurance			
Secretary: Yosihnoru Fukuba		THIS DOCUMENT IS STILL UNDER STUDY AND SUBJECT TO CHANGE. IT SHOULD NOT BE USED FOR REFERENCE PURPOSES. RECIPIENTS OF THIS DOCUMENT ARE INVITED TO SUBMIT, WITH THEIR COMMENTS, NOTIFICATION OF ANY RELEVANT PATENT RIGHTS OF WHICH THEY ARE AWARE AND TO PROVIDE SUPPORTING DOCUMENTATION.	

Title:

IEC 62433-3 Ed.1 : EMC IC modelling – Part 3: Models of Integrated Circuits for EMI behavioural simulation – Radiated emissions modelling (ICEM-RE)

(Titre) :

Introductory note

Copyright © 2014 International Electrotechnical Commission, IEC. All rights reserved. It is permitted to download this electronic file, to make a copy and to print out the content for the sole purpose of preparing National Committee positions. You may not copy or "mirror" the file or printed version of the document, or any part of it, for any other purpose without permission in writing from IEC.

CONTENTS

FOREWORD.....	5
1 Scope.....	7
2 Normative references	7
3 Terms, definitions, abbreviations and conventions	8
4 Philosophy	9
5 ICEM-RE model description.....	10
5.1 General.....	10
5.2 PDN description	11
5.3 IA description	14
5.4 Electromagnetic field calculation and simulation.....	14
6 REML format	15
6.1 Preliminary definitions	15
6.2 REML structure	16
6.3 Global keywords.....	17
6.4 Header section	17
6.5 Frequency definitions	17
6.6 Coordinate system definition	18
6.7 Reference definition	18
6.8 Validity section.....	19
6.9 PDN	20
6.10 IA	28
7 Extraction of model parameters	36
7.1 General.....	36
7.2 Obtaining model parameters from near-field data	36
7.3 Extraction based on ICEM-CE simulation	42
8 Validation	44
8.1 Modelling the magnetic fields of a microcontroller	44
8.2 Modelling the electromagnetic fields of an oscillator	47
9 Model usage.....	51
9.1 General.....	51
9.2 Methodology for exploiting ICEM-RE model.....	51
Annex A (Informative) Preliminary definitions for XML representation	53
A.1 XML basics	53
A.2 Keyword requirements.....	54
Annex B (Informative) Example files	59
B.1 Minimum default ICEM-RE file.....	59
B.2 Microcontroller example in REML format	59
Annex C (Informative) Electromagnetic fields radiated by an elementary electric and magnetic dipole	62
C.1 Electric dipole	62
C.2 Magnetic dipole	64
Annex D (Informative) REML extraction methods	67
D.1 General.....	67
D.2 ICEM-RE Modelling methods.....	67
D.3 ICEM-RE modelling environment from near-field data.....	70
D.4 IC-EMC: ICEM-RE modelling from ICEM-CE	73

Annex E (Informative) REML valid keywords and usage	76
E.1 Root element keywords	76
E.2 File header keywords	76
E.3 Validity section keywords	77
E.4 Global keywords	78
E.5 Pdn section keywords	78
E.6 Ia section keywords	79
Annex F (Informative) ICEM-RE model validation on other devices	81
F.1 General	81
F.2 Validation on passive devices	81
F.3 Validation on active devices	81
Bibliography	83
Figure 1 – General ICEM-RE model structure	10
Figure 2 – Geometrical representation of the ICEM-RE PDN: (a) Integrated Circuit under test (b) Equivalent PDN described with a set of elementary dipole sources	11
Figure 3 – (a) An elementary electric dipole of length ℓ in 3D space and (b) the parameters defining an electric dipole of the PDN	11
Figure 4 – An elementary current loop of radius “a” in 3D space	12
Figure 5 – The duality theorem between a magnetic loop and a magnetic dipole in the magnetic dipole PDN	12
Figure 6 – Example of referential points to describe the geometry	13
Figure 7 – PDN definition at three different frequencies.	14
Figure 8 – REML inheritance hierarchy	15
Figure 9 – Format for defining PDN vector data in an external file	24
Figure 10 – Format for defining IA vector data in an external file	32
Figure 11 – Electromagnetic field measurement with (a) magnetic and (b) electric probes	37
Figure 12 – Near field scanning measurement using horizontal H probe: B_z field [nT] measured at 3 mm above the microprocessor at 80MHz.	37
Figure 13 – Example of electromagnetic field emitted by an elementary current line	38
Figure 14 – Manual current mapping	39
Figure 15 – Model representation with N automatically detected dipoles	39
Figure 16 – Comparison between the modelled and measured EM fields at 2 mm above an oscillator	41
Figure 17 – A simple ICEM-CE PDN representing the package and the internal network impedance between, the power rails	43
Figure 18 – Reconstructing the geometry of the package model (ICEM-RE PDN) from IBIS and its link with the electrical model (ICEM-CE PDN)	43
Figure 19 – Microcontroller circuit used for model validation	44
Figure 20 – Manual dipoles representing the PDN of the microcontroller	45
Figure 21 – Comparison between the modelled and measured fields at 4 mm above the microcontroller using $Model_{Hman}$	45
Figure 22 – Validation of $Model_H$ on the microcontroller	46
Figure 23 – Detection of dipoles representing the microcontroller using $Model_{EM_Iter}$ from (a) H_x field and (b) H_y field. The white spots show the centre of the electric dipoles	46
Figure 24 – Validation of $Model_{EM_Iter}$ on the microcontroller	47

Figure 25 – Oscillator circuit used for model validation	47
Figure 26 – Schematic of the oscillator used for validation	48
Figure 27 – Validation of the magnetic field predicted with Model _{EM_Inv} and Model _{EM_Iter} on the oscillator at 10 mm height	49
Figure 28 – Validation of the electric field predicted with Model _{EM_Inv} and Model _{EM_Iter} on the oscillator at 10 mm height	50
Figure 29 – Modelled maximum total magnetic field as a function of height (z) above the oscillator compared with measurements	51
Figure 30 – Typical EMC issues at equipment and system level covered by ICEM-RE	52
Figure A1 – Multiple XML files	55
Figure A2 – XML files with data files (*.dat)	56
Figure A3 – XML files with additional files	57
Figure B1 – Microcontroller used for illustration	60
Figure B2 – Data file representing the PDN information of the microcontroller	61
Figure B3 – Data file representing the IA information of the microcontroller	61
Figure C1 – An elementary current line in space	62
Figure C2 – An elementary magnetic dipole in space	65
Figure D1 – Manually defined electric dipole array in Model _{Hman}	67
Figure D2 – Electric and magnetic dipole array in Model _{EM_Inv}	69
Figure D3 – Example of an ICEM-RE modelling environment	71
Figure D4 – ICEM-RE modelling design-flow	72
Figure D5 – An example of an imported ICEM-RE PDN and IA in a 3D simulation tool	73
Figure D7 – Screen-shot of the IC-EMC tool [11]	74
Figure D8 – IC-EMC design-flow to obtain ICEM-RE from ICEM-CE model	74
Table 1 – Proposed PDN geometry and associated format	13
Table 2 – Definition of the Validity section	19
Table 3 – Definition of the Submodel section of the Pdn element	21
Table 4 – Definition of the Vector keyword in the Pdn section	22
Table 5 – Valid fields of the Submodel keyword for single-frequency PDN	23
Table 6 – Conditions for correct annotation of single-frequency PDN by the REM parser	23
Table 7 – Valid fields of the Vector keyword for single-frequency PDN	23
Table 8 – Conditions for correct annotation of multi-frequency PDN by the REM parser	26
Table 9 – Definition of the Submodel section of the Ia element	29
Table 10 – Definition of the Vector keyword in the Ia section	29
Table 11 – Valid fields of the Submodel keyword for single-frequency IA	30
Table 12 – Conditions for correct annotation of single-frequency IA by the REM parser	31
Table 13 – Valid fields of the Vector keyword for single-frequency IA	31
Table 14 – Conditions for correct annotation of multi-frequency IA by the REM parser	34
Table 15 – Guidelines for choosing between the different modelling methods using near-field data	42
Table F1 – ICEM-RE model validation on passive structures	81

INTERNATIONAL ELECTROTECHNICAL COMMISSION

EMC IC modelling –

**Part 3: Models of Integrated Circuits for EMI behavioural simulation –
Radiated emissions modelling (ICEM-RE)**

FOREWORD

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

International Standard IEC 62433-3 has been prepared by subcommittee 47A: Integrated Circuit, of IEC technical committee 47 : Semiconductor devices.

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

FDIS	Report on voting
47A/XX/FDIS	47A/XX/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 date¹ indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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

¹ The National Committees are requested to note that for this publication the stability date is



EMC IC modelling –

Part 4: Models of Integrated Circuits for EMI behavioural simulation – Radiated emissions modelling (ICEM-RE)

1 Scope

The objective of this standard is to provide a flow for deriving a macro-model to allow the simulation of the radiated emission levels of an Integrated circuit. This model is commonly called Integrated Circuit Radiated Emissions, ICEM-RE. It is intended to be used for predicting the emission levels emanating from the integrated circuit.

The model can be used for modelling a complete IC, with or without its associated package, a functional block and an Intellectual Property (IP) block of both analogue and digital ICs (input/output pins, digital core and supply).

The proposed IC macro model will be inserted in 3D electromagnetic simulation tools so as to:

- simulate and predict the near-radiated emissions from the IC at any desired point in space
- simulate and evaluate the effect of the radiated emissions on neighbouring ICs, cables, transmission lines, etc.

This document has two main parts:

- the first is the electrical description of ICEM-RE model elements,
- the second part proposes a universal data exchange format called REML based on XML. This format allows encoding the ICEM-RE in a more useable and generic form for emission 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 62433-1: *EMC IC modelling- Part 1: General modelling framework.*

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

IEC 61967-1: *Integrated Circuits – Measurement of electromagnetic emissions – Part 1: General conditions and definitions*

IEC 61967-3: *Integrated Circuits – Measurement of electromagnetic emissions – Part 3: Measurement of radiated emissions – Surface scan method*

IEC 61967-1-1: *Integrated circuits - Measurement of electromagnetic emissions - Part 1-1: General conditions and definitions - Near-field scan data exchange format*

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

ANSI INCITS 4:1986, *Information Systems – Coded Character Sets – 7-Bit American National Standard Code for Information Interchange (7-Bit ASCII)*

3 Terms, definitions, abbreviations and conventions

For the purpose of this International Standard, the following terms and definitions apply.

3.1 Terms and definitions

3.1.1

Electric Dipole

An electric dipole is a linear current-carrying element (wire). It is always of finite length even though it may be very short physically.

3.1.2

Magnetic Loop

A magnetic loop is a closed current-carrying element (wire). It is always of finite radius even though it may be very small physically.

3.1.3

Infinitesimal dipole

An infinitesimal dipole is a vanishingly short current carrying element (dipole or loop).

3.1.4

Model_{Hman}

Refers to the radiated magnetic emission model with manual sources.

3.1.5

Model_H

Refers to the radiated magnetic emission model with automatic source detection.

3.1.6

Model_{EM_Inv}

Refers to the radiated electric and magnetic emission model based on automatic source detection, using the matrix inverse method for problem solving.

3.1.7

Model_{EM_Iter}

Refers to the radiated electric and magnetic emission model based on automatic source detection, using an iterative method for problem solving.

3.1.8

Model_{EMTD}

Refers to the time-domain radiated electric and magnetic emission model based on automatic source detection, using an iterative method for problem solving.

3.1.9

Section

A section is an XML element placed one level below the root element or within another section. It contains one or more XML elements, but no value.

3.1.10

Parent

A parent refers to a keyword which is one level above another keyword (child).

3.1.11

Child

A child refers to a keyword which is one level below another keyword (parent).

3.1.12

Parser

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

3.2 Abbreviations

3.2.1

REML

Radiated Emissions Markup Language: Data exchange format for ICEM-RE model.

3.2.2

REMLBase

Radiated Emissions Markup Language Base: The abstract type from which all REML model components are directly or indirectly derived in the ICEM-RE model definition.

3.2.3

PDN

Passive Distribution Network: represents the geometrical base within which electric and magnetic dipoles would be positioned. It contains the geometrical co-ordinates of the model.

3.2.4

IA

Internal Activity: represents the excitation source of the electric and magnetic dipoles of the PDN. It contains the amplitude and phase of the electrical current passing through the dipoles.

3.2.5

REM

Radiated Emissions Model

3.2.6

XML

eXtensible Markup Language

3.3 Conventions

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

4 Philosophy

With every generation, Integrated Circuits have become more and more complex and diverse with respect to integration density and functional capabilities in a reduced form-factor. ICs have become faster more than ever with lower supply voltages. Modern ICs may contain on-chip radio frequency modules co-existing with analogue and/or digital logic cores. Printed Circuit Boards carrying these ICs have also become denser. The emissions from one IC can couple back into neighbouring components and provoke undesired system performance or even system failure. Consequently, the emissions from ICs are becoming more and more critical.

Due to this increased risk of emissions emanating from ICs, it is indispensable to use simulation tools for evaluating the emission behaviour of every module during the IC design stages. It is therefore necessary to have accurate radiated electromagnetic emission models in order to predict the radiated emission behaviour of ICs and their effects on neighbouring circuits. Precise evaluation of emission risks at board level cannot be done otherwise.

This document describes such models for simulating the radiated emission behaviour at IC level. For ICs with multiple operating modes, functionalities and programmable logics, depending on the operating modes and conditions of the IC, its emission profile would be completely different. Consequently, these models are valid in the conditions in which they have been established. They will be used to predict the radiated electromagnetic emissions at application level.

ICEM-RE model data is arranged in a decipherable nested manner using XML format. The objective of this exchange format, called Radiated Emission Markup Language (REML), is to create simple and practical universal access to ICEM-RE model. The preliminary definitions for XML representation is given in Annex A.

5 ICEM-RE model description

5.1 General

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

- Passive parts, (RLC tracks, ESD protection, pins and bonding) which connects the external environment to the internal IC blocks.
- Active parts, (CPU core, clock system, memory, analogue blocks). It is these active internal blocks that are the emission sources in an IC..

The ICEM-RE model consists of a set of data describing these two parts:

- PDN: the Passive Distribution Network (PDN) represents the geometrical base within which electric and magnetic dipoles would be positioned. It contains the geometrical coordinates of the model.
- IA: the Internal Activity (IA) represents the excitation source of the electric and magnetic dipoles of the PDN. It contains the amplitude and phase of the electrical current of the model.

Figure 1 presents the general ICEM-RE model structure.

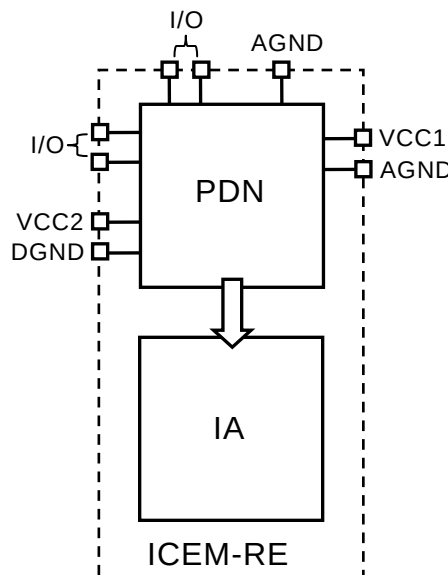


Figure 1 – General ICEM-RE model structure

There is a direct link between the PDN block and IA block. The PDN represents a set of equivalent radiation sources such as electric dipoles or magnetic dipoles which serves as the geometrical base for the IA. The dipole coordinates are defined with respect to a point in space which is called the reference point. More details of the reference point can be found in 5.2.

The IA represents the current flowing in each of the equivalent dipole in the PDN. The current value is complex in nature, i.e., the currents through the dipole are represented with their magnitude and phase. The phase value is relative to the EM field's phase at the reference point. By definition, each element of the PDN has a specific IA, both the PDN coordinates and IA phase values are referenced to the reference point.

The ICEM-RE model is generally defined in the frequency domain. It does not inherently have a frequency limit for validity i.e. ICEM-RE structure is valid over any frequency range. However, depending on the data used for model extraction, the model's limit of validity is set by the input data used for extracting the model. Moreover, the model is defined only in the conditions in which it has been extracted: IC's operating conditions, activated functions, external components (decoupling capacitors, external oscillators, etc) needed for IC's basic functioning, etc. Any variation from the specified conditions could necessitate a modification.

of the model (re-extract the model). The incorporation of the variation is not included in the current edition.

5.2 PDN description

The PDN consists of passive elements for the package, bonding and on-chip interconnections. These elements behave like radiating antennas when high-frequency signals (currents) and transients' flow through them. The PDN block of ICEM-RE can be described using a set of equivalent radiation sources such as electric dipoles or magnetic loops representing the different package/bonding/interconnection elements as shown in Figure 2.

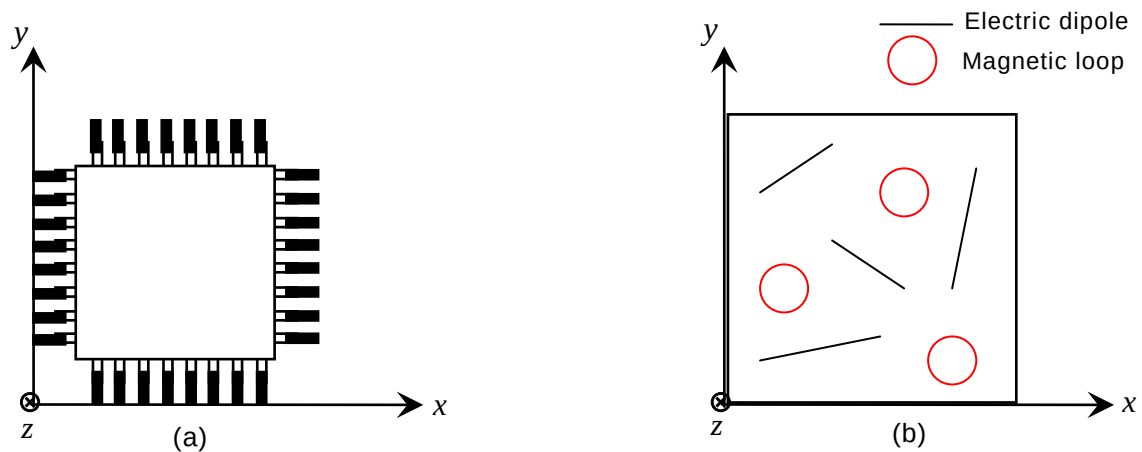


Figure 2 – Geometrical representation of the ICEM-RE PDN: (a) Integrated Circuit under test (b) Equivalent PDN described with a set of elementary dipole sources

An elementary electric dipole in 3D space, representing the PDN, is shown in Figure 3.

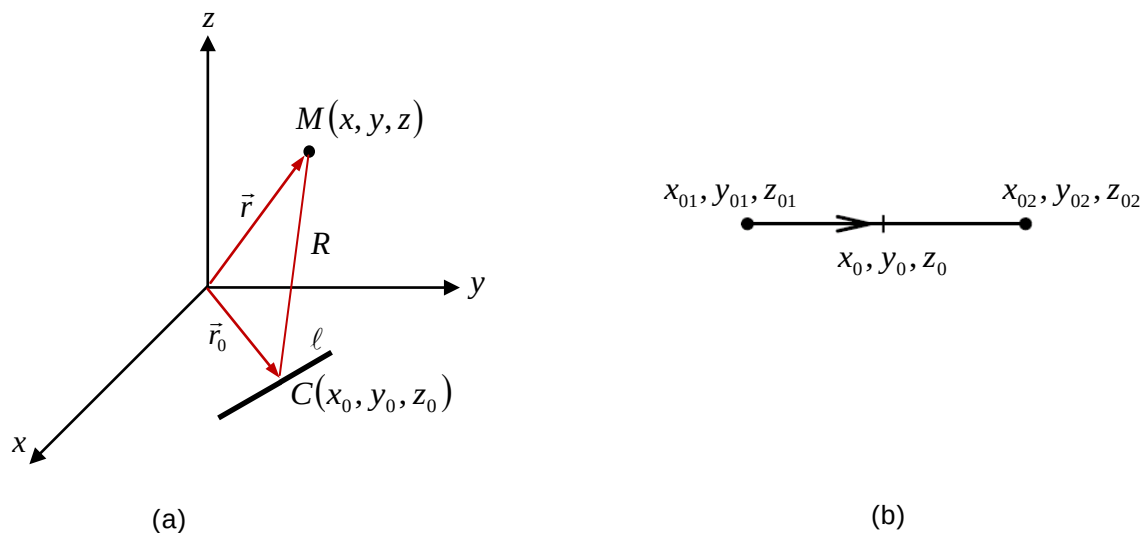


Figure 3 – (a) An elementary electric dipole of length ℓ in 3D space and (b) the parameters defining an electric dipole of the PDN

Similar to an electric dipole, an elementary current loop of the PDN is shown in Figure 4.

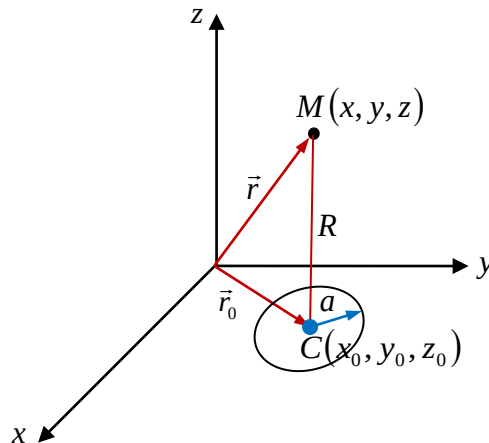


Figure 4 – An elementary current loop of radius “a” in 3D space

In order to facilitate the representation of the current loop and to correlate it very similar to an electric dipole, the duality theorem between a loop and a magnetic dipole is used as shown in Figure 5. The magnetic dipole is oriented in such a way that the vector is “normal” to the current loop.

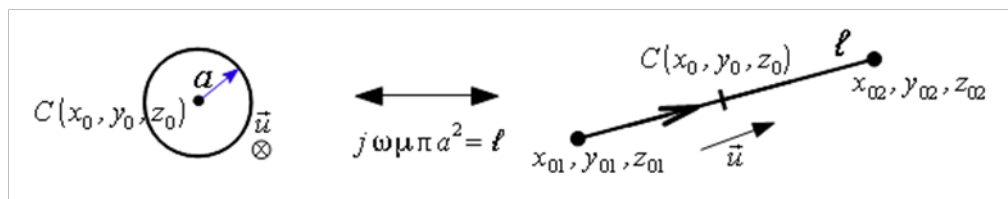


Figure 5 – The duality theorem between a magnetic loop and a magnetic dipole in the magnetic dipole PDN

Using this duality, it is now possible to represent the loop using parameters very similar to those of an electric dipole as seen in Figure 3 (b) since they share a same topology.

The definition of the PDN must include all the necessary information to implement the model for simulation. In general the following main items must be defined:

- The geometry of the equivalent radiation structure (dipole type: electric or magnetic)
- The list giving the dipoles coordinates in triplet

The dipole coordinates are defined with respect to the reference point in space. An example of the reference point is described in Figure 6.

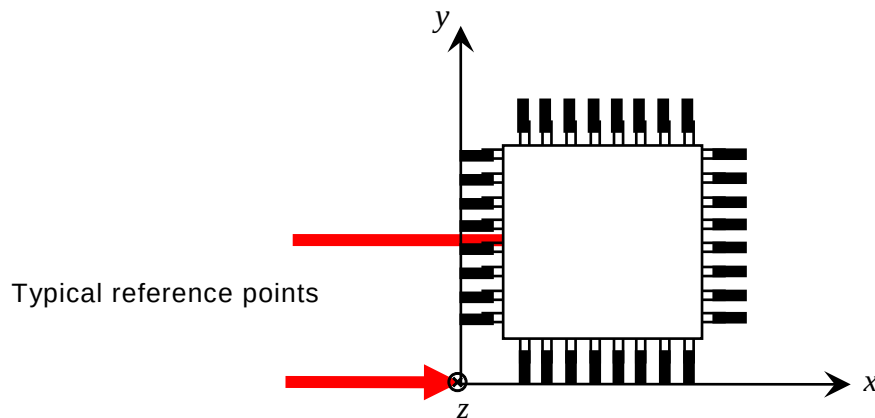


Figure 6 – Example of referential points to describe the geometry

The reference point can be either one of the extremities of the IC under test or the centre of the IC under test. Typical reference points are the lower-left corner or the centre of the IC as shown in Figure 6.

The PDN definition must precise the equivalent radiation structures in the frequency domain with the type of the dipole used and the coordinates of the dipoles. The proposal for defining the PDN is given in Table 1.

Table 1 – Proposed PDN geometry and associated format

Geometry of the equivalent structure	Proposed format
Electric dipole	Start-coordinates (x_{01}, y_{01}, z_{01}) and End-coordinates (x_{02}, y_{02}, z_{02}) in the Cartesian system or Start-coordinates ($r_{01}, \varphi_{01}, z_{01}$) and End-coordinates ($r_{02}, \varphi_{02}, z_{02}$) in the cylindrical system Start-coordinates ($r_{01}, \theta_{01}, \varphi_{01}$) and End-coordinates ($r_{02}, \theta_{02}, \varphi_{02}$) in the spherical system
Magnetic dipole	Start-coordinates (x_{01}, y_{01}, z_{01}) and End-coordinates (x_{02}, y_{02}, z_{02}) in the Cartesian system or Start-coordinates ($r_{01}, \varphi_{01}, z_{01}$) and End-coordinates ($r_{02}, \varphi_{02}, z_{02}$) in the cylindrical system Start-coordinates ($r_{01}, \theta_{01}, \varphi_{01}$) and End-coordinates ($r_{02}, \theta_{02}, \varphi_{02}$) in the spherical system

One or several vectors (dipoles) can be used to describe the device for a particular frequency. For a given frequency, each vector must represent either an electric dipole or a magnetic dipole. Thus an electric dipole or a magnetic dipole vector contains two parameter definitions: start-coordinates (x_{01}, y_{01}, z_{01}) and end-coordinates (x_{02}, y_{02}, z_{02}) as proposed in Table 1. It is possible to represent these coordinates in Cartesian coordinate system (x,y,z) or in the cylindrical system (radius:r,azimuth: φ ,height:z) or in the spherical coordinate system (radius:r,elevation: θ ,azimuth: φ). It is possible to represent multiple dipole types for a given frequency as presented in Figure 7.

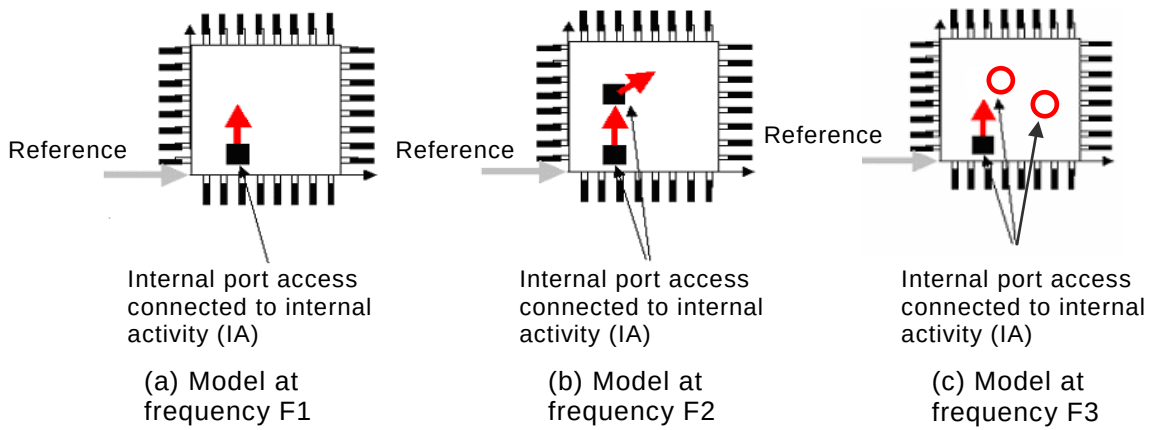


Figure 7 – PDN definition at three different frequencies.

5.3 IA description

An IA sub-model consists of an electric (I_e) or magnetic (I_m) current source, depending on the PDN chosen to define the device. It is assumed that the current in the electric or magnetic dipole is constant over the length of the dipole. The sub-model description is mainly defined in the frequency domain. In some case, description can be done in the time domain. In that case, a Fourier transform can be used to work in the frequency domain. IA will be described by its magnitude and phase extracted from measurements or simulations at a particular frequency. The referential point used when defining the PDN is used as the referential point for the IA. The phase component of the IA is referenced to the phase of the EM fields at the referenced point.

5.4 Electromagnetic field calculation and simulation

Once the PDN and IA are established, the expressions of the electric and magnetic fields radiated at a point M by an electric dipole, deduced from the magnetic vector potential $\vec{A}$, are used to build the model. Thus, the different components ($p = \{x, y, z\}$) of electric and magnetic fields emitted by an electric dipole can be expressed as follows:

$$E_{A,p} = f_{1p}(k, x, y, z, x_{01}, y_{01}, z_{01}, x_{02}, y_{02}, z_{02}, I_e, \varepsilon) \quad 1)$$

$$H_{A,p} = g_{1p}(k, x, y, z, x_{01}, y_{01}, z_{01}, x_{02}, y_{02}, z_{02}, I_e) \quad 2)$$

where f_1 and g_1 are functions depending on the following variables:

- (x, y, z) are the coordinates of the point M where electromagnetic field is evaluated
- (x_{01}, y_{01}, z_{01}) are the coordinates of the start point of the dipole (vector)
- (x_{02}, y_{02}, z_{02}) are the coordinates of the end point of the dipole (vector)
- k is the wave number ($2\pi/\lambda$, λ is the wavelength)
- I_e is the current through the electric dipole, flowing from (x_{01}, y_{01}, z_{01}) to (x_{02}, y_{02}, z_{02})
- ε is the permittivity of the medium in which point M is located

Similarly, the different components ($p = \{x, y, z\}$) of electric and magnetic fields radiated by a magnetic dipole are deduced from the electric vector potential, $\vec{F}$ and are calculated to be:

$$E_{F,p} = f_{2p}(k, x, y, z, x_{01}, y_{01}, z_{01}, x_{02}, y_{02}, z_{02}, I_m, \varepsilon) \quad 3)$$

$$H_{F,p} = g_{2p}(k, x, y, z, x_{01}, y_{01}, z_{01}, x_{02}, y_{02}, z_{02}, I_m, \mu) \quad 4)$$

where f_2 and g_2 are functions depending on the following variables:

- (x, y, z) are the coordinates of the point M where electromagnetic field is evaluated
- (x_{01}, y_{01}, z_{01}) are the coordinates of the start point of the dipole (vector)
- (x_{02}, y_{02}, z_{02}) are the coordinates of the end point of the dipole (vector)
- k is the wave number ($2\pi/\lambda$, λ is the wavelength)
- I_m is the current through the magnetic dipole, flowing from (x_{01}, y_{01}, z_{01}) to (x_{02}, y_{02}, z_{02})
- ϵ is the permittivity of the medium in which point M is located
- μ is the permeability of the medium in which point M is located

The detailed expressions of fields emitted by an electric or magnetic dipole are given in Annex C.

6 REML format

6.1 Preliminary definitions

6.1.1 General

Data of the ICEM-RE model is arranged in XML format, henceforth called as Radiated Emissions Markup Language (REML). The model data is separated into seven parts:

- Header containing general information
- Description of frequencies in which the model is established
- Description of the coordinate system in which details are specified
- Description of the reference point in the specified coordinate system
- Description of the ICEM-RE validity criteria
- Description of the PDN data
- Description of the IA data

Each of the main components composing an REML model definition has a specific data type that is derived directly or indirectly from a single abstract type called REMLBase. The inheritance hierarchy is depicted in Figure 8.

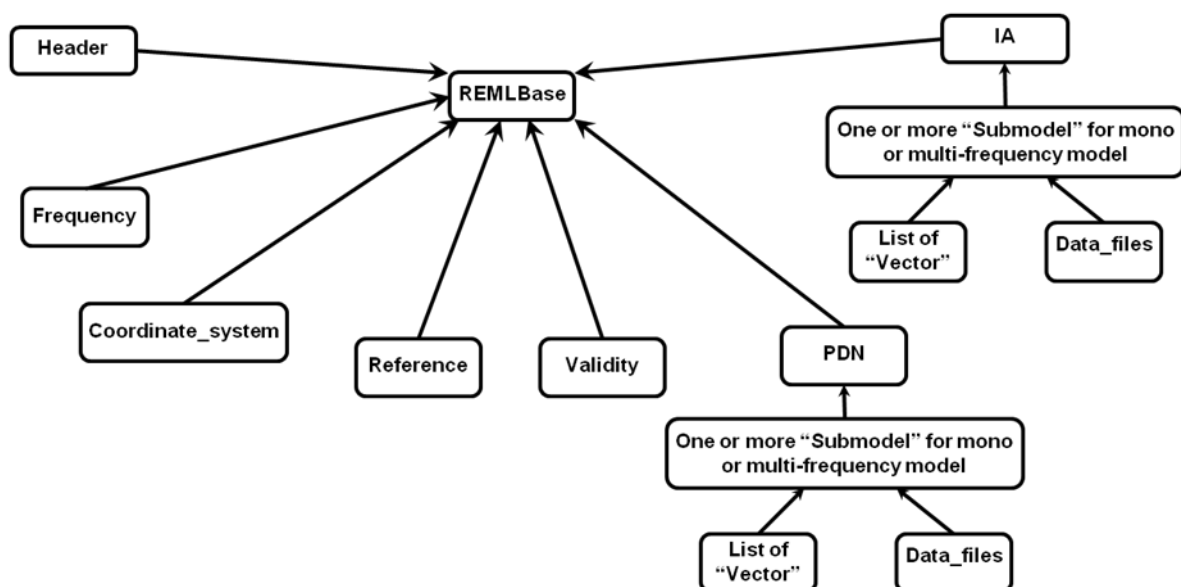


Figure 8 – REML inheritance hierarchy

The top level of a REML model definition consists of these components:

```

beginning of model definition
  model header definition
  frequency definition
  coordinate system definition
  reference point definition
  model validity definition
  model PDN
  model IA
end of model definition

```

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

The XML encoding rules discussed in Annex A ensure that the XML (REML) file can be correctly parsed by a Radiated Emission Model (REM) parser. An example a REML file conforming XML encoding format is given in Annex B.

6.2 REML structure

Considering all the rules defined above, a typical ICEM-RE model file is represented as shown below:

```

<?xml version="1.0" encoding="UTF-8"?>
<Remodel>
  <!-- HEADER -->
  <Header>
    ...
  </Header>
  <!-- FREQUENCY DEFINITIONS-->
  <Frequency>
    ...
  </Frequency>
  <!-- COORDINATE SYSTEM DEFINITION-->
  <Coordinate_system>
    ...
  </Coordinate_system>
  <!-- REFERENCE POINT DEFINITION-->
  <Reference>
    ...
  </Reference>
  <!-- MODEL VALIDITY DEFINITION-->
  <Validity>
    ...
  </Validity>
  <!-- MODEL PDN DATA -->
  <Pdn>
    ...
  </Pdn>
  <!-- MODEL IA DATA -->
  <Ia>
    ...
  </Ia>
</Remodel>

```

REML format is based on XML representation. The basic XML encoding rules in Annex A are applicable for REML structure. The root element of REML file is *Remodel*. All model information must be listed under the root element.

The *Header*, *Frequency*, *Validity*, *Pdn* and *Ia* sections are minimum and mandatory information of the ICEM-RE model. The *Coordinate_system* and *Reference* sections are optional and when absent, the REM parser will assume default values. Each section of the file is presented below.

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 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 `<Remodel> ... </Remodel>`. We chose instead to group them within the XML element `<Header>`, because we believe this helps 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, etc...

An example Header section is shown below:

```
<Remodel>
  <Header>
    <Rem_ver>1.0</Rem_ver>
    <Filename>ExampleICEMRE_file.reml</Filename>
    <File_ver>1.0</File_ver>
    <Author>Valeo 1</Author>
    <Dut>Microcontroller HC68</Dut>
    <Date>August 1, 2013</Date>
    <Meas_method>Near-field scan</Meas_method>
  </Header>
  ...
</Remodel>
```

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

6.5 Frequency definitions

As stated previously, the ICEM-RE model is defined in the frequency domain. The frequency terms and units involved in the model are defined within the *Frequency* and *Unit* tags respectively. The *Unit* tag is a child to the *Frequency* element. An example is shown below:

```
<Remodel>
  ...
  <Frequency>
    <Unit>MHz</Unit>
    <List>
      100 200 300 400 500
    </List>
  </Frequency>
  ...
</Remodel>
```

A minimum of one frequency must be entered in the list. For cases when only one frequency value is to be entered, it is possible to use the numerical value with unit string together as explained in A.2.5.3. An example is shown below:

```
<Remodel>
  ...
```

```

    <Frequency>100MHz</Frequency>
    ...
</Remodel>

```

Nevertheless, the unit can also be optionally described within the *Unit* section as stated below:

```

<Remodel>
    ...
    <Frequency>
        <Unit>MHz</Unit>
        100
    </Frequency>
    ...
</Remodel>

```

It is not possible to create a list of unit definitions under a *Unit* section.

6.6 Coordinate system definition

The coordinate system in which the PDN parameters are defined is specified in this section. As explained in 5.2, the dipole parameters of the PDN can be either expressed in the Cartesian system or in the Cylindrical system or in the Spherical system. Therefore, only the following strings are allowed as a value to this attribute:

- "Cartesian": parameters in Cartesian system (x,y,z)
- "Cylindrical": parameters in Cylindrical system (radial distance:r,azimuth:φ,height:z)
- "Spherical": parameters in Spherical system (radial distance:r,elevation:θ,azimuth:φ)

An example is illustrated below:

```

<Remodel>
    ...
    <Coordinate_system>
        Shperical
    </Coordinate_system>
    ...
</Remodel>

```

This section does not possess any child elements.

This is an optional section. When absent, the default value is "Cartesian" is used for the entire ICEM-RE model.

6.7 Reference definition

The *Reference* section is used to represent the reference point (coordinates) of the PDN and IA data. As explained in 5.2, this coordinate is used as reference for the dipole vector points in the PDN and the phase of the currents flowing through the dipoles in the IA. The coordinates must be specified in the coordinate system defined in the *Coordinate_system* section. The coordinates must always be defined in three-dimensional space in an ordered triplet of axis written in parentheses and separated by commas without any spaces.

The units of the coordinates can be directly passed along with the values of each point as explained in A.2.5.3 or using the global keyword *Unit* (see 6.3). For example:

```

<Remodel>
    ...
    <Coordinate_system>
        Cartesian
    </Coordinate_system>
    <Reference>
        <Unit>mm</Unit>
        (10,6,0)
    </Reference>
    ...

```

</Remodel>

The above lines defined the Reference point in the Cartesian system: 10 mm in x-axis, 6 mm in the y-axis and 0 mm in the z-axis. When defining with Cylindrical or Spherical coordinates, the *Unit* attribute is applied only to the radial distance and height (cylindrical system). The accepted unit is meters ("m") for radial distance with all the valid scaling factors described in A.2.5.5 and degree for angular parameters.

This section is optional. When absent, the default value is (0,0,0).

6.8 Validity section

The *Validity* section is used to represent the conditions in which the ICEM-RE model is defined. This section is strictly informative to the user and independent to all other sections in the REML file.

Table 2 lists the various recognized keywords in the *Validity* section.

Table 2 – 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: Temperature range in which the model is extracted with units (optional)

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

Documentation pertaining to the IC such as datasheets, test-reports, ICEM-RE extraction report etc can 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 test condition such as activated functions, clock details, internal operating points, etc. can 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 *Remodel* root element. For example:

```
<Remodel>
...
  <Validity>
    <Power_supply>9V</Power_supply>
    <Frequency_range>40MHz</Frequency_range>
    <Temperature>25degrees</Temperature>
    <Notes>Quartz=20MHz, Iin=10mA, PLL unused</Notes>
  </Validity>
...
</Remodel>
```

6.8.1 Attribute definitions

6.8.1.1 Power_supply

The *Power_supply* attribute is used define the supply conditions for which ICEM-RE is valid. This attribute informs the user that the ICEM-RE model is extracted in the specified supply range. The value of this attribute is a data string containing valid text string and/or numerical values with our without units. This is a required field.

6.8.1.2 Frequency_range

The *Frequency_range* attribute is used to define the frequency range in which ICEM-RE is valid. This attribute informs the user that the ICEM-RE model is extracted in the specified frequency range and is usable in the same range. The value of this attribute is a data string containing valid text string and/or numerical values with or without units.

The value of this attribute can be different from that specified within the *Frequency* section, but shall not contradict the same. For example, the *Frequency* section can contain a list of frequencies, but the *Frequency_range* attribute of the *Validity* section can contain a single value defining the whole frequency range as illustrated below:

```
<Remodel>
  ...
  <Frequency>
    <List>
      10MHz, 30MHz, 100MHz, 300MHz, 500MHz, 700MHz, 900MHz, 1100MHz
    </List>
  </Frequency>
<Validity>
  ...
  <Frequency_range>[10MHz - 1.1GHz]</Frequency_range>
  ...
</Validity>

</Remodel>
```

For a single-frequency model, both the sections would carry similar information. The main purpose of this attribute is to inform the user about the model validity and thus any contradiction will induce misunderstanding.

NOTE Contradiction between the *Frequency_range* definition and *Frequency* definition will not stop model annotation since the *Validity* section is only for user information. REM parser will use the *Frequency* section for model annotation irrespective of what is specified in the *Validity* section.

This is a required field.

6.8.1.3 Temperature

The *Temperature* attribute is used to define the temperature range in which ICEM-RE is extracted. The value of this attribute is a data string containing valid text string and/or numerical values with or without units. This is an optional field. It defaults to "Unknown" when absent.

6.9 PDN

6.9.1 General

The *Pdn* section of the ICEM-RE model contains the PDN data that describes the model. In order to represent both mono-frequency PDN and multi-frequency PDN, the data must be defined within the *Pdn* keyword using the *Submodel* tag as follows:

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

The unit of the PDN data can be specified within the *Unit* tag under the *Pdn* element. The accepted unit for the PDN is meters ("m") with all the valid scaling factors described in A.2.5.5.

The PDN data pertaining for a given frequency is specified within a *Submodel* section. The frequency of each *Submodel* is also defined within. On one hand, mono-frequency ICEM-RE contains one and only *Submodel* entity with the *Pdn* tag. On the other hand, a multi-frequency ICEM-RE contains multiple *Submodel* elements listed one below another. See Figure 8 for the structural hierarchy.

When many *Submodel* sections are present within a *Pdn* element, the REM parser will check if the total number of *Submodel* sections equals the total number of frequency terms present in the *Frequency* section (see 6.5 for more information).

The frequency range of the PDN shall be specified in the *Validity* section with the *Frequency_range* tag (see 6.8 for more information).

NOTE The frequency range of validity of the PDN is the same as that of the IA.

Table 3 lists the various recognized keywords in the *Submodel* section.

Table 3 – Definition of the Submodel section of the Pdn element

Submodel
Frequency_value: Frequency at which the model parameters are defined (required for multi-frequency PDN, else optional)
Frequency_unit: Defines the unit of the frequency term (optional)
Vector: Keyword for defining the a single dipole vector (required)
List: PDN source parameter defined inline (required if not Data_files)
Data_files: PDN source parameter defined in an external file (required if not List)

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's operating mode, decoupling capacitors on supply lines, activated functions, grounding details, datasheets, test-reports, etc can be defined.

6.9.2 Attribute definitions

6.9.2.1 Frequency_value and Frequency_unit

The *Frequency_value* attribute is used to define the specificity and validity of the *Submodel*. The listed PDN vectors within this section are defined for that frequency. It is possible to use both numerical value and units together as described in A.2.5.3.

The *Frequency_unit* is an optional attribute to define the units of the frequency term defined in the *Frequency_value* attribute. If this field is absent, default SI unit ("Hz") is used.

For each *Submodel* element within the *Pdn* section, the REM parser will link a data structure by attaching the value defined *Frequency_value* field of the *Submodel* element with one of the values defined in the *Frequency* element. If a match is not found, then the particular *Submodel* is not annotated by the REM parser.

6.9.2.2 Vector

Each dipole defining the PDN data is defined within a *Vector* tag in the specified coordinate system (see 6.6) with respect to the reference point specified in the *Reference* section (see 6.7).

If the ICEM-RE PDN contains only one *Vector* element, then the corresponding *Vector* is directly defined under the *Submodel* section defined at a particular frequency.

If the PDN at a particular frequency is defined with multiple dipole vectors, then the different *Vector* elements are listed under a *Submodel* section using a *List* Keyword. Table 4 lists the various recognized fields of the *Vector* keyword in the *Pdn* section:

Table 4 – Definition of the Vector keyword in the Pdn section

Vector
Type: Type of the dipole source: "Electric", "Magnetic" (required) Name: Name of the dipole describing the PDN - Any valid string. Shares the same namespace with the IA vector element (required) Start: Start-coordinates of the dipole: "(x ₀₁ ,y ₀₁ ,z ₀₁)" or "(r ₀₁ ,θ ₀₁ ,φ ₀₁)" or "(r ₀₁ ,φ ₀₁ ,z ₀₁)" (required) End: End-coordinates of the dipole "(x ₀₂ ,y ₀₂ ,z ₀₂)" or "(r ₀₂ ,θ ₀₂ ,φ ₀₂)" or "(r ₀₂ ,φ ₀₂ ,z ₀₂)" (required)

The *Type* attribute tells the REM parser on what kind of dipole is used. The dipole type can be either "Electric" or "Magnetic" signifying electric or magnetic dipoles respectively. This is a mandatory field. If undefined, the REM parser will not decipher the information of the particular Vector.

The *Name* field specifies a valid name of the dipole. This is a mandatory field and shares the same namespace with the IA data as described in 6.10. A dipole vector with a specific name in the *Pdn* shall find its IA counterpart in the *Ia* section. It must be valid string containing alphanumerical characters. If undefined, the REM parser will not read the information of the particular vector.

The *Start* and *End* attributes are used to define the start and end-coordinates of the dipole respectively. The coordinates must be represented in the coordinate system defined in the *Coordinate_system* tag. The coordinates must always be defined in three-dimensional space in an ordered triplet of axis written in parentheses and separated by commas without any spaces. Both these fields are mandatory. The *Vector* entity is invalid if either of them is empty / undefined. The coordinates may or may not contain local units defined along with the numerical value. When units are used, they are used as first choice.

6.9.2.3 List

The *List* attribute tells the REM parser that the ICEM-RE PDN information is defined inline and is constituted of several dipole vectors. The dipoles constituting the ICEM-RE PDN are listed one after another with the *List* entity to define the PDN information using the *Vector* Keyword (see 6.9.2.2). A detailed illustration of the *List* usage in the *Pdn* tag is done in 6.9.3.2.

6.9.2.4 Data_files

The *Data_files* attribute tells the REM parser that the PDN information is available in an external data file. When used, the "Type", "Name", "Start" and "Stop" fields are specified in the external file. All header information pertaining to data description as comment lines should start with an exclamation mark ("!") as the first character of the line. A detailed description of the *Data_files* usage in the *Pdn* tag is done in 6.9.3.3.

6.9.3 PDN of a single-frequency ICEM-RE

6.9.3.1 General

This is the simplest form of PDN representation. The PDN data consisting of several dipole vectors must be listed in the *Submodel* section using a *List* Keyword. If the PDN data contains only one dipole vector, then it can be directly specified under the *Submodel* section. The different attributes of the *Submodel* section of the *Pdn* along with their usage for single-frequency ICEM-RE model is shown in Table 5.

Table 5 – Valid fields of the Submodel keyword for single-frequency PDN

Field	Description	Usage	Rules
Frequency_value	Attribute to specify the frequency term of the PDN	Required	A valid value with or without units
Frequency_unit	Attribute to specify the units of the frequency term of the PDN	Optional	A valid unit string
Vector	Keyword for defining the coordinates of the dipole vectors	Required	Vector entities are listed one after another within a List element.
List	Section for defining the dipole vectors for one frequency	Required if not Data_files or unique dipole PDN	Several Vector entities are listed one after another
Data_files	Keyword for representing PDN parameters with an external file	Required if not List or unique dipole PDN	Valid for external ASCII file with PDN data. One definition per Submodel section is valid

The compositions of all the above attributes have been described in 6.9.2. The REM parser understands that the PDN is for a single-frequency when the conditions in Table 6 are met. All other conditions are invalid.

Table 6 – Conditions for correct annotation of single-frequency PDN by the REM parser

No. of terms in Frequency section	No. of Submodel sections	Status
1	1	Valid

Table 7 lists the valid fields of a *Vector* structure for a single-frequency PDN definition and their usage in the *Submodel* section.

Table 7 – Valid fields of the Vector keyword for single-frequency PDN

Field	Description	Usage	Rules
Type	Type of dipole	Required	Valid string: "Electric" or "Magnetic"
Name	Name of the dipole vector	Required	Valid string. Cannot be reused within the same section
Start	Start coordinates of the vector	Required	Coordinates in triplet in Cartesian, cylindrical or spherical system enclosed in parenthesis, separated by a comma: "(x,y,z)"
End	End coordinates of the vector	Required	Coordinates in triplet in Cartesian, cylindrical or spherical system enclosed in parenthesis, separated by a comma: "(x,y,z)"

The details of all the above attributes have been described in 6.9.2.2.

6.9.3.2 Inline PDN data: single-frequency

Dipole vector PDN data is listed with the use of *Vector* tags within a *Submodel* section with or without a *List* tag. Each *Vector* entity must carry a unique *Name* attribute in a given *Submodel* section. An example of a mono-frequency PDN at 500 MHz is shown below. Also note that units have been defined in the *Reference* section.

```

<Remodel>
  <Header>
    ...
  </Header>
  <Frequency>
    <Unit>MHz</Unit>
    500
  </Frequency>
  <Coordinate_system>Cartesian</Coordinate_system>

```

```

<Reference>
  <Unit>mm</Unit>
  (0,0,0)
</Reference>
<Validity>
  <Power_supply>5V</Power_supply>
  <Frequency_range>500MHz</Frequency_range>
</Validity>
<Pdn>
  <Unit>mm</Unit>
  <Submodel Frequency_value="500MHz">
    <List>
      <Vector Type="Electric";Name="Dipole1">
        <Start>(0,0,0)</Start>
        <End>(.2,.2,0)</End>
      </Vector>
      <Vector Type="Electric";Name="Dipole2">
        <Start>(1,1,0)</Start>
        <End>(1.5,1,0)</End>
      </Vector>
      <Vector Type="Magnetic";Name="Dipole3">
        <Start>(1.25,0,0)</Start>
        <End>(2.25,0,0)</End>
      </Vector>
      ...
    </List>
  </Submodel>
</Pdn>
<Ia>
  ...
</Ia>
</Remodel>

```

6.9.3.3 External file PDN data: single-frequency

For directing the REM parser to use the necessary external data file in ASCII format, definition must be made using *Data_files* keyword. A typical PDN data must be represented as shown in Figure 9.

```

!Dipole data at frequency=100MHz
!type Name Start End
0 Dipole1 (0,0,0) (.2,.2,0)
0 Dipole2 (1,1,0) (1.5,1,0)
1 Dipole3 (1.25,0,0) (2.25,0,0)
...

```

Figure 9 – Format for defining PDN vector data in an external file

All comment lines must start with an exclamation mark ("!"). The first column of the file must contain data pertaining to the type of dipole. For simplifying the parsing of data, type="0" represents electric dipole and type="1" represents magnetic dipole. However, it is also allowed to use "Electric" and "Magnetic" as terms in the type column. The second column contains the name of the dipole as a valid string. The third and fourth columns define the "Start" and "End" coordinates of the dipole vector. It is also possible to specify the numerical value along with units for the "Start" and "End" coordinates (each value of the triplet). Each column of the file can be delimited by any of the following characters: space (" "), comma (","), semi-colon (";"), and tab. No other delimiters are allowed.

Similar to the example in 6.9.3, PDN information (*Vector* entities) can be listed under the *Submodel* section. The same example can be represented with the data file as shown below:

```

<Remodel>
  <Header>

```