TECHNICAL REPORT

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First edition
2002-12

Electronic design automation libraries –

Part 3:
Models of integrated circuits for EMI behavioural simulation

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ELECTRONIC DESIGN AUTOMATION LIBRARIES –

Part 3: Models of integrated circuits for EMI behavioural simulation

FOREWORD

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IEC 62014-3, which is a technical report, has been prepared by IEC technical committee 93: Design automation.

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

Enquiry draft	Report on voting
93/146/DTR	93/157/RVC

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

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

The committee has decided that the contents of this publication will remain unchanged until 2005. At this date, the publication will be

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- withdrawn;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

ELECTRONIC DESIGN AUTOMATION LIBRARIES –

Part 3: Models of integrated circuits for EMI behavioural simulation

1 Scope

The objective of this Technical Report (TR) ICEM (Integrated Circuit Electrical Model) for Components is to propose electrical modelling for integrated circuit internal activities. This model will be used to evaluate electromagnetic behaviour and performances of electronic equipment.

1.1 General

Integrated circuits integrate more and more gates on silicon and the technologies are faster and faster. To predict the electromagnetic behaviour of equipment, it is required to model IC interface switching and their internal activities as well. Indeed IBIS and IMIC models are focused mainly on interface activity predictions (cross-talk, overshoot, etc.). See IEC 62014-1.

This report describes a model for EMI simulation due to IC internal activities. This model gives more accurately the electromagnetic emissions of electronic equipment by taking into account the influence of internal activities. This model gives general data which could be implemented in different format such as IBIS, IMIC, SPICE, etc.

During the design stage of the application that will exploit the IC, it becomes useful to predict and to prevent electromagnetic risks with the CAD tool. Accurate IC modelling is necessary to run on these simulation tools.

Three coupling mechanisms of the internal activities for emission (Figure 1) are proposed in the ICEM model:

- conducted emissions through supply lines;
- conducted emissions through input/output lines;
- direct radiated emissions.

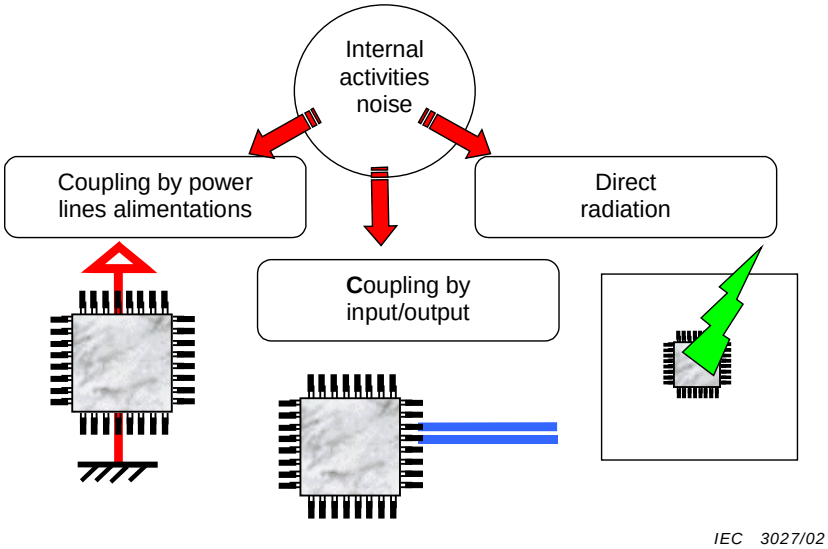

Figure 1 – Mechanisms for parasitic emission covered by ICEM

This report proposes a model that addresses those three types of coupling in a single approach. The elements of the model would be kept as simple as possible to ease the identification and simulation process.

1.2 Philosophy

The purpose of this report is to provide data to enable printed-circuit-board level (PCB) electromagnetic tools to compute the electromagnetic fields produced by integrated circuits and their associated PCB. These data can be extracted from measurement methods, as described in IEC 61967, or obtained from IC simulation tools.

1.2.1 Origin of parasitic emission

The origin of parasitic emission in IC is due to the current flowing through all the IC gates (*Iv* and *Iv*) during high to low or low to high transitions as shown in Figure 2.

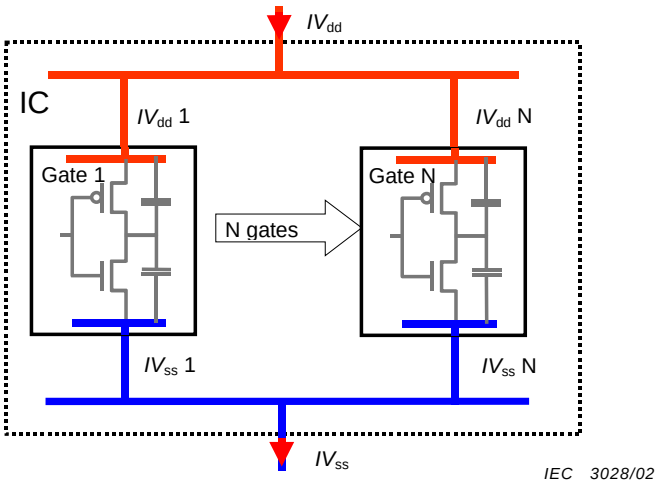

Figure 2 – The basic mechanism for parasitic emission is due to the current driving by all the gates

The combination of several hundred thousands of gates lead to very important peaks of current, mainly at rise and fall edges of the clock circuit. For example Figure 3 plots the number of gates switching versus the time for an IC integrating 1 000 000 transistors. Consequently, high current spikes are created inside the die and induce voltage drops of the internal voltage references.

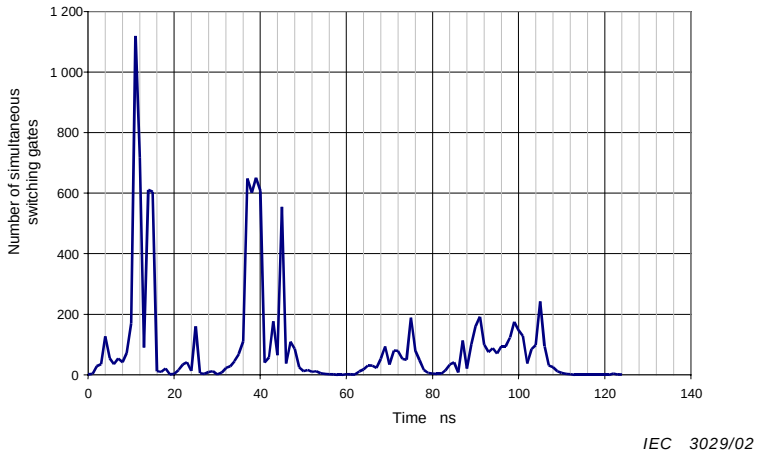

Figure 3 – Number of switching gates versus time

1.2.2 Conducted emission through power-supply lines

The current spikes created inside the die are partially reduced thanks to the on-chip decoupling capacitance. Anyhow, a significant portion of the current spikes is present at the power-supply pins of the chip. This current could be measured according to IEC 61967 or other methods permitting to have the power-supply currents.

1.2.3 Conducted emissions through input/output lines (I/O)

The internal voltage drops generated by the current spikes create noise on the I/Os through direct connection, parasitic capacitive and inductive couplings and/or through common impedance. The PCB wires connected to the I/O can act as antennas and propagate electromagnetic emissions. The measurement set-up is done according to IEC 61967.

1.2.4 Direct radiated emissions

The internal current flowing in low impedance loops generates electromagnetic fields which can be measured in near field according to IEC 61967.

2 Normative references

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

IEC 61967-1, *Integrated circuits – Measurement of electromagnetic emissions, 150 KHz to 1 GHz – Part 1: General conditions and definitions*

IEC 61967-4, *Integrated circuits – Measurement of electromagnetic emissions, 150 kHz to 1 GHz – Part 4: Measurement of conducted emissions, 1 Ω /150 Ω direct coupling method*

IEC 61967-6, *Integrated circuits – Measurement of electromagnetic emissions, 150 kHz to 1 GHz – Part 6: Measurement of conducted emissions – Magnetic probe method*

IEC 62014-1, *Electronic design automation libraries – Part 1: Input/output buffer information specifications (IBIS version 3.2)*

3 Terms and definitions

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

3.1
ElectroMagnetic Compatibility EMC
ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbance to anything in that environment

3.2
electromagnetic emission
phenomenon by which electromagnetic energy emanates from a source

3.3
electromagnetic radiation

a) the phenomena by which energy in the form of electromagnetic waves propagates from a source into space

b) energy transferred through space in the form of electromagnetic waves

4 ICEM models description

The proposed model includes 3 sections which describe the 3 coupling mechanisms of the internal activities for emission introduced in Part 1:

- ICEM power-supply line model for conducted emissions through supply lines;
- ICEM input/output for conducted emissions through input/output lines;
- ICEM direct radiation for direct radiated emissions.

Models are defined with electrical schematics described below for each IC pin.

4.1 ICEM power-supply line model

The IC equivalent model shown in Figure 4 is able to determine the peak harmonics spectrum and main resonances.

This model consists of:

I_b current generator,
$LpackV_{dd}$ package inductance of the positive supply V_{dd},
$LpackV_{ss}$ package inductance of the ground V_{ss},
$RpackV_{dd}$ package resistor of the positive supply V_{dd},
$RpackV_{ss}$ package resistor of the ground V_{ss},
C_d parasitic capacitor between V_{dd} and V_{ss} package pins,
Rv_{dd}, series resistor of V_{dd}, bonding and die connection,
Rv_{ss}, series resistor of V_{ss}, bonding and die connection,
Lv_{dd}, inductance of V_{dd}, bonding and die connection,
Lv_{ss}, inductance of V_{ss}, bonding and die connection,
C_b internal die capacitor.

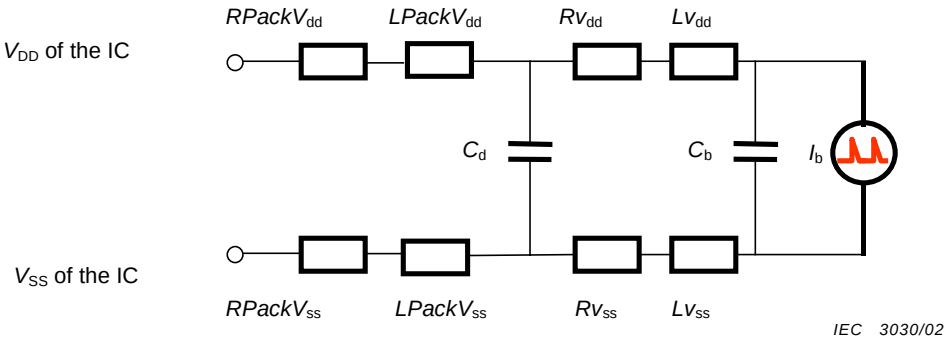

Figure 4 – Model of the IC supply lines

4.1.1 First and second order effects

The inductance of the package $LpackV_{dd}$, $LpackV_{ss}$, in series with the capacitance C_d create a first resonance, while the serial inductances Lv_{dd}, Lv_{ss}, in series with the local block capacitance C_b create a second resonance (Figure 5).

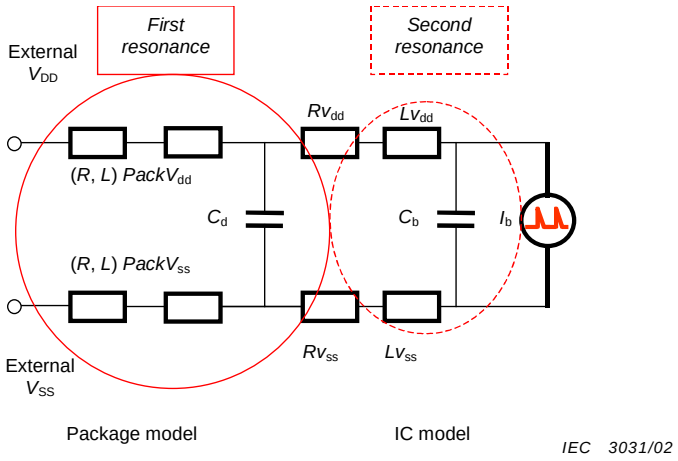

Figure 5 – Origin of primary and secondary resonance in the IC model

Taking into account second order effects in the proposed model give more accurate simulation results regarding measurement results, as shown in Figure 6.

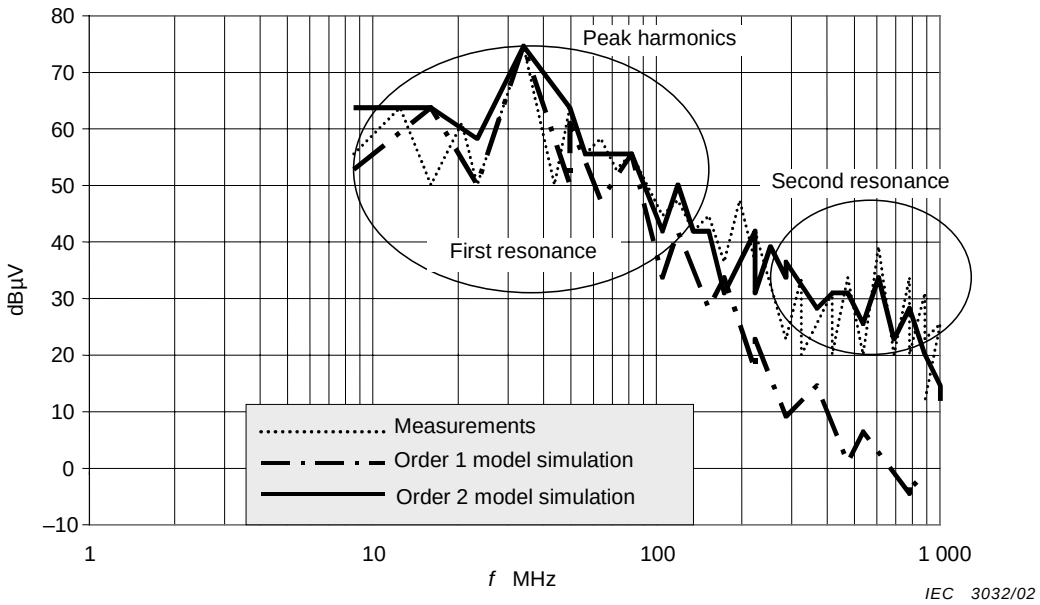

Figure 6 – Comparison between simulation and measurements (IEC 61967-4, 1 Ω method)

4.2 ICEM Input/output

4.2.1 Single supply structure

Disturbances on I/O are mainly due to the current flow in the supply and ground impedances added to I/O stage. The ICEM Input/output is modelled by the superposition of that internal current noise with functional signals.

Functional signals are described with models such as IBIS, IMIC or SPICE. The I/O on which the simulation is performed could be active or not. When other I/Os are activated on the same power lines a new equivalent current generator, $I_{i/o}$, representing peripheral activity, must be added in parallel to the generator representing the internal activity I_b.

The schematic of the model is reported in Figure 7.

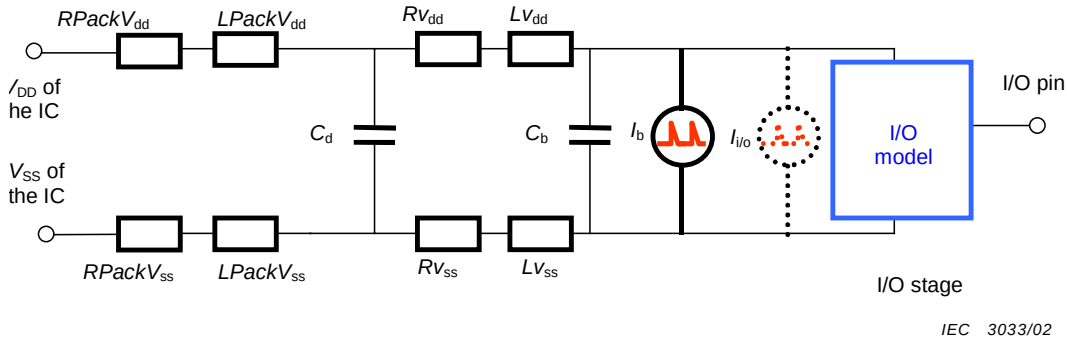

Figure 7 – Coupling between core and I/Os

NOTE Frequency limits of functional I/O models would be taken into account for EMC high frequency simulation. For instance a second order model would be defined, bonding and package elements, to simulate the resonances.

4.2.2 Multiple supplies structure

In many cases, the core supply and the I/O supply have separate internal networks. The core model is still identical, but two supplementary components are inserted, as illustrated in Figure 8. The first parameter, named Z_{sub}, accounts for the substrate coupling path between the core V_{ss} and the I/O V_{ss}. The second parameter is the decoupling capacitance between I/O supplies, named C_{io}.

When other I/O's are activated on the same power lines a new equivalent current generator, $I_{i/o}$, representing peripheral activity, must be added to the generator representing the internal activity I_b.

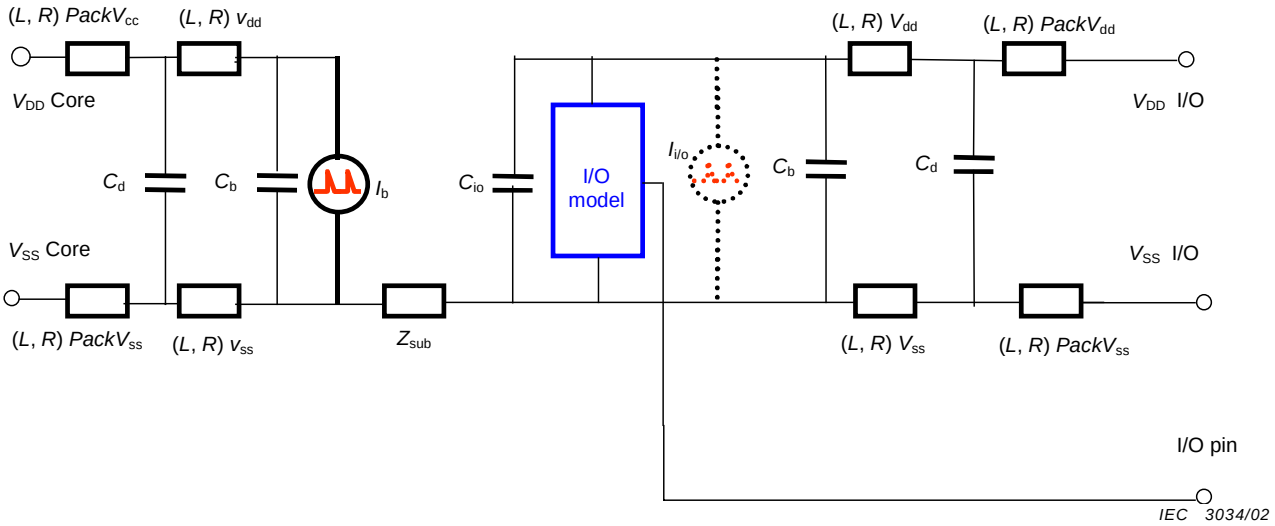

Figure 8 – Coupling between core and I/Os in the case of separate supplies

NOTE Frequency limits of functional I/O models would be taken into account for EMC high frequency simulation. For instance, a second order model would be defined bonding and package elements, to simulate the resonances.

4.3 ICEM direct radiation

Electromagnetic emission could radiate directly from IC itself. The level is closely linked to current flowing in internal loops on package and on die.

The radiated electromagnetic emission will be characterized by measurement methods which measure direct radiation as for instance described in IEC 61967-2 in TEM cell.

Figure 9 shows measurement results in TEM cell with 2 microcontrollers

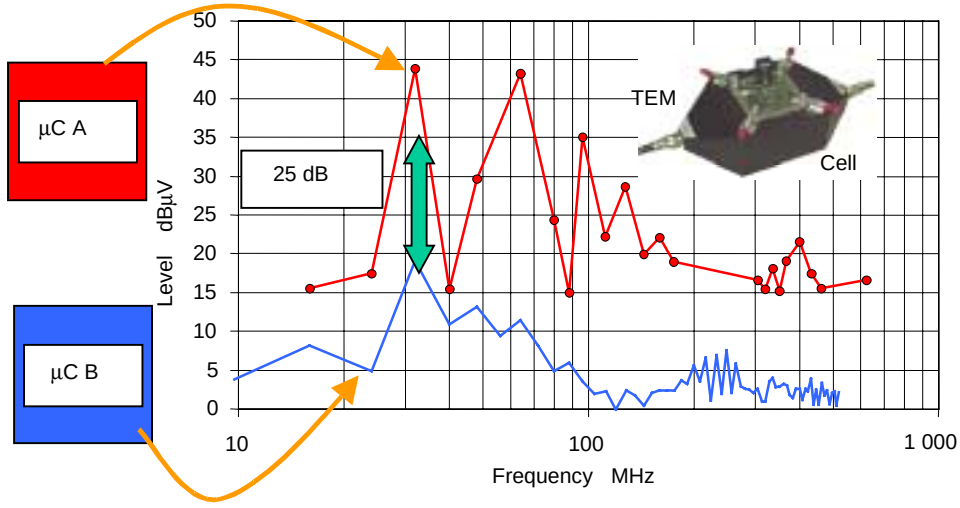

Figure 9 – IC direct emissions measured in TEM cell

Model parameters would be electrical parameters as internal currents and geometrical parameters as die size, internal loops area and package characteristics.

4.3.1 ICEM direct radiated model

This model would be based on an equivalent representation with dipoles.

It will be possible to implement it in models like IBIS, IMIC or SPICE.

The model is under definition and will be completed in future.

5 ICEM models parts details

The model parts are detailed in this clause. The current generator I_b, the decoupling capacitance, the serial resistances and inductances and the local block capacitance are reviewed.

Methods to determine model parts values are also considered in this clause.

5.1 Passive parts parameters

Passive components of the model are: $LpackV_{dd}$, $LpackV_{ss}$, C_d, Rv_{dd}, RV_{ss}, LV_{dd}, LV_{ss}, C_b, $C_{i/o}$, and Z_{sub}.

$LpackV_{dd}$, $LpackV_{ss}$ are package inductances.

C_d represents the parasitic capacitor between V_{dd} and V_{ss} package pins.

Rv_{dd}, RV_{ss} series resistances of the supply network model the metal interconnect that connects the block supply to the main supply ring, which goes to the external supply through specific pads.

LV_{dd}, LV_{ss} series inductances of the supply network model the metal interconnect that connects the block supply to the main supply ring.

C_b is the internal die capacitor, placed in parallel with the local current generator. It accounts for the equivalent decoupling capacitance of the block.

$C_{i/o}$ is the internal die capacitor, placed in parallel with the I/O block (Figure 8). It accounts for the equivalent decoupling capacitance between I/Os power supply lines.

Z_{sub} coupling impedance is valid for most CMOS technologies with P-type substrate. It accounts for the substrate coupling path between the core V_{ss} and the I/O V_{ss}.

Value ranges of these components are given in Table 1.

Table 1 – Value range of the model parameters

Part name	Minimum value	Maximum value
LpackV , *LpackV*	1 nH	10 nH
C	10 pF	100 nF
Rv , *RV*	0,1 Ω	10 Ω
LV , *LV*	1 nH	20 nH
C	10 pF	100 nF
C	10 pF	100 nF
Z d.c. value	0 Ω	100 Ω

These values are for informative purpose only. They may vary with new technologies.

In order to perform accurate simulations, the values of these parameters would be accurately determined for each specific case.

5.1.1 Measurement of part values

Input impedance would be measured according to the time domain recflectometry method (TDR) or with a network analyzer.

From the measurement results and the already known data (e.g. package) it is possible to extract all the part values using mathematical procedures.

5.1.2 Prediction of part values

Part values could be determined with IC design tools which compute the RLC parameters from geometrical and electrical characteristic of IC.

5.2 The current sources I_b and $I_{i/o}$

The main source of parasitic emission considered in the model is the current source *I* . The current shape may consist of the time-domain description of the current in PWL (Piece Wise Linear) format (Figure 10).

Typical values for *I* are several mA, up to 1 A for the amplitude, 0,1 to 5 ns for duration, and 500 ps to 50 ns for the period. These values are closely dependent on the software running.

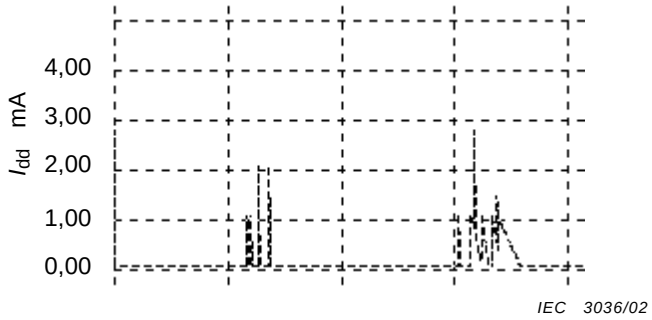

Figure 10 – Current source definition as a PWL description versus time

5.2.1 Measurement of I_b and $I_{i/o}$

External current will be measured, with or without I/O activities, but according to the measurement method described in IEC 61967. The software would be clearly described during that test.

A reverse engineering simulation of this external current with previous parameters permits then to extract the internal current value. In the case of a single supply line, the I_b current is obtained taking account of the $I_{i/o}$s currents values following the interfaces are working or not. In case of multiple supply lines, each current is measured separately. So, the reverse engineering process is used similarly for the two currents.

Annex A

Simulation tools implementation

The ICEM model described in this report includes additional elements specified to provide a capability to simulate EMC/EMI performances of a complete application or to optimize the PCB layout regarding EMC/EMI phenomena. Such simulation can also help to select active and passive components.

To perform an EMC/EMI simulation the different elements of the model previously defined need to be implemented in a software simulation tools.

This implementation and the exact definition of the final model depend on the software tool used and also is based on the model type required, Spice for real time simulation or IBIS and IMIC for behavioural modelling.

SPICE MODELLING

If the software tools uses SPICE models, the element of the ICEM models have to be directly added to the spice electrical models so that the simulation can take into account the noise due to internal activity of the ICs.

IBIS MODELLING

If the software tool require the IBIS modelling format, the element can be described as data files and these additional files need to be added to the model description under IBIS format, for example specific keywords.

Evaluation of a new IBIS release including EMC modelling is ongoing based on this report.

IMIC MODELLING

Same comment as the ones done on IBIS modelling may be done on IMIC.

Evaluation to include the EMC elements of the ICEM model in the next release has to be done.

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