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TECHNICAL REPORT

RAPPORT TECHNIQUE

colour inside

EMC IC modelling – Part 2-1: Theory of black box modelling for conducted emission

Modèles de circuits intégrés CEM – Partie 2-1: Théorie du modèle de la boîte noire pour les émissions conduites

IEC/TR 62433-2-1:2010

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FOREWORD

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IEC 62433-2-1, which is a technical report, has been prepared by subcommittee 47A: Integrated circuits, of IEC technical committee 47: Semiconductor devices.

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

Enquiry draft	Report on voting
47A/826A/DTR	47A/834/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.

A list of all parts of IEC 62433 series, under the general title *EMC IC modelling*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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EMC IC MODELLING –

Part 2-1: Theory of black box modelling for conducted emission

1 Scope

This part of IEC 62433-2-1 covers black box modelling which has the potential to make the modelling of conducted emission very simple, very fast, and can provide complete protection of proprietary information of IC vendors.

This technical report is intended to provide the theoretical background on black box modelling for IC conducted emission.

2 Integrated circuit and modelling board

Figure 1 shows an integrated circuit (IC) and a modelling board. The IC is equipped with power/ ground pins, output pins and input pins. Usually an IC requires different power supply connections, namely, to supply digital cores, I/Os, and analogue circuits. Each one of these power supplies may have plural pins.

An IC cannot be activated by itself. To activate the IC properly, the IC has to be provided with power supplies, a set of input signals or an input signal vector, and appropriate loads for output pins.

To achieve these requirements, the modelling board is used. The modelling board provides minimum requirements for the activation. It supplies power, and input signals to the IC, and it gives typical loads for the output pins. In addition, power/ ground pins of the same category are connected to each other in the modelling board resulting in one terminal for each category of the power/ ground supply at the interface of the modelling board.

The board is also used for parameter extractions for modelling the IC. The IC modelling includes the board. The relationship between the IC modelling and the modelling board is just like the relationship between measured data and measurement board that affects measurement data. Therefore the modelling board should be as simple and general as possible.

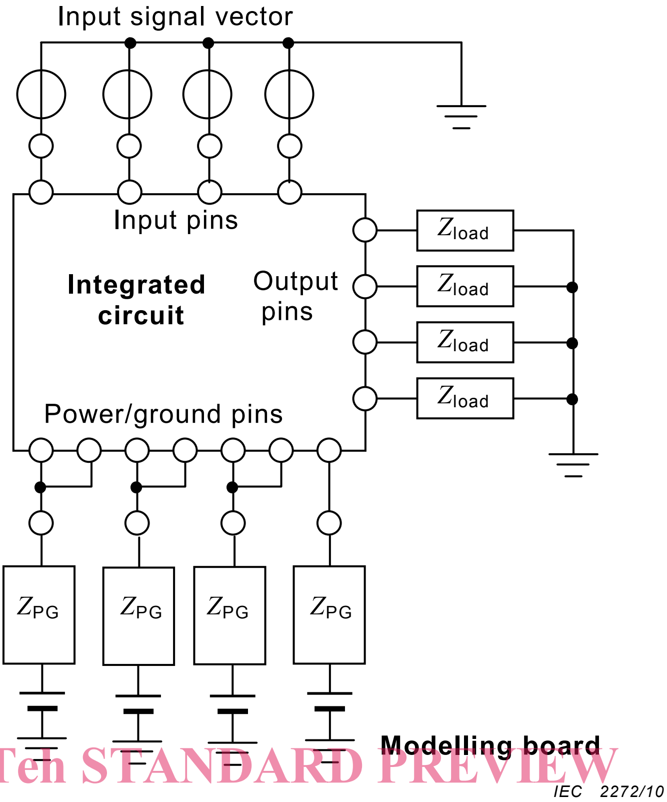

Figure 1a) – Entire structure

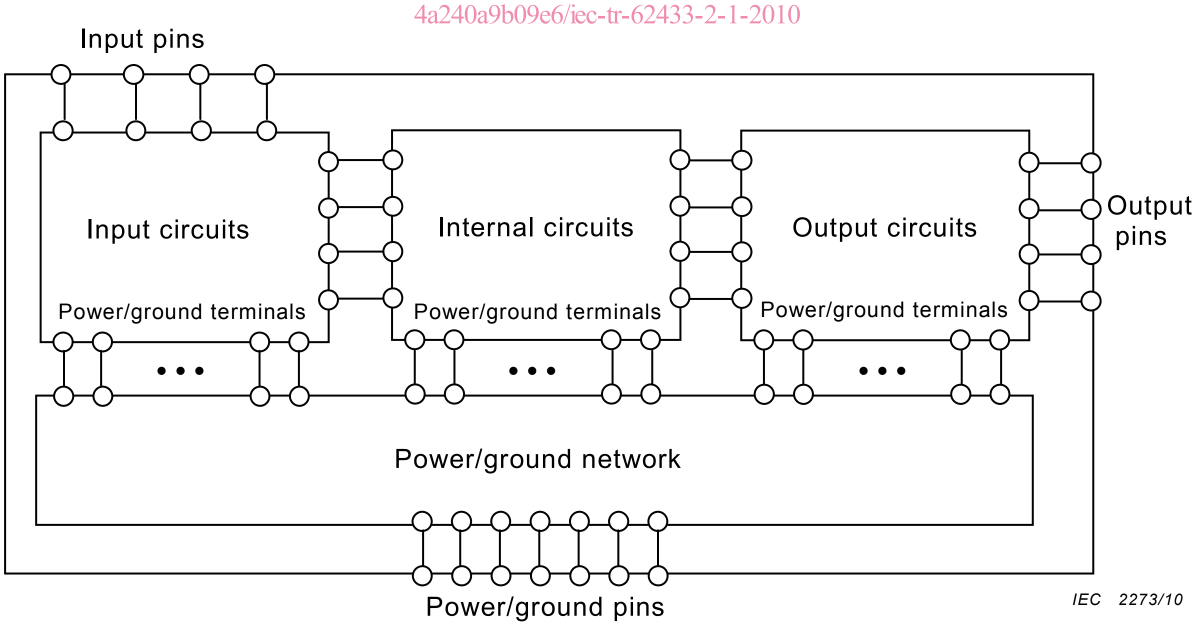

Figure 1b) – Structure of the IC part

Figure 1 – Integrated circuit and its modelling board

3 Assumptions

3.1 ICEM-CE

ICEM-CE is a macro model that approximates conducted emission behaviour of an IC using two types of components, internal activity (IA) and passive distribution network (PDN) as shown in Figure 2. These two types of components are connected through internal terminals (ITs).

The IAs represent noise sources that originate in switching of active devices within the IC. The PDN represents noise propagation characteristics from the internal terminals to the external terminals (ETs).

The black box modelling is based on this ICEM-CE model structure.

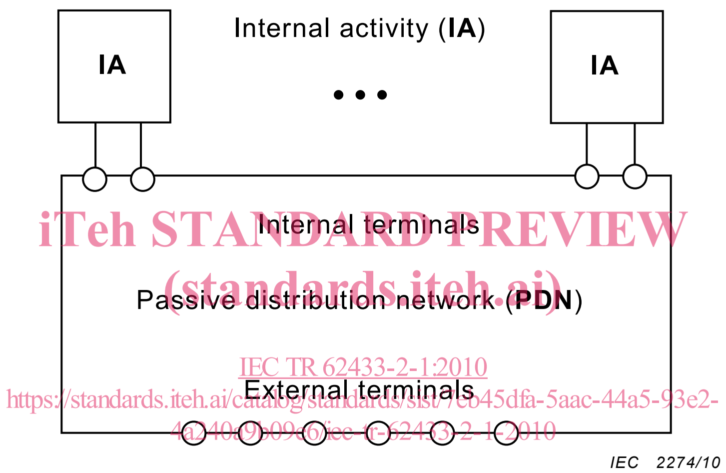

Figure 2 – Basic ICEM-CE model structure for an IC

Figure 3 shows how to make an ICEM-CE model for the example of an IC and its modelling board shown in Figure 1. Figure 3a) shows the assignment of IA and PDN. The IA part includes input vector generators and output loads on the modelling board. The PDN part consists of the IC PDN part and Board PDN part. The IC PDN part consists of the power/ ground network of the die and the package of the IC. Figure 3b) shows the ICEM-CE structure of the IC and its modeling board with IAs and PDNs.

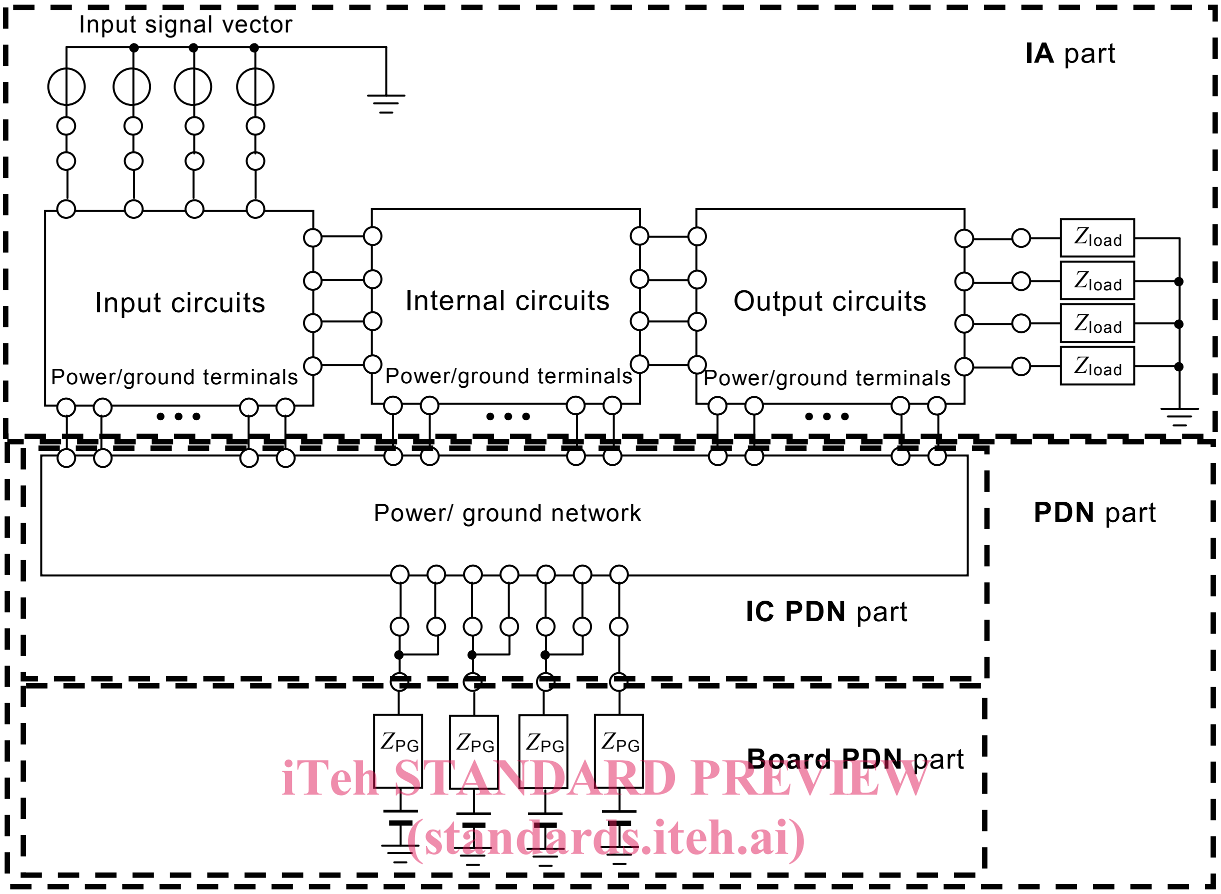

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Figure 3a) – IA and PDN assignment

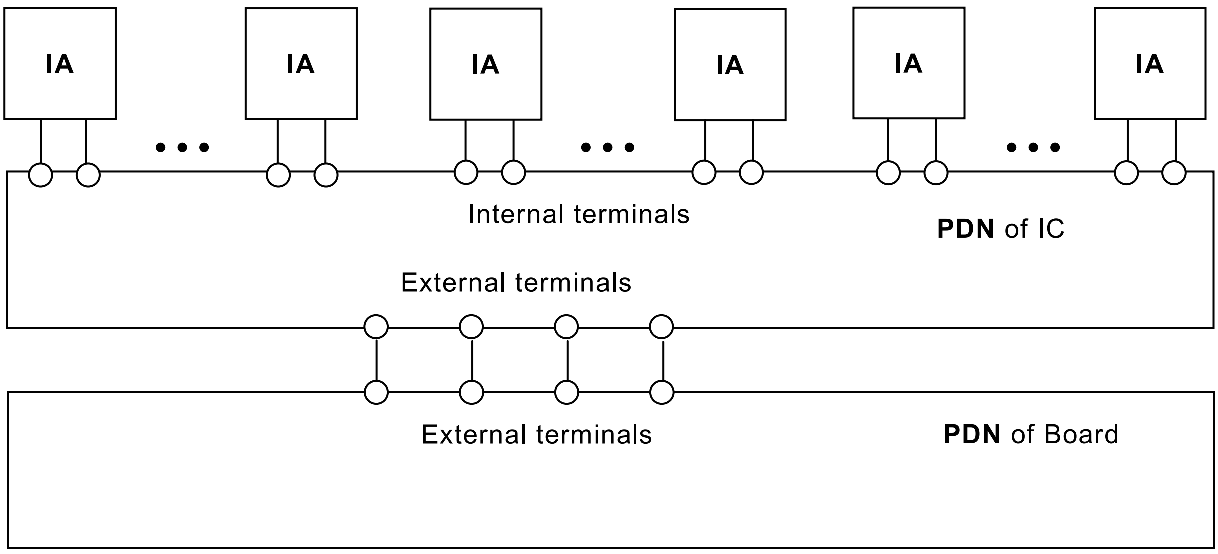

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Figure 3b) – ICEM-CE representation

Figure 3 – Representation of the integrated circuit and its modelling board by ICEM-CE

3.2 Black box model

In black box modelling, the PDN is described using a numerical matrix. To represent the PDN using a matrix, the PDN is assumed to be a linear circuit. Although the PDN is usually non-linear, this assumption is generally valid because noise voltages are small enough.

The elements of the matrix depend on noise frequency. Therefore, the PDN and the IAs should be described in frequency domain, and the PDN and IAs should be given for each frequency concerned.

The PDN can be represented either by an impedance matrix or an admittance matrix. This technical report uses an admittance matrix because admittance is more convenient than impedance to combine other models to the black box model.

4 Modelling

4.1 Terminals and objectives

As shown in Figure 1 and Figure 3, an input signal vector is applied to the IC through input terminals. The signal vector activates the IC and it causes IAs inside the IC. Therefore, the voltages and currents of the input terminals are conditions for the modelling. Noise voltages and currents at the input terminals are not the objectives of the modelling.

For the output pins of the IC, the modelling board provides typical loads. These loads generate IAs at the output circuits of the IC and consequently, from the IAs noise voltages and noise currents appear at the power/ ground terminals. This effect is included into the black box modelling. Output terminals themselves are also a source of conducted emissions, but the black box modelling given in this technical report cannot handle these emissions, because the characteristics of output circuits are non-linear. To simulate conducted emissions through output terminals, other black box modelling such as IMIC or IBIS has to be combined with this black box modelling.

Users cannot manipulate the internal terminals shown in Figure 2 that connect the IAs to the PDN. Therefore, the noise voltages and noise currents of internal terminals are also not the objectives of the black box modelling. But for the first step of this study, these terminals have to be used for the modelling, because these terminals provide the noise sources to the PDN. They are necessary particularly when a model is built from design data.

As the result, the objectives of the black box modelling are to provide models that can be used for numerical calculation of conducted emissions through power and ground terminals of an IC, which is applicable for an application board.

The ICEM-CE model structure for the black box modelling is shown in Figure 4. The IAs are expressed by current sources, and the PDN is given as an admittance matrix.

The noise voltages of the power/ ground terminals are defined with reference to a reference ground terminal (ET0) that is directly connected to the reference plane of the modelling board. The other power/ ground terminals of the PDN are named as ETx. The value of n is the number of power/ ground terminals minus one. The number of IAs is m. Therefore there are $2 \cdot m$ internal terminals, and these terminals are named as ITx as shown in Figure 4.

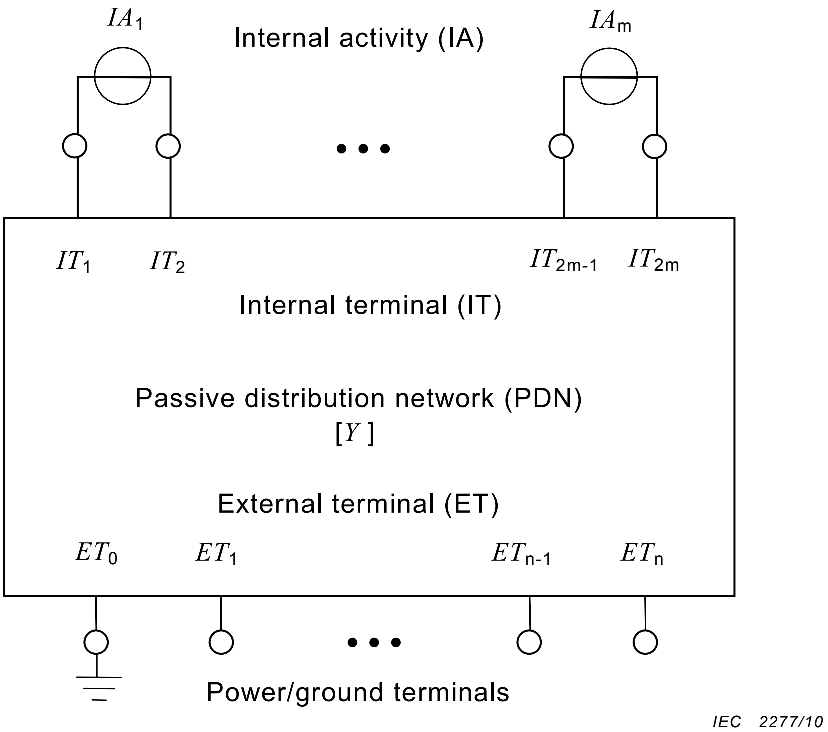

Figure 4 – Structure of the ICEM-CE for IC black box modelling

4.2 Admittance matrix

The PDN in Figure 4 is assumed to be a linear circuit. Therefore, the PDN can be expressed using an admittance matrix based on the nodal analysis method. The equation that expresses the IC, shown as Figure 4, is given below.

$$\left[\begin{array}{ccc|ccc} Y_{\mathrm{ET1\,ET1}} & \cdot & Y_{\mathrm{ET1\,ETn}} & Y_{\mathrm{ET1\,IT1}} & \cdot & Y_{\mathrm{ET1\,IT2m}} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ Y_{\mathrm{ETn\,ET1}} & \cdot & Y_{\mathrm{ETn\,ETn}} & Y_{\mathrm{ETn\,IT1}} & \cdot & Y_{\mathrm{ETn\,IT2m}} \\ \hline Y_{\mathrm{IT1\,ET1}} & \cdot & Y_{\mathrm{IT1\,ETn}} & Y_{\mathrm{IT1\,IT1}} & \cdot & Y_{\mathrm{IT1\,IT2m}} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ Y_{\mathrm{IT2m\,ET1}} & \cdot & Y_{\mathrm{IT2m\,ETn}} & Y_{\mathrm{IT2m\,IT1}} & \cdot & Y_{\mathrm{IT2m\,IT2m}} \end{array}\right] \times \left[\begin{array}{c} V_{\mathrm{ET1}} \\ \cdot \\ V_{\mathrm{ETn}} \\ \hline V_{\mathrm{IT1}} \\ \cdot \\ \cdot \\ \cdot \\ V_{\mathrm{IT2m}} \end{array}\right] = \left[\begin{array}{c} I_{\mathrm{ET1}} \\ \cdot \\ I_{\mathrm{ETn}} \\ \hline I_{\mathrm{IT1}} \\ I_{\mathrm{IT2}} \\ \cdot \\ I_{\mathrm{IT2m-1}} \\ I_{\mathrm{IT2m}} \end{array}\right] \qquad (1)$$

Here, V_{ETx} and I_{ETx} are the noise voltage and the noise current of ETx, respectively. V_{ITx} and I_{ITx} represent the noise voltage and the noise current of ITx, respectively.

NOTE Equation 1 describes the PDN without using variables of voltages and currents for internal nodes, which connect passive elements making up the PDN. Annex A gives the proof of the equation.

The admittance matrix is regular and its dimension is (n+2m, n+2m). For simplicity, Equation (1) is represented using sub-matrices and vectors as follows. In this equation, IAs substitute the currents of the internal terminals.

$$\begin{bmatrix} [Y_{\mathrm{ET\,ET}}] & [Y_{\mathrm{ET\,IT}}] \\ [Y_{\mathrm{IT\,ET}}] & [Y_{\mathrm{IT\,IT}}] \end{bmatrix} \times \begin{bmatrix} [V_{\mathrm{ET}}] \\ [V_{\mathrm{IT}}] \end{bmatrix} = \begin{bmatrix} [I_{\mathrm{ET}}] \\ [I_{\mathrm{IT}}] \end{bmatrix} \qquad (2)$$

where,

$[Y_{ET\,ET}]$ is the regular admittance sub-matrix that represents interactions between ETs;

$[Y_{ET\,IT}]$ is the admittance sub-matrix that represents interactions between ETs and ITs;

$[Y_{IT\,ET}]$ is the admittance sub-matrix that represents interactions between ITs and ETs;

$[Y_{IT\,IT}]$ is the regular admittance sub-matrix that represents interactions between ITs;

$[V_{ET}]$ is the voltage vector that represents noise voltages of ETs;

$[V_{IT}]$ is the voltage vector that represents noise voltages of ITs;

$[I_{ET}]$ is the current vector that represents noise currents of ETs; and

$[I_{IT}]$ is the current vector that represents noise currents of ITs.

$[I_{IT}]$ is given as follows.

$$[I_{IT}] = [IA] \equiv \begin{bmatrix} IA_1 \\ -IA_1 \\ . \\ . \\ IA_m \\ -IA_m \end{bmatrix} \tag{3}$$

4.3 Matrix compaction

$[V_{IT}]$ is eliminated out from Equation (2), as follows.

Equation (2) can be expanded into following two equations, combining Equation (3).

$$[Y_{ET\,ET}] \times [V_{ET}] + [Y_{ET\,IT}] \times [V_{IT}] = [I_{ET}] \tag{4}$$

$$[Y_{IT\,ET}] \times [V_{ET}] + [Y_{IT\,IT}] \times [V_{IT}] = [IA] \tag{5}$$

From Equation (5), $[V_{IT}]$ is obtained as follows.

$$[V_{IT}] = [Y_{IT\,IT}]^{-1} \times ([IA] - [Y_{IT\,ET}] \times [V_{ET}]) \tag{6}$$

By substituting Equation (6) by Equation (4), $[V_{IT}]$ can be eliminated out from Equation (4).

$$([Y_{ET\,ET}] - [Y_{ET\,IT}] \times [Y_{IT\,IT}]^{-1} \times [Y_{IT\,ET}]) \times [V_{ET}] = [I_{ET}] - [Y_{ET\,IT}] \times [Y_{IT\,IT}]^{-1} \times [IA] \tag{7}$$

The coefficient of $[V_{ET}]$ in the left-hand side is an admittance matrix whose dimension is (n, n). And the second term of the right-hand side is a current vector with n-dimension. The dimension of $[IA']$ is n, and the dimension of $[Y'_{ET\,ET}]$ is (n, n). Therefore, $[IA']$ and $[Y'_{ET\,ET}]$ can be defined as follows.

$$[IA'] \equiv -[Y_{ET\,IT}] \times [Y_{IT\,IT}]^{-1} \times [IA] \tag{8}$$

$$[Y'_{ET\,ET}] \equiv [Y_{ET\,ET}] - [Y_{ET\,IT}] \times [Y_{IT\,IT}]^{-1} \times [Y_{IT\,ET}] \tag{9}$$

Then, Equation (7) becomes very simple.

$$[Y'_{\mathrm{ET\,ET}}]\times[V_{\mathrm{ET}}]=[I_{\mathrm{ET}}]+[IA'] \qquad (10)$$

4.4 Black box model structure

In Equations (8) and (9), $[IA']$ and $[Y'_{\mathrm{ET\,ET}}]$ are constant. Therefore $[IA']$ and $[Y'_{\mathrm{ET\,ET}}]$ are named as "equivalent internal activities (equivalent IAs)" and "equivalent passive distribution network (equivalent PDN)", respectively.

Equation (10) means that the black box model structure consists of an equivalent PDN and equivalent IAs as illustrated in the dotted area of Figure 5.

Compared with Figure 4, the IAs at the internal terminals are modified and transferred to the parallel positions to the external terminals. And the PDN is modified and simplified.

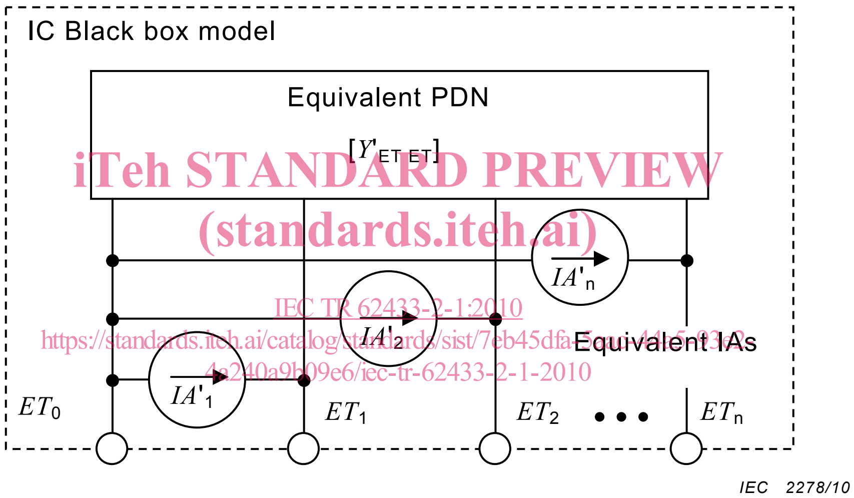

Figure 5 – IC Black box model structure

The IC black box model structure, as shown in Figure 5, is modelled using the expression having the (n+1) external terminals including the reference, where the number of the independent terminal voltage is n. Equation (10) is the Y matrix expression that determines the n external terminal voltages except for the reference as independent variables, and it is the n port circuit which has the reference terminal as the common negative terminal and the other terminals as the positive terminals. A n port circuit of black box model is expressed with circuit elements as shown in Figure 6. It consists of the parallel connection of passive elements having the admittance of the diagonal elements of the Y matrix, voltage controlled current sources having the current of the product of the non-diagonal element value and the other port voltage, and the independent current source having the current calculated from Equation (8).

The Y matrix expression of Equation (10) can be converted into an expression using Z or S matrices easily using conversion formulas.

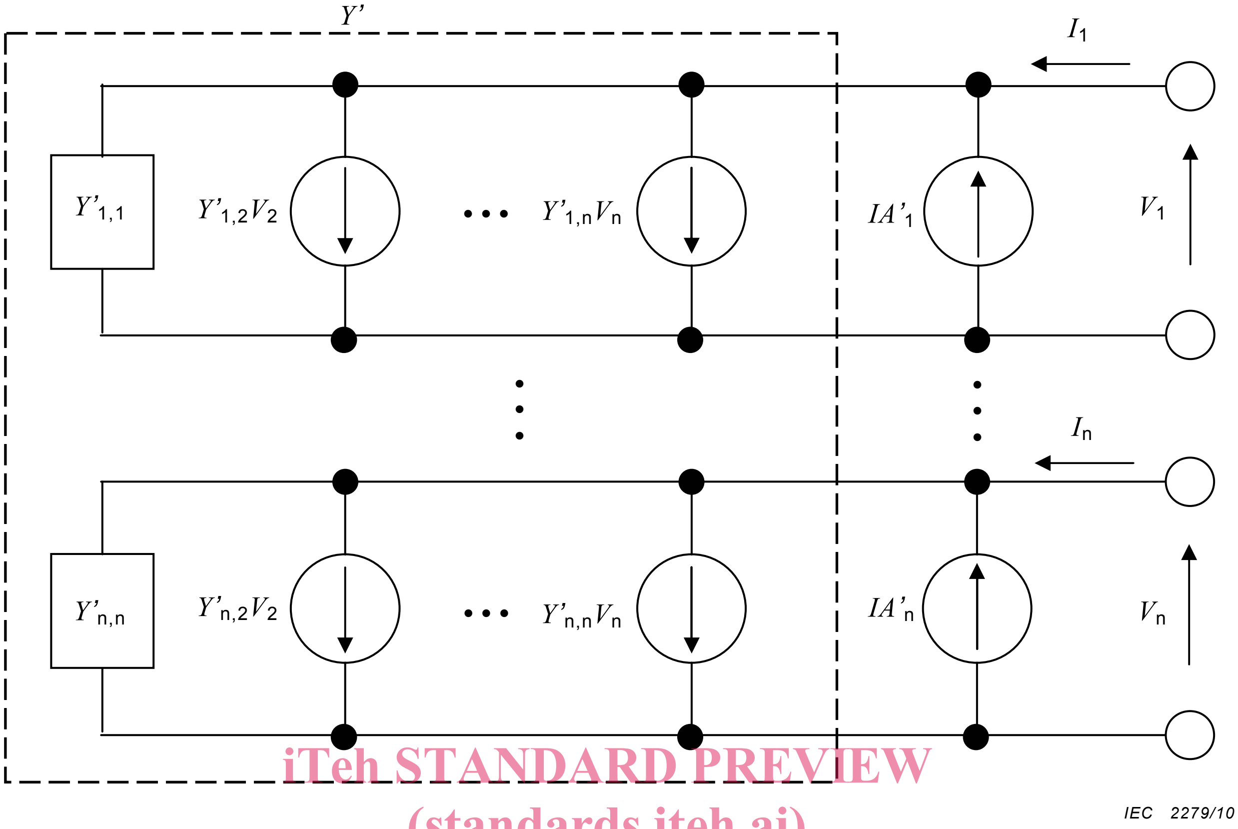

Figure 6 – IC black box model description with circuit elements

5 Parameter extractions

5.1 General

The black box model for conducted emission consists of two components, the equivalent IAs and the equivalent PDN. To build a black box model from measurements, elements of these two components should be obtained. This clause describes the methods used to obtain these components from measurements.

The equivalent IAs depend on the operational mode and power supply condition of the IC. Therefore, the typical power supply condition and the repetitive specific input signal vector that corresponds to the operational mode should be applied to the power/ ground terminals and the input terminals of the modelling board during the measurements of equivalent IAs, respectively.

The equivalent PDN is assumed as a linear function, but it actually depends on voltages. Therefore, the typical power supply is given to the power/ground terminals of the modelling board during the measurements. Relatively small signals should be used for the measurements to assure the assumption is valid.

5.2 Equivalent internal activities

From Equation (10), the equivalent noise current sources can be,

$$[IA'] = -[I_{ET}], \text{ when } [V_{ET}] = [0] \tag{11}$$