A 3DLogic modeling for 3D electronic circuits (3D-MID)

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Abstract:

The need of lighter and smaller devices in Mechatronic, specially in the automotive industry has been forced to have a new generation of electronics, which unlike the traditional electronic boards (Printed Circuit Board-PCB) in which the parts are installed on the 2D surfaces, the electronic parts and connections will be installed on the 3D surfaces (Molded Interconnect Device-MID). Unfortunately the actual electronic tools as ALLEGRO/CADENCE cannot perform the part placement or the routing process on any other surface rather than the 2D surfaces. This is one of the weak points of this new technology as it will increase concept to product time, because the designer has to perform the placement and the routing himself in the actual CAD systems. Also, it’s a barrier to the applicability of this kind of electronics to the bigger circuits.

In this paper we will present a methodology which from the 0Dlogic will perform a 3Dphysic, which we call it the 3DLogic environment. To perform this, 3D-logical components have to be made, so that each component can be presented at a time geometrically and logically. The geometrical presentation of the components is consists of their 3D general shape in the 3D and the points to position them in the 3D environment. Also a 3D geometry of the surface that the MID will be installed on it will be introduced. The existing of the logical and geometrical connections at a same model will permit us to add the multi-physic constraints such as electrical properties, thermal attributes, etc. Our choice for the programming language is the MODELICA and the DYMOLA as the solver.

Key words: 3DLogic, MCAD, ECAD, MID, electric/multi-physics simulation

1 Introduction

In general the first need of any electronic conception is the multi-physics simulation to validate the operability of the device in the different conditions. The different multi-physics simulations will vary from thermal to the EMC (Electro Magnetic Compatibility) or even vibration simulations. The today’s electronic software’s (ECAD) are incapable of performing such simulations and so the need of the mechanical software’s (MCAD) can be sensed. This needs a connection between the ECAD and MCAD software’s, to transfer the needed geometrical and electrical data, to perform the simulation, which due to their unrelated concept of operation is not operational [1]. Although there are some solutions for this problem[1][2], the conception cycle, which force the user to do the electronic circuit and then perform the multi-physic simulation demand an enormous time due to the redesign process needed.

Also the arrive of the new generation of electronic circuits called MID(molded Interconnected Devices)[3], which are the electronic circuit who are installed on the 3D surfaces needs a new ECAD software’s, cause the usual electronic tools are only capable of performing the conception on 2D surfaces. For this result new generation of electronic conception software’s such as, EM-designer [4], NEXTRA [2] or MIDDAC [5] has been produced. Unfortunately the first two systems provide a rather limited support for an efficient design of complex MID-products [6][7], and the last solution, although propose a large freedom of geometrical modeling while at the same time provides an integration of electronic and mechanical functions in one system[5], will provide the multi-physic simulation in the end of the electronic conception cycle. At the same time none of these tools provide the total integration of the electrical and mechanical functions so that, the user has all the essential parameters (electrical and multi-physics parameters) for simulation in the same model.
The 3Dlogic has been proposed, to respond to these needs. The idea is to combine the logic of the electronic (schematic view) to the geometry. This will not only give us the capability of have a early multi-physic simulation, which will avoid the costly multi-physics simulations when the circuit has been designed, but also will enable us to do the MID conceptions as it can represent the logical aspect of the electronic on the 3D surfaces.

2 Molded Interconnect Devices (MID)

One of the fundamental innovations in the field of mechatronics is the direct integration of mechanical and electrical functions using molded interconnect devices[3], these products do not build of the conventional 2D circuit boards(PCB) but circuits are directly installed on the 3D surface of the product. This architecture will results in the miniaturization of the product. Currently, the common MID-design process uses the coupling of 2D electronic CAD (ECAD) and 3D mechanical CAD (MCAD)[5]. The problem is that, the MCAD systems do not e.g. know what electrical connection is, and on the other hand the ECAD systems ignore the requirements of the 3D circuits due to their 2D origin. On (figure 1) we can observe a product which has been made by this technology.

![MID circuit application-source : BMW](image)

As it can be observed unlike the conventional mechatronic products there is a mutual dependency between the geometry and the electronics, which makes it impossible to independently design one aspect without another. This will results in a need of a new tool which can combine the electrical and mechanical aspects in one single model.

3 3Dlogic concept

The aim is to start from the 0DLogic presentation of the electronic circuit (electronics-schematic) and end up on a 3D physic-modeling of the circuit. The electronics-schematic is the start point for any electronic circuit conception. In this model the components logical-connections will be presented. As in the final goal the geometry and placement of the components and the connections will be presented in CAD systems like CATIA. The 0DLogic is what is normally called the electronic schematic. It contains the electrical components, logical connections between them and the electrical properties of the components and the connections. The 3DLogic, which is next step for the electronic conception cycle, includes the logical properties of the 0DLogic plus the simplified geometry of the electronic and its surroundings. This means reduce the geometrical complexity of the shapes so that they can be represented by the simple geometrical shapes and object. As an example, Figure 9, in part 3.3 of this text represent a simplified geometry of a resistance combined with its electrical properties. The combination of the electronic and geometry will offer the capability to include simplified multi-physics inside this model, cause on general the multi-physics simulations such as thermal modeling and simulations need the geometry to be calculated. The 3DPHYS is the next step on the electronic conception. It contains the detailed geometry of the electronic and its environment. The existence of the detailed geometry will permit us to perform the detailed multi-physique simulations with the help
of the Finite Element simulation software’s such as FLOTHERM [8] for thermal analysis. (Figure 2) shows the 0DL-3DL-3DP steps of the new electronic conception.

As it can be figured in this figure, to establish the 3DLogic model of the electronic, both the logical information from the 0DLogic and the geometrical data from 3DPhysic has to transform to 3DLogic. The 0DLogic and 3DPhysic already exists in different ECAD or MCAD software, and the 3DLogic will serve as a connection between these two unconnected systems.

### 3.1 Topological structure

The heart of the 3DLogic modeling is the topological diagram [9] [10], as it will give us the capability of having the relations and thus the equations between different components and their parameters. The capability of this has been shown by [11] which explained the need of the topological structure to model the complex systems. (Figure.3) shows the algebraic diagram which by that we can associate the different properties of our model. On the first step the analysis will start from nodes on the Primal object. The nodes present the properties of the nodes which in our case are the coordination of the nodes (P), electrical potential of the nodes (V) and the temperature of each node (T). We will call the matrix which contains these properties matrix [N]. The incidence matrix [C], which builds up of the relations between different nodes will capable us to have the relations of the same properties between two nodes (Branches) such as the vector between two nodes, the potential differences between nodes and the temperature differences., this will be presented in matrix [B]. The dual object $R_B$ will be the properties which can be reached by equations or calculations from the primal objects. In our case, it would be current and the heat flow in the branches. To arrive to the $R_B$ we would need the admittance matrix $Y_B$ which represents the relation between different properties. E.g. the electrical connection between the electrical potential in primal object and current in branches in dual object
As it can be seen, once we have the topological diagram of the model, from any property as the departure data we will be capable of calculating the other properties of the model. These relations will help us to perform our modeling and analysis. Although this method will respond to our need of knowing the relation between the components in the model but it would be hard to perform if the model is complicated. [12] Show that by partitioning the matrixes into smaller model and matrices we will be able to simplify the model. This is done by associate to each part of the model a topological diagram and incidence matrix \([C]\) and by connecting the smaller parts together construct the bigger incidence matrix.

### 3.2 A 3D electronic example

To validate our concept we have used the example of two resistances installed on two different planes. (Figure 4) shows the schematic view of this circuit and (Figure 5) shows the final 3DPhysic. The usual ECAD tools are not capable of performing the component placement or routing process on this kind of surfaces. Although, this model would be the simplest model which can be produced with our model, but the more complicated circuits and surfaces can be solved with the same process.

The geometrical presentation of this circuit is presented in (figure 6). This figure illustrates our idea of the simplified geometry. As it can be seen, the surfaces on which the components will be installed, represented by the simple plane object without the details which would be applied in the 3DPhysic section in CATIA for example. Also components, which in here are the resistances has been represented by three vectors. For instance the R1 resistance is represented by IH, HG and GF vectors. These would represent the branches in the topological diagram, and the points I, H, G and F represents the nodes. Also the electrical connections are represented by the simple connection lines. The incidence matrix \([C]\) of the circuit will be developed by identify the relation between different nodes and branches. These relations will be represented by the 0, 1 and -1. The 0 value means there is no direct connection between the node and the branch, 1 means the branch direction is into the node and -1 would means that the branch comes out of the node. The direction of the nodes has to be defined at the first stage of conception, but cannot be changed once defined.

![FIG 4 - Logical view of the circuit](image1)

![FIG 5 - 3DPhysical view of the circuit](image2)

![FIG 6 - Simplified geometrical presentation of the model and its incidence matrix \([C]\)](image3)
As said before the incidence matrix \([C]\) has been built up by connecting some smaller incidence matrixes, as the matrixes for the components and the connections between them (fig. 6). These smaller matrixes will be used to define the internal equations of the components and connections.

Once the equations of the components, connections and their environments have been developed they can be modeled in DYMOLA and by connecting these smaller models we would reach our entire circuit with its environments modeled by the 3DLogic concept. Connecting these smaller parts and models will result in the incidence matrix of the entire circuit.

### 3.3 Modeling process

The 3DLogic modeling needs an environment which can offer us the capability of working with the different variables at once. The Modelica [13] modeling language and its solver DYMOLA [14] offer us this capability, as combined modeling and simulations can be performed with Modelica. As Modelica is an object oriented modeling language, it gives use the capability of modeling the complicated models by means of connecting the simpler models to build up the more complicated models. (figure 7) shows the bases which is needed to build up the other components. To connect different components, we have described a new connector in DYMOLA called PET (Physic-Electric-Thermal) which as can be viewed in (figure 8) can communicate the geometrical, thermal and electrical information throughout the two object which it connects them together.

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Real</td>
<td>r[3]</td>
<td>the normal vector</td>
</tr>
<tr>
<td>Position</td>
<td>P[3]</td>
<td>position ([r])</td>
</tr>
<tr>
<td>Temp K</td>
<td>T</td>
<td>temperature of the connection ([K])</td>
</tr>
<tr>
<td>flow</td>
<td>Q_flow</td>
<td>heat flow pass by the connection ([W])</td>
</tr>
<tr>
<td>flow</td>
<td>Current</td>
<td>current pass by the connection ([A])</td>
</tr>
<tr>
<td>Voltage</td>
<td>v</td>
<td>the voltage at the connection ([V])</td>
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FIG 7- library of the 3Dlogic basic components in DYMOLA  
FIG 8- properties of the new connection build in DYMOLA

The modeling bases will be the point-line (vector)-plane and connecting these will give use the more complicated components and models. As an example the resistance will be modeled by connecting three components called two_port_pet (figure 5) each has the geometrical characteristics of a vector, electrical and thermal characteristics by the means of the PET connectors. Figure 7 present this modeling for a thermal resistance. This model will be served as a 3DLogic model of the resistance and can be used in any further modeling by connecting its two or three connections to the other components.

FIG 9- 3DLogic presentation of a heating resistance
To fulfill the different characteristics of the different components of the model each component has the geometrical, electrical and thermal characteristics which can be changed by the user. As an example the plane does not possess any electrical characteristic, which give us the ability to connect it to the electrical components, but the connections can transfer the connections can transfer the geometrical properties such as the connection position and the normal vector of the connection or the thermal properties such as the temperature and heat flow at the connection junction between the plane and the component.

This new process will give us the capability to have a simplified model which enables us to perform the component placement and logical connections on the 3D surfaces. The existence of the simplified geometry combined with the electrical and thermal properties will capable us to perform a optimized placement of the components.

4 Conclusion and perspective

Conception of the products include electronic functions and mechanical properties, specially the MID circuits, is a complex process and involves interactions between different engineering domains such as electronic, geometry, thermal science, etc. The optimization process, due to their multi-physics properties needs an environment which supports different kind of engineering domains.

To respond to this demand the 3DLogic modeling process has been presented, which can include the different domains which the electronic and MID devices needs. This new modeling process will not only give us the ability to design the different electronic devices, but also with its possibility to include the multi-physics properties, can be served as a pre-design multi-physics simulation for the conception of the electronic devices.

To complete the functionality of this process, future work will be focused on including more multi-physics properties, and perform the thermal simulation from the electrical behavior of the circuit.

Also the electrical connections between the components (routing process) will be the aspect, needed to be included in this modeling process.

5 References