THE 8th INTERNATIONAL SYMPOSIUM ON ADVANCED TOPICS IN ELECTRICAL ENGINEERING
May 23-25, 2013
Bucharest, Romania

GDS2M: Preprocessing Tool for MEMS Devices

Andreea Alexandru, Sorin Lup, Bogdan Dita
POLITEHNICA University of Bucharest
andreeaa@lmn.pub.ro, sorin@lmn.pub.ro, bogdan@lmn.pub.ro

***Abstract*-This paper proposes an effective software tool that extracts geometric information of Micro-Electro-Mechanical Systems (MEMS) or other integrated circuits (IC) devices, and exports it to data structures in MATLAB, aiding the electromagnetic modeling. The use of this preprocessing tool is illustrated for a capacitive RF shunt switch from the literature. Finally, this tool is included in the RF simulation flow of the switch and its validation consists of the comparison between the computed frequency characteristic and the results from the literature.**

***Keywords*: RF MEMS, GDSII, geometric preprocessing, RF simulation**

I. INTRODUCTION

During the past 20 years, IC technological research was aimed towards minimizing the circuits and working in microwave and millimeter waves areas [1] [2]. The development of microfabrication and processing techniques favored the use of MEMS circuits. Bulk production and reduced dimensions brought increasing interest in the MEMS area and especially in the radio frequency (RF) MEMS. One of the RF MEMS applications that has attracted much interest are switches, widely used in the communications area. The main advantages of the RF MEMS switches over the currently used devices (PIN diodes and field effect transistors) are low insertion losses, high isolation, null power consumption and reduced costs [3].

The final outcome of the MEMS design process consists of a file describing the masks that will be used during the fabrication, accompanied by a technology documentation describing the layers and the materials used. If further research needs to be carried out and new prototype tools need to be developed, then it is useful to easily access the geometrical and material information from the files that designers provide. The main contribution of our paper is related to this preprocessing step.

Among the available file formats for MEMS fabrication, summarized in [4], the most commonly used stream format is GDSII, preferred because of its binary format and small file size. The information provided by the GDSII format are two-dimensional geometrical shapes, text labels and database units, grouped by labels in a hierarchical form.

The small number of available (and free) software tools capable of extracting the information from a GDSII file and exporting it to other programming environments has determined us to create GDS2M, a MATLAB [5] based tool that satisfies the requirements above.

The paper is structured as follows: section II describes the GSD2M tool, section III explains the main steps of the RF simulation code with which the new tool is linked and section IV validates our approach, showing results obtained for a benchmark defined in the literature [6], by using the new tool we propose. Finally, conclusions are drawn. The tools developed and used, along with the complete definition of the benchmark can be downloaded from [7].

II. FEATURES EXTRACTION

A. *KLayout*

There are several software tools for viewing and editing GDSII files. We mention KLayout, CleWin, Layout Editor, Java GDS [8]. KLayout is a free GDSII viewer and editor that supports *Ruby* scripting, as well as manual manipulation of the GDSII files [9].

The layers in the GDSII file represent the masks used (Fig. 1). By using the facility Trace Net in KLayout, the user can export the 2D information of each object from the layers in a lyn file, which uses the XML format.

B. *The technology file*

The other information necessary for a complete processing, such as the height, thickness and the material information for each layer, is taken from the documentation provided by the designers. Since there is no standard in this respect, we defined a XML file, called the technology file, that holds this information. This file includes details about the substrates and exterior layers that encapsulate the switch, and the masks that compose it. The exterior layers are defined by the thickness and the constitutive material. The masks contain information

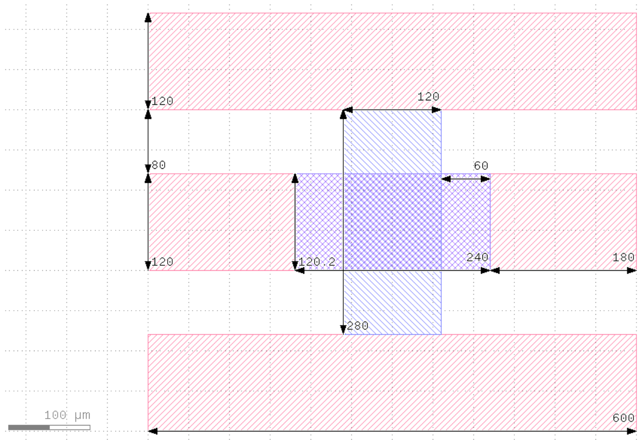

Fig. 1. KLayout view and dimensions for the capacitive switch in [6].

978-1-4673-5980-1/13/$31.00 ©2013 IEEE

about the path where the associate lyn file is stored, the type of the object the mask represents (e.g. electrode, membrane etc.), the height, thickness and material. There is also a tag named <holes> which is "1" if the layer contains holes and "0" otherwise. If the value is "1", the <holes_dimensions> tag becomes valid and holds the maximum area of a hole, specified to avoid elimination of important geometry.

C. Processing the files

The technology and lyn files are processed using the free XML toolbox [10]. After parsing these files, the information is imported and the program returns data structures for each layer. The information stored by the data structures is: shape, coordinates, thickness and material for each. Additionally, the maximum domain of the switch is computed, information used in creating a drawing background, as well as in establishing the borders of the computational box. Our program creates 2D and 3D drawings of each layer of the switch in the up state. For the RF capacitive switch in [6], one of the output representations of GDS2M is shown in Fig. 2.

The program also has the option of eliminating the holes from the bridge, in order to obtain a simpler electromagnetic model (Fig. 3). If the value of the <holes> field from the technology file is "1", the information in the field <holes_dimensions> is used to eliminate the rectangular shapes with areas less than the given maximum value.

D. Preparing the data structure for chamy

The final RF simulation of the switch is carried out with an in-house tool, called *chamy,* developed in the frame of the Chameleon-RF European research project [11]. The devices are defined by using bricks, parallelipipedic blocks described by their size, position and by their homogeneous material. To link the information in GDS2M to *chamy*, we create an orthogonal 2D grid that splits the objects in rectangles with edges parallel to the axes. The grid is obtained by considering horizontal/vertical lines for each pair of consecutive points having same *x* or *y* coordinate. The MATLAB function *inpolygon* is used to check which rectangles from the grid are, actually, parts of the object. The next step is to minimize the number of bricks, merging the rectangles with a common

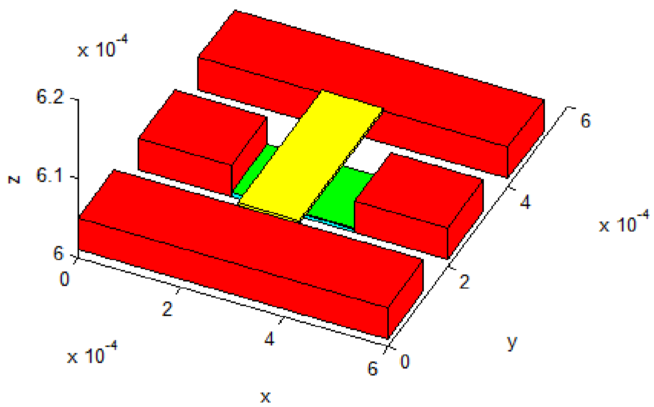

Fig. 2. The GDS2M 3D representation of the RF MEMS switch in [6]. The *x* axis is parallel to the coplanar waveguide (the red shapes), the *y* axis is parallel to the membrane of the switch (the yellow shape) and the *z* axis shows the thickness of the switch. The green layer represents the dielectric layer, poured on the bottom electrode of the switch (the thin blue layer).

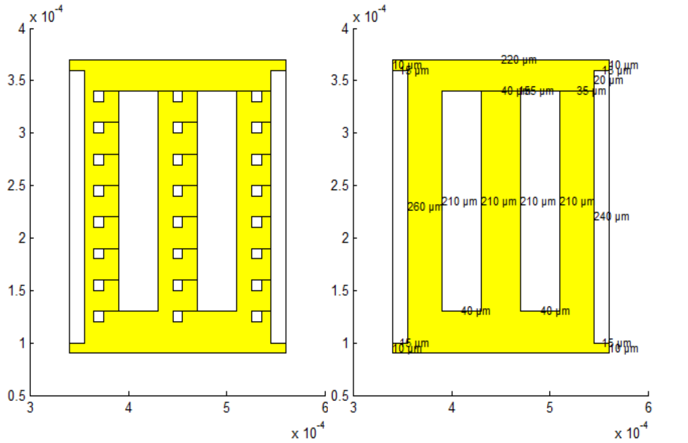

Fig. 3. Elimination of holes from a bridge for a more complex form of the switch in [6].

edge into one object, with the outcome as in Fig. 4. The final objects thus created represent the union of bricks in *chamy*.

E. The Problem File

Chamy requires another input file, which describes the solved problem, containing details about the electric or magnetic terminals, geometric parameters and other dimensions for the layout included in the computational domain used in the EM analysis.

Electric and magnetic terminals are defined on the domain boundary. Intentional electric terminals are attached to bricks, whereas non-intentional electric terminals and magnetic terminals can be freely placed on the boundary, provided they do not overlap or touch. The terminals are described by their labels, the bricks they are attached to, the domains they are included in and their types. A domain is defined by their limits: "xmin", "xmax", "ymin", "ymax", "zmin", "zmax". The terminal types may be: "eg" – electrical ground terminal, "ev" – electrical terminal excited in electric voltage, "ec" – electrical terminal excited in current, "mg" – magnetic ground terminal, "mv" – magnetic terminal excited in magnetic voltage, "mg" – magnetic terminal excited in magnetic flow.

The parameters represent the dimensions that can be varied in the parametric analysis, e.g. for variation studies or design optimization. The parameters must contain a tag that defines the type of dimension that is varied: W (width), L (length), H

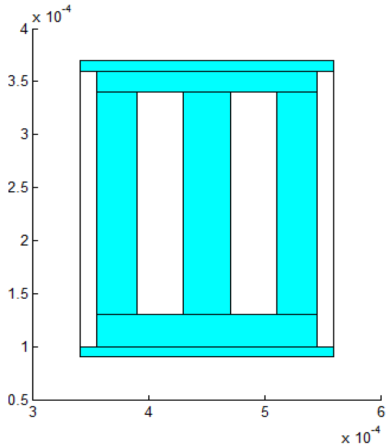

Fig. 4. Example of rectangle separation for a more complex form of the switch in [6].

(height). Finally, the interval in which the value can be varied is specified in <lower_value> and <upper_value>. For example, in the case of the capacitive switch [6], we simulate the variation of the membrane's width W.

III. *CHAMY*

Chamy is a software tool developed by the Numerical Modeling Laboratory team for the modeling of high-frequency integrated circuits components and their interaction with the electromagnetic environment. It computes the frequency characteristics of analyzed devices. The entire process consists of the following steps: *import* the passive device description, *extract* the model and *generate* the state-space representation of the device, *compute* the frequency characteristics of the device and *export* the results in a standard *.snp* format [12].

The input parameters are mainly related to the device geometry and material properties. In the process of setting up a new simulation in *chamy*, this step is the one that takes the longest user's time to complete. This happens mainly because it is usually done by hard coding into the layout file, defining the parameters, the domain, layers, bricks and terminals. This is not only time consuming, but is also the main source of runtime errors. By automating this step, GDS2M removes the possibility of human errors, especially in the case of complex device layouts, and makes a solid correspondence with the GDSII layout source files that are usually provided by our industrial partners.

IV. VALIDATION

To validate the GDS2M tool, a shunt capacitive MEMS switch taken from [6] was modeled. The switch consists of a thin metal membrane bridge suspended over the center conductor of a coplanar waveguide (CPW) and fixed on the ground conductor of the CPW. The model generated with *chamy* using information files created by GDS2M tool is presented in Fig. 5.

The MEMS switch consists of a substrate of 600-µm-thick high-resistivity silicon. A 1-µm-thick layer of silicon dioxide is used as a buffer layer. The CPW's conductors are treated as aluminum with thickness of 4.0 µm and length of 600 µm. The bottom electrode of the switch consists of a 0.4-µm-thick aluminum coated with silicon nitrate (Si3N4) having the thickness of 0.1 µm. The metallic membrane of 0.4-µm-thick aluminum sized at 280 µm by 120 µm is suspended at 3.5 µm above the CPW transmission line having the center conductor width of 120 µm and a gap on each side of 80 µm.

In the OFF-State, the signal passes through the CPW transmission line, and in the ON-State, the membrane crashes on the electrode shunting the signal.

In order to set the boundary conditions, 6 terminals have been attached to the computational domain: 4 of type "eg" and 2 of type "ev", like in Fig. 5.

A discretization grid (Fig. 6), necessary for the FM field analysis, is created in *chamy* by partitioning the domain in rectangles. 17 nodes are placed on the *x* axis, 22 nodes are placed on the *y* axis and 13 nodes are placed on the *z* axis. This discretization grid is used for both (ON-state and OFF-state) positions of the membrane.

The full wave EM analysis is performed by *chamy* and scattering parameters are extracted in the frequency range going from 1 GHz to 60 GHz. In Fig. 7 and 8 the absolute value of S11 and S21 obtained with *chamy* are presented. The resemblance with the results obtained by the authors in [6] is very significant. Thus, for a given switch of fixed ranges of parameters, the results obtained by GDS2M and *chamy* inhouse package are the same as the results obtained by HFSS professional package, used in [6].

By repeating this process for different bridge widths, in the ON-State position, a set of S-parameters have been extracted (Fig. 9). The nominal width of the bridge was $W_{nominal}$ = 120 µm with a variation between 60 to 180 µm.

V. CONCLUSIONS

A software tool aimed to facilitate the processing of geometrical information of MEMS devices has been developed by the authors, and it is presented in this paper. It starts from the GDSII fabrication file, which describes the 2D geometry of the device's layers, and from the technology file, which describes the vertical structure of the device. These two input files are translated in XML format and then, by merging their content, the input for the EM analysis tool,

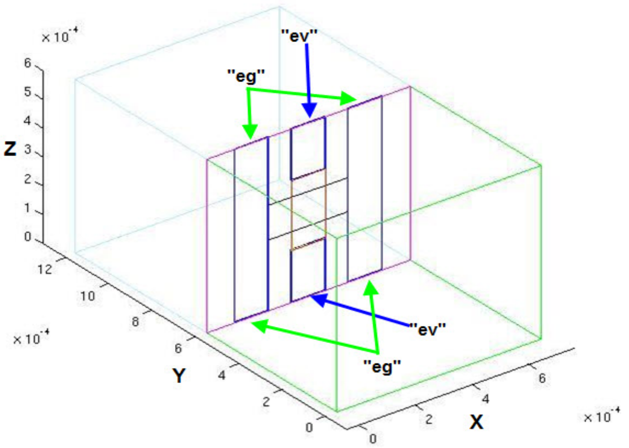

Fig. 5. Model of the capacitive switch in [6] generated by *chamy*. The 'eg' terminals are at both ends of the two ground conductors of the CPW. On the central conductor of the CPW, two 'ev' are attached at both ends.

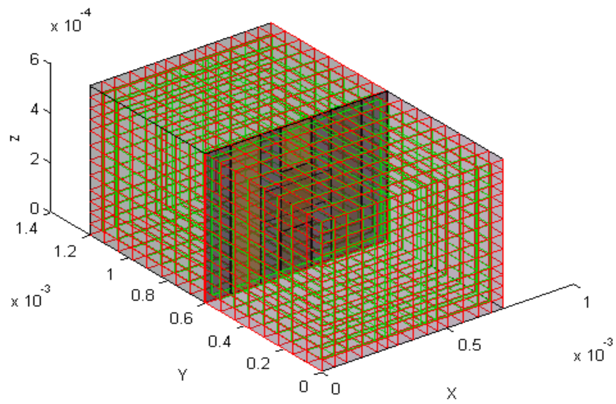

Fig. 6. The discretization grid used in *chamy* for the capacitive switch in [6].

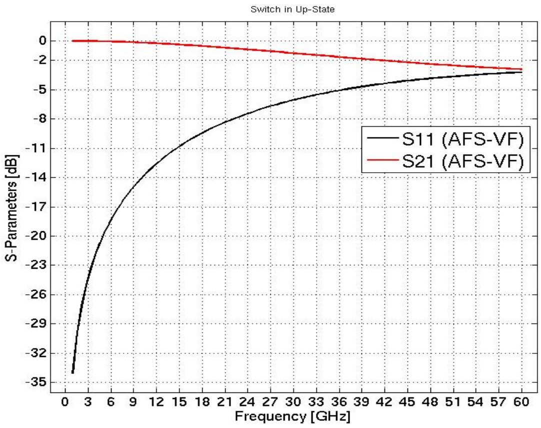

Fig. 7. S-parameters in OFF-State generated from *chamy*.

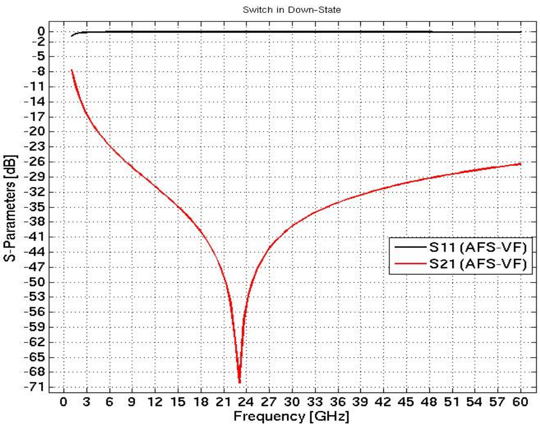

Fig. 8. S-parameters in ON-State generated from *chamy*.

chamy, is generated.

The preprocessing tool, called GDS2M, was used for the modeling and analysis of the performances of an RF-MEMS capacitive shunt switch, described and analyzed in literature [6]. There, a series of switches are characterized using a full wave analysis, based on a finite element method to extract the S-parameters of the switches for different geometrical dimensions. From the S-parameter database, a scalable lumped circuit model is extracted. In our approach, the device was simulated in *chamy* - a software tool for full wave EM analysis based on FIT. S-parameters were also extracted. The proposed procedure is validated by the agreement between these results and the simulation results presented in the reference article [6].

GDS2M is a free and open-source tool, available at [7], created for research purposes. The advantage of our approach consists in the flexibility of the program, which can be extended, optimized and customized for particular designs of RF MEMS switches, as opposed to available mainstream packages. Another advantage is the inclusion of the parametric geometric modeling from the beginning of the procedure, with the variable parameters being indicated in the problem description file. This approach facilitates the parametric studies as well as the device optimization.

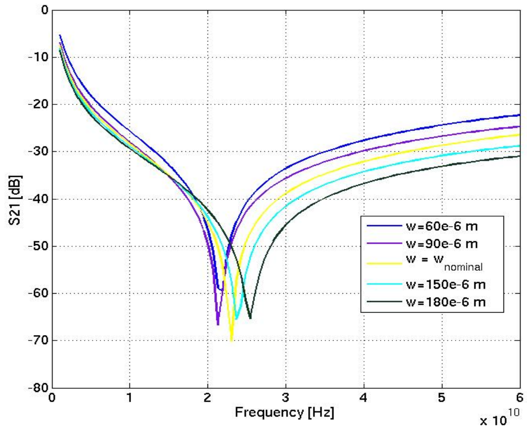

Fig. 9. S-parameters in ON-state for different width of the bridge.

ACKNOWLEDGMENT

This work was done under the guidance of Prof. Daniel Ioan and Assoc. Prof. Gabriela Ciuprina, UPB. The program is part of the ToMeMS project, conducted under the financial support of the Romanian Government program PN-II-PT-PCCA-2011-3, managed by ANCS, CNDI – UEFISCDI, grant no. 5/2012. This work has been co-funded by the Sectoral Operational Program Human Resources Development 2007-2013 of the Romanian Ministry of Labor, Family and Social Protection through the Financial Agreement POSDRU/107/1.5/S/76813.

REFERENCES

[1] V. K. Varadan, K.J. Vinoy, K.A. Jose, *RF MEMS and Their Application Electricity and Magnetism,* John Wiley & Sons Ltd, West Sussex, England 2003, pp.13-16.

[2] A. Racasan, C. Munteanu, V. Topa, C. Pacurar, C. Hebedean, *Minimization of the Equivalent Parallel Capacitance in Planar Magnetic Integrated Structures*, Proceedings of the 13th International Conference on Optimization of Electrical and Electronic Equipment, Brasov, Romania, May 2012, pp. 219-224.

[3] G. M. Rebeiz, G.B. Muldavin, *RF MEMS Switches and Switch Circuits,* IEEE Microwave Magazine, December 2001, pp. 59-71.

[4] Jürgen Thies, Layout Editor, IC and MEMS designs Viewer and Editor; list of MEMS and IC file formats, available at http://www.layouteditor.net/wiki/CategoryFileFormat

[5] MATLAB, an interactive numerical computing environment and high-level language, developed by MathWorks http://www.mathworks.com/matlabcentral/ .

[6] J.Y. Qian, G.P. Li and F. De Flaviis, *A parametric model of low-loss RF MEMS capacitive switches*, Asia-Pacific Microwave Conference*,* APMC 2001, Taipei, Taiwan, 2001.

[7] Homepage for the software tool GDS2M http://www.lmn.pub.ro/~andreeaa/

[8] Jürgen Thies, Layout Editor, IC and MEMS designs Viewer and Editor; extensive list of similar software tools, available at http://www.layouteditor.net/links/ .

[9] M. Kofferlein, KLayout High Performance Layout Viewer And Editor, Version 0.21.16, Free software and documentation available at http://klayout.de .

[10] M. Molinari, XML toolbox, Conversion of MATLAB data types into XML and vice versa, April 2005 http://www.mathworks.com/ matlabcentral/fileexchange/4278-xml-toolbox

[11] CHAMELEON-RF project: http://www.hitech-projects.com/euprojects/chameleon%20RF/ .

[12] D. Ioan, G. Ciuprina, M. Radulescu, *Compact modeling and fast simulation of the on-chip interconnect lines*, IEEE Transactions on Magnetics, vol.42, issue 4, pp.547-550, 2006.