DEVICE MODELS FOR (M)MIC CIRCUIT DESIGN - BENEFITS AND LIMITATIONS

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ABSTRACT

An efficient and reliable device model library is the base for an accurate prediction of (monolithic) microwave integrated circuit ((M)MIC) performance and for computer aided circuit design in general. In this paper some trends in connection with microwave circuits are listed as well as the satisfaction of circuit designer with corresponding model libraries obtained by a survey is described. This will finally lead to an estimation of future demands in the area of CAD tool and model development.

INTRODUCTION

A fast and reliable computer-aided circuit design for hybrid and monolithic microwave integrated circuits, the so-called (M)MICs, is a basic requirement for todays RF system development. In particular, the strong demand for short time-to-market developments leads to a high pressure on RF circuit designer to develop complex circuits without utilizing redesign procedures. The first attempt should already meet the specifications.

However, this requirement can only be fulfilled if highly accurate and fast (with respect to computational efforts) circuit design models are available for the circuit design process. But, are the currently available models already of this high level performance? In order to find out how satisfied circuit designers are with the standard models available on the market a survey in the world wide web (questionnaire available at: http://homepages.hrz.tu-darmstadt.de/~d868/cad_survey.html) has been performed.

At the current stage (July 1999) the survey is still running, however, a representative amount of circuit designer has already filled out the questionnaire. Thus, some early results can be presented here. Most of the replies come from circuit designers with an experience of more than 20 different circuits designs mainly for wireless applications.

COMMON MICROWAVE CIRCUIT DESIGN

The device models integrated in suitable libraries (e.g. library integrated in the simulation tool, foundry library, in-house developed library) can be divided into the following categories:

1) active elements (e.g. MESFET, HEMT, HBT, Schottky diode)
2) transmission lines (e.g. microstrip, coplanar waveguide, slot line, coax transmission line)
3) transmission line discontinuities (e.g. open and short circuit, T-junction)
4) lumped passive elements (e.g. thin film resistor, MIM capacitor, spiral inductor)
5) connections to other circuits (e.g. wire bonds, connectors, solder bumps for flip chip mounting)
6) antennas (e.g. microstrip antenna, slot antenna)
7) optoelectronic devices and circuits (e.g. photo diodes, optical waveguides)
8) microelectromechanical devices (e.g. mechanical switches, movable shorts)

The first item (No. 1 in the list above) summarizes the active and nonlinear elements. The corresponding models are most important for a high circuit design accuracy (see Fig. 1) in the opinion of the circuit designer. Thus, research work in this area still seems to be useful since the ranking for some types of transistors does not reach excellent marks (see Fig. 2). It must be mentioned that in particular for the silicon bipolar transistor the opinion of the circuit designer is quite divergent. This can be explained by the different models which has been used for the circuit design so far. Some of them are extended versions of low frequency models whereas others are complete new developments for pure RF applications.

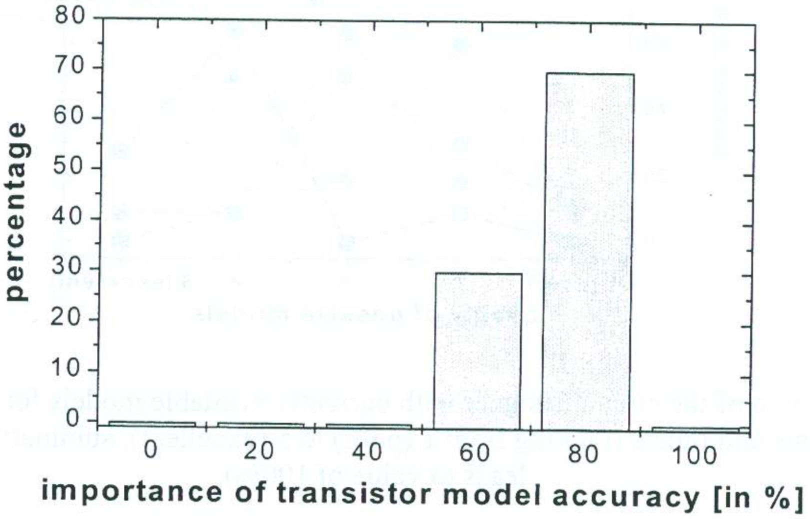


Fig. 1: Amount of importance of transistor model accuracy on the overall circuit design accuracy (summation leads to 100%).

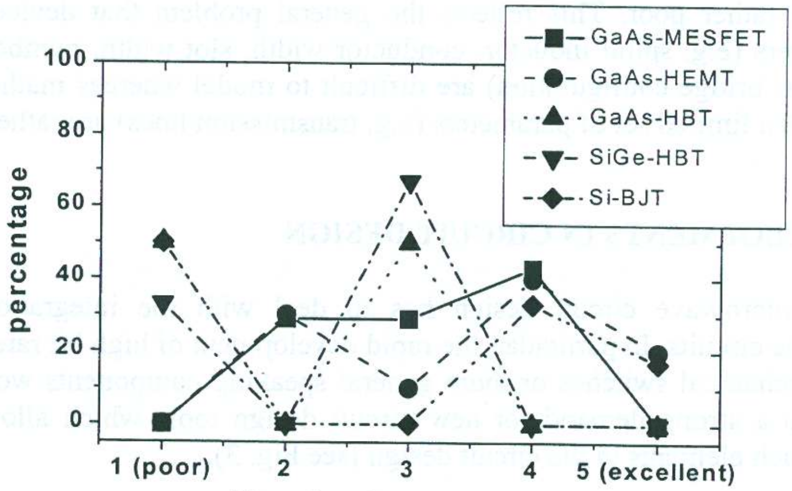


Fig 2. Satisfaction of the circuit designer with currently available models for different types of transistors (ranking from 1 (poor) to 5 (excellent), summation for each transistor type leads to a value of 100%).

The values given for MESFET and HEMT device models are quite similar as well as for GaAs-HBTs and SiGe-HBTs. However, it is obvious that in general the ranking for HBT models is not as high as for field effect type transistors. This seems to be originated in the different application areas for both devices. Since the HBTs are mainly used for high power and high efficiency (which automatically leads to a large-signal modulation of the transistor), the modeling is much more complicated than for devices mainly used in small-signal applications.

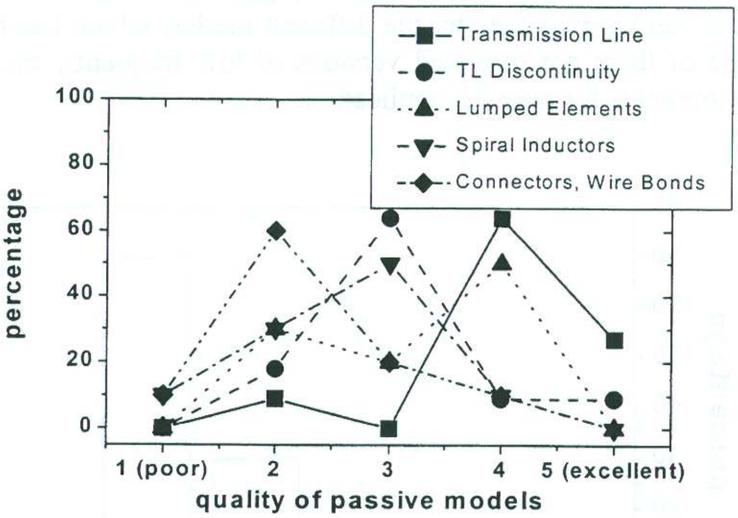


Fig 3. Satisfaction of the circuit designer with currently available models for transmission lines, lumped elements and others (ranking from 1 (poor) to 5 (excellent), summation for one category leads to value of 100%).

Besides the active elements a microwave circuit consists usually of many different passive elements like transmission lines with corresponding discontinuities and lumped elements (No. 2-5 in the list given above). The ranking of these elements with respect to their quality is shown in Fig. 3. One observes that circuit designer in general are very pleased with transmission line models, whereas the models available for spiral inductors and connecting devices (bond wires, connectors, etc.) are considered to be rather poor. This reflects the general problem that device models with many different parameters (e.g. spiral inductor: conductor width, slot width, number of turns, inner and outer diameter, air bridge configuration) are difficult to model whereas mathematical descriptions for structures with a limited set of parameters (e.g. transmission lines) are rather easy to develop.

FUTURE DEVELOPMENTS IN CIRCUIT DESIGN

In near future microwave circuit design has to deal with the integration of new kinds of functionality in the circuits. In particular, the rapid development of high bit rate optical links and the integration of mechanical switches or more general speaking components working on mechanical principles lead to a strong demand for new circuit design tools which allow to incorporate the performance of such elements in the circuit design (see Fig. 3).

Concerning the incorporation of optical devices some work has already been done in the past and there are some circuit design tools available which allows to model combined microwave and optical circuits in one step. However, the quality of the models which is most important for a reliable prediction of a circuit performance is of great importance and still needs some improvements.

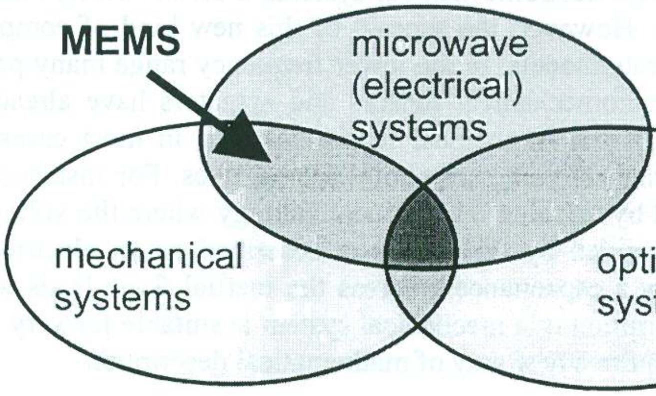
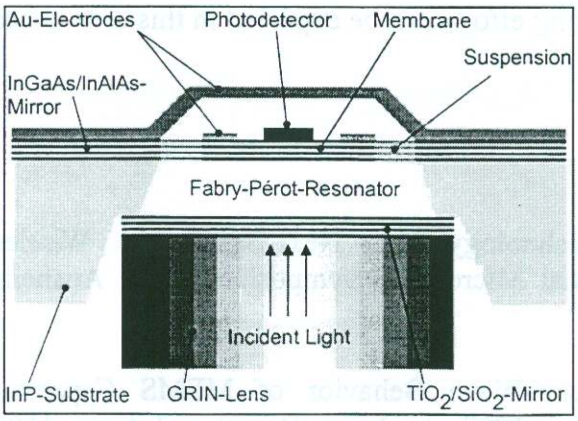


Fig. 4: Integration of electrical, optical and mechanical systems in order to allow new functionality and to improve the performance.

The arise of the microelectromechanical systems, the so called MEMS, has opened a new area of functionality (see Fig. 3) where suitable design tools still need to be developed. So far, most of the work in this MEMS and micromachining area deals with the development of mechanical switches [1] which allow to interrupt a signal line with an excellent isolation and lead to an extremely low insertion loss in case of the connection. Since the interaction of this element with the electrical circuit is limited to the two end conditions (open and close, on and off) only a time invariant assumption is necessary for a mathematical description [2]. This is also the case for many other MEMS applications (e.g. movable backshorts, tunable filters, see [3,4]).

However, some applications are already under development where the change of a mechanical parameter dynamically interacts with the electrical circuit performance. One well known example for such an interaction are, of course, the surface acoustic wave (SAW) filters which are already used in many applications. However, the interaction between electrical, optical and mechanical systems becomes more and more complex. One example is given in Fig. 5 where a mechanical tunable, optical filter for wave division multiple access (WDMA) systems is presented [5]. It allows to select different channels with a excellent performance by applying a static DC voltage between the electrodes which results in a small change of the position of the membrane. The functionality of the filter relies on the principle of a Fabry-Perot filter.



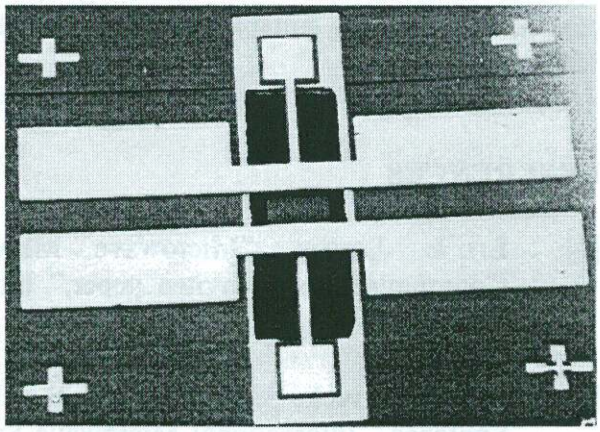


Fig 5: Fabry-Perot filter for optical WDM systems (from TU Darmstadt, see [5]) as an example for the integration of mechanical and optical functionality. Left: principle sketch of the total system; Right: SEM picture of the tunable InGaAs/InAlAs-mirror (without photodetector).

In particular, in the area of microelectromechanical systems a lot of efforts will be spend in near future to develop new devices. However, the success of this new kind of components is strongly related to the demand for accurate models. In the lower frequency range many people have already worked on this topic, since micromechanical sensors and actuators have already gained a lot of interests [6,7]. The modeling of the mechanical functionality is in most cases done by using a simple transformation of mechanical parameters to electrical ones. For instance, a spring damper system can easily be described by utilizing an electrical analogy where the voltage is equivalent to the spring way and the force given by the spring is described as an electrical resistance. The damping can be represented by a capacitance whereas the inertial force leads to a voltage driven current source [6]. Such a description of a mechanical system is suitable for very simple models but higher sophisticated models require a new way of mathematical description.

Comparable to the use of numerical electromagnetic field solver (Finite-Difference method, Finite-Element method) the mechanical properties of a device can be simulated by a Finite-Element approach, e.g. by ANSYS. However, since the MEMS devices are usually based on a three dimensional structuring of the substrate besides the analysis of the mechanical property a suitable process simulation to get the correct layout of etch masks is necessary to allow a full CAD capability up to the layout level. Therefore, future activities in this area of combining these still autonomous tools will be of great importance for the success of MEMS in (monolithic) microwave integrated circuits ((M)MICs).

CONCLUSIONS

In conclusion, the paper demonstrates that the active elements are still considered to be the significant devices for the circuit design reliability. The development for MESFET and HEMT models is rather finished. There is, of course, still need for improvement in connection with special applications but compared to HBTs the work has nearly be done. Regarding passive devices, transmission line models have already reached a satisfactory accuracy. However, the difficult area of mounting and packaging of devices and chips which is necessary for a complete system design still needs improvement.

The increasing interest in the integration of new kinds of functionality in MMICs (optical and mechanical systems) leads to a strong demand for new circuit design tools and requires new concepts for deriving suitable device model. Thus, strong efforts can be expected in this area in near future.

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