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Thermal Management and Monitoring Based on Embedded Ring Oscillator Network Sensors for Complex System Design

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ABSTRACT

This paper presents a new method for determining the exact number of inverters in one ring oscillator of temperature sensors that must be used optimally to monitor and control a complex system design. This method is very efficient, simple and easy to implement. The proposed temperature sensor was designed using TSMC 65 nm CMOS technology, which occupies an extremely small area of silicon. To deduce the exact number of inverters that form a single ring oscillator we will need to make simulations based on Computational Fluid Dynamics (CFD) which will allow us to measure the minimum and maximum temperature of the system used in order to intervene in case of overheating, also to monitor the state of the complex system design.

Keywords: *Inverters, Ring Oscillator, TSMC, CMOS, CFD, Complex System Design.*

1. INTRODUCTION

This paper presents a new orientation for the characterization of thermal dynamics and for monitoring high density. It recognizes the growing importance of microsystems on the chips that represent the convergence of several nanoscale device systems and technologies as an integration solution for the future of the microelectronics industry. However, the magnitude of the integration of complete electronic microsystems on a single chip and the increase in operating speed lead to insurmountable problems of thermo-mechanical stresses. If these aspects are not adequately addressed, this will pose a serious threat to the complex design of microsystems of the future. More precisely, these aspects become critical in more complex models [1]. The evolution of the integrated circuit (IC) industry over the last decade has been so rapid that it is now possible to integrate complex systems on a single SoC chip. However, this created new problems related to thermo-mechanical stress (Thermo-mechanical stress) formed by the combination of residual mechanical stress (static stress) caused by the number of integrated encapsulation transistors and thermal stresses (Thermal stress) caused by Dissipated Power Density [2-7]. Thermal analysis is a first step in a complete characterization of thermal dynamics in a complex circuit that takes into account a single heat source [8-11]. The characterization is based on two numerical techniques, the Computational Fluid Dynamics (CFD) and the other Heat Transfer Analysis (HTA) [9]. The CFD technique which already takes into account the strength of the heat transfer mechanism specific to the complex electronic system and the physical properties will be linked with the temporal and spatial aspect of the HTA to treat the boundary conditions and the temperature distribution in dynamic mode. The oscillation frequency will be used subsequently to determine the exact number of inverters to be used, the frequencies produced are typically several hundred MHz in 65 nm technology. To achieve a low output frequency we respect our proposition, the number of steps must be very large, but much research has been done to increase the time in each step instead of increasing the number of steps [12-14]. A temperature sensor with a 65 nm ring oscillator with competitive performances was presented. It has a maximum measured inaccuracy of ± 3 ° C after a 2-point calibration and a resolution of 0.3 ° C in the temperature range 0 ° C ~ 120 ° C [14]. The main objective of the method developed is to provide the designers with adequate means to act in time and during the design stages in order to control thermo-mechanical stress without deteriorating the characteristics of the system in operation. The rest of our work is organized as follows. In Section 2, we will present our method in general. In Section 3, we perform thermal simulations on the complex system using the COMSOL tool. In section 4, we will present a different variation of the frequency of the sensors of the ring oscillator network for the complex design of the system.

2. DESCRIPTION OF THE PROPOSED NEW METHOD

The new methodology adopted to control the temperature of complex microsystems on a chip will be based on the exact and well-determined number of inverters that will be formed a ring oscillator. This methodology has given very encouraging results for thermal monitoring in more complex circuits. These concepts will then be generalized in high density microsystems, for the development of an integrated thermo mechanical stress control unit using our proposal described in this paper, and Fig. 1 according to the general flowchart shows the complete steps to be followed for controlling the temperature in the most complex system.

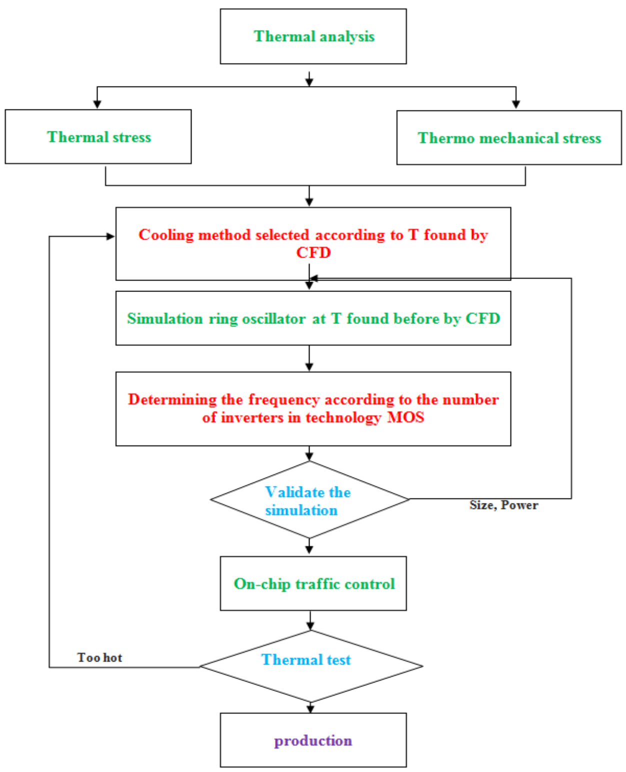

Fig. 1. Methodology for controlling the temperature in the complex system.

We propose this new method of controlling thermo-mechanical stress based on a network of sensors with thermal compensation allowing the smooth operation of complex microsystems. The idea of using a network of sensors to characterize constraint thermal, this method has become a central asset for this thermal problem resulting in a promise of assured control. We will follow our methodology presented in Fig. 1 step by step until we reach our objective. Thereafter it is possible to determine the exact number of inverters in an optimum manner and which will form a sensor based on a single ring oscillator, it is well known that the characteristic of the temperature of the ring oscillator is already present. As a function of the frequency of the linear oscillation at the temperature in the paper [15], and the following Fig. 2 presents the values of the temperature as a function of the frequencies of a ring oscillator.

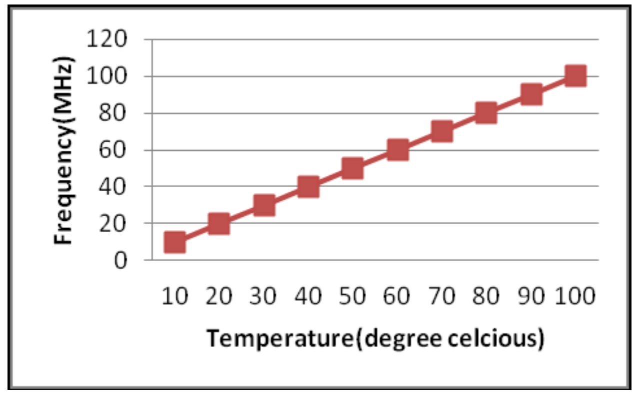

Fig. 2. Temperature of (RO) ring oscillator showing frequency of oscillation linear to temperature.

The results presented in this graph are really important to have our results, so we will start to perform thermal analyzes in our complex system, we will determine the temperature generated by our design thanks to the COMSOL tool then we use Fig. 2 which will help us to find precisely the frequency value that we will use later to find the number of inverters that must be used to generate the same frequency. We have to do thermal simulations first then we will use the Cadence tool for the conception and realize different simulations until we find the right temperature according to the frequency. More precisely, we had to specify a configuration of inverters (number, dimensions) and we varied the simulation temperature to determine the corresponding frequencies.

3. THERMAL ANALYSIS OF COMPLEX SYSTEM DESIGN

The thermal analysis of models integrating CAD software in microelectronics is particularly interesting for the designer. In our case, each subset must be modeled with the same degree of approximation. The simulation tool allows to analyze the operation of the integrated circuit, to provide the thermal behavior and thermo-mechanical stresses on each component in steady state in transient mode. It can also provide operating temperatures because it is an essential parameter for the choice of the component. This requires developing thermal models compatible with all simulation tools.

3.1 Thermal boundary conditions

One of the major problems that arise when one wants to make a thermal study at the complex system is to determine the boundary conditions. Thus, for this purpose, a new approach has been established for the determination of a coefficient of natural or forced convection to avoid specifying the temperature below module, which introduces a thermal short circuit. This requires the use of a model that can reach tens of millions of items making the analysis more complex and even impossible. This method of finite elements used must impose simplifying assumptions more or less on the material properties and boundary conditions. The finite element method is based on the discretization in space and time. The main advantage of this method is its great generality; it can handle complex geometries, taking account of the boundary conditions and properties of temperature dependent materials.

3.2 Presentation of the complex system in COMSOL tool

Fig. 3 shows the complex system and its support. We have made the simulation in COMSOL tool appointment with different materials and hardware layers and well on their ranking on the semiconductor.

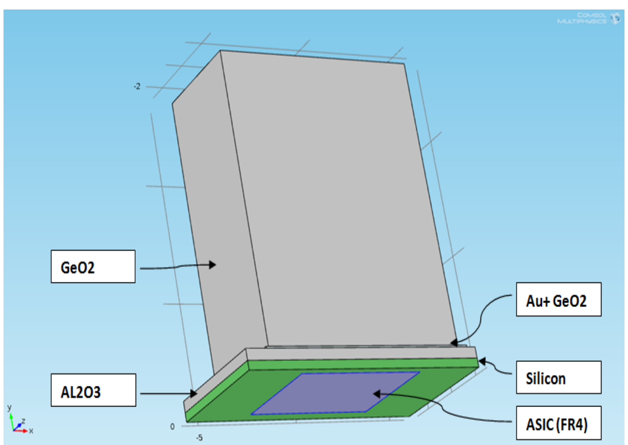

Fig. 3. Geometry of the complex system and under COMSOL tool.

This structure thus represents a continuous domain, by the method of finite elements consists first of a geometric discretization. The structure is subdivided into sub domains of the simple geometric form called finite element and defined not on the whole of the structure, but for each of its elements. In other words, the problem of the continuous medium is reduced to a set of discrete problems with a finite number of unknown parameters which are determined by application of energy criteria. The problem consists of calculating an overall stiffness matrix of the system from the stiffness matrices of each element determined to use the virtual work theorem. The details of these calculations, which fortunately are done automatically in matrix form by the COMSOL software.

3.3 Presentation of the thermal simulation of the complex system

In this part, we will present the simulation results from heat sources represented the complex system module in COMSOL. Fig. 4 shows the thermal behavior of our model which consists of a heat source 4.68 mm X 5.97 mm.

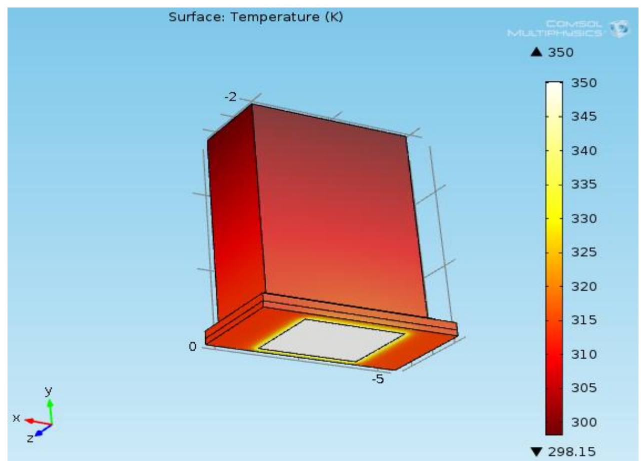

Fig. 4. Evolution of the thermal simulation of complex system in COMSOL.

This simulation of the complex system module in COMSOL gives a good idea of the behavior and the thermal diffusion of heat sources in our complex system and shows the temperature increase in a significant way to nearly 350 °K. This temperature is accumulated at the top of the complex system head that shows us the total power to be dissipated throughout the conditions simulated limits. We took a vertical line from the center of the model of multiple nodes, and Fig. 5 shows the evolution of the temperature (°K) versus time (s).

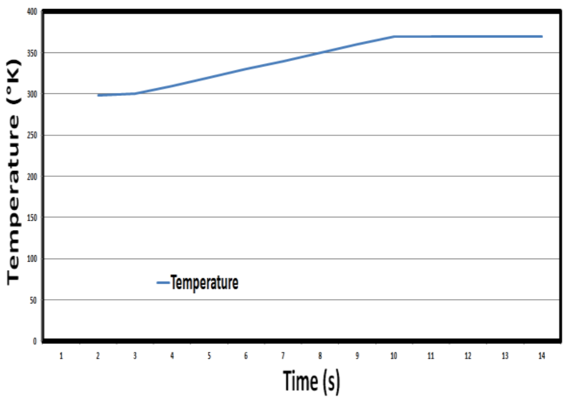

Fig. 5. Thermal evolution for several points in the complex design.

This graph gives a good idea of the thermal evolution of the source of the complex system dissipates 0.6 W and can be viewed as the temperature starts to increase peak to peak 298.15 °K equivalent to 25 °C up to 370 °K equivalent to 77 °C at this temperature of our module began to stabilize at the 10th second this result will, in fact, help us to determine the temperature and its stability throughout the system complex.

4. RING OSCILLATOR NETWORK SENSORS FOR COMPLEX SYSTEM DESIGN

Technologically now we can integrate the ring oscillator in the electronic systems more complex to control its temperature [16-18]. Several methods and architectures have been developed to enable integration of CMOS technology to reduce costs and to measure directly the internal temperature of integrated circuits. Built-in temperature sensors can be divided into three categories based on voltage, frequency or time. The reading of the difference of the oscillation frequencies makes it possible to convert the temperature information into frequency [19-24]. The period of the oscillations is then.

$$T = 2 \times N \times \tau, \quad (1)$$

where N is the number of cascaded cells and τ the delay generated by each cell. The advantage of this structure is that it can be implemented with an odd number of cells. This provides a greater degree of freedom over the in phase constellation of the signals available at the output, but above all enables, in the case of an implementation

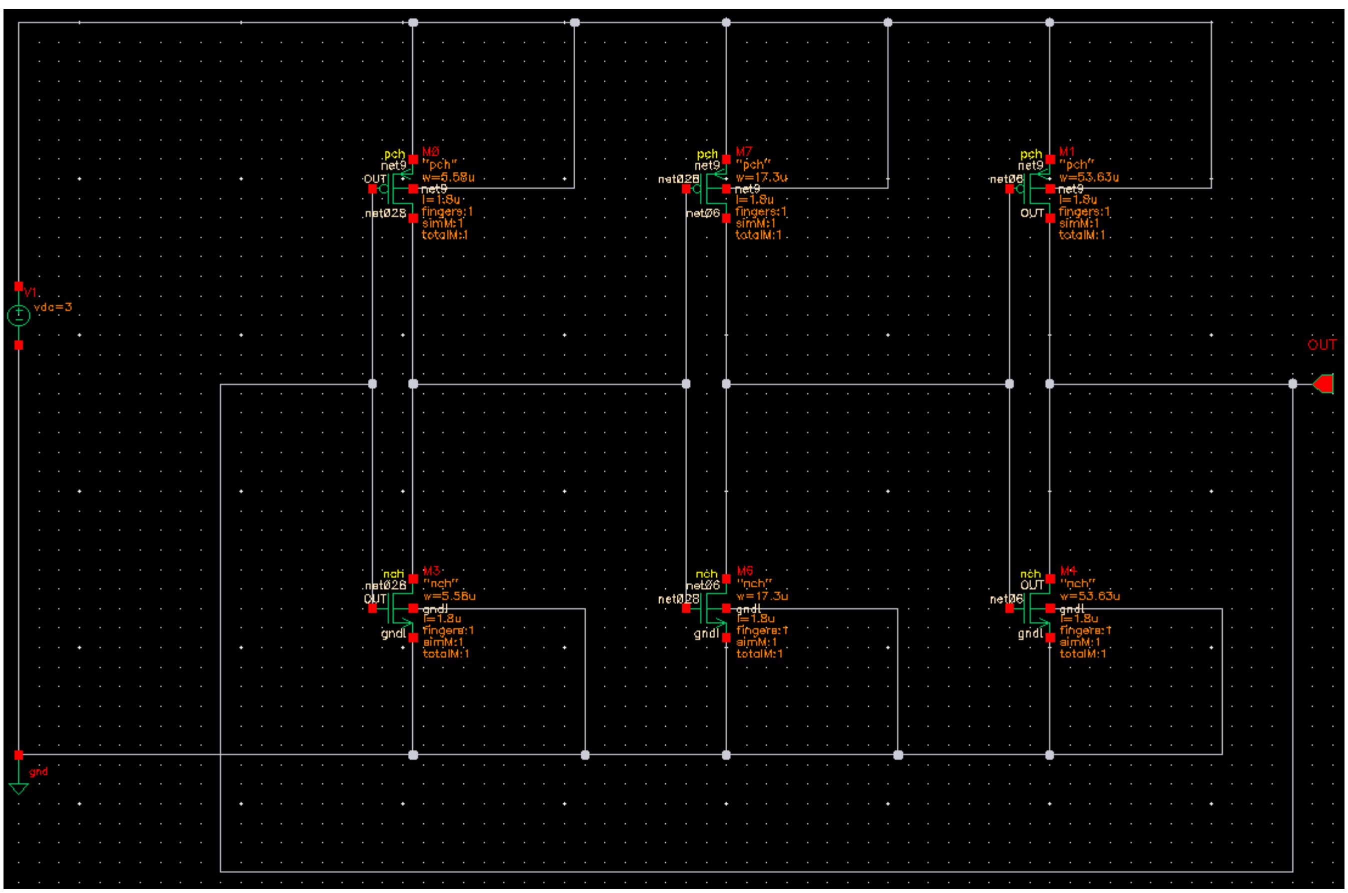

Fig. 6. Schematic of simulation of a ring oscillator with three inverters.

with an even number of cells, to generate quadrature phase signals [25].

4.1 Simulation of a ring oscillator under CADENCE tool

The first step is carried out starting from a circuit of a normal inverter and adding two others to form the oscillator. The minimum size of the 65 nm CMOS technology which has been obtained is a transistor length of l = 1.8 µm and width W = 5.58 µm. It is this inverter that will be the first in the design of our oscillator. A combination was made by taking a value of the minimum size K = e = 3.1 in order to obtain symmetrical inverters. Fig. 6 shows the three combinations made as well as the value of the voltage used.

4.2 Variation the frequency of the ring oscillator with three inverters

To observe the variation of the frequency of a ring oscillator as a function of the number of inverters we will begin our simulations by a ring oscillator based on three inverters. To do this, we performed simulations for ring oscillators with three inverters at temperature of 77 ° C. The ring oscillator with three inverters is shown in Fig. 7.

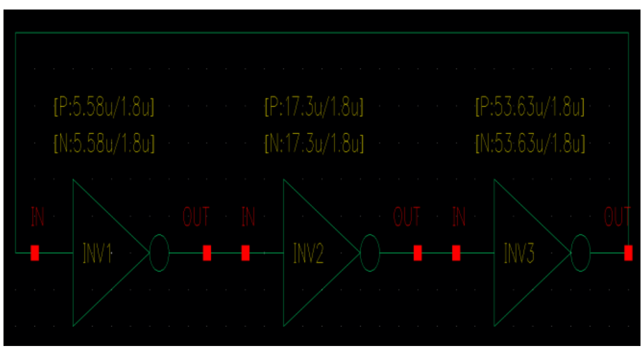

Fig. 7. Schematic ring oscillator with three inverters.

All simulations can be configured and started from ADE GXL. The use of ADE GXL remains quite complex under Cadence because of a large number of menus. For the sake of simplicity, we will begin by presenting a simpler way of configuring simulations, using the ADE XL tool. With more experiments, we will be able to manage all the simulations from ADE XL. The window below opens. To validate our work we have to do several simulations with three, five and seven inverters under temperature 77 ° c and the following Fig. 8 shows the good configuration of our parameters.

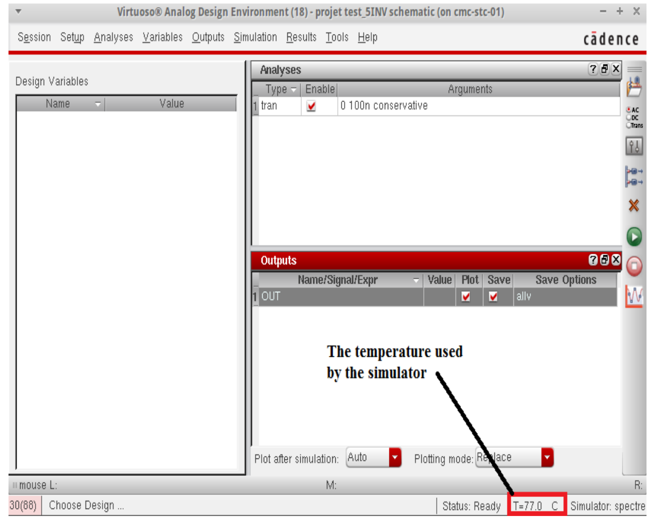

Fig. 8. Virtuoso analog design environment and launch simulations.

By simulating this ring oscillator of 3 inverters, we obtain a period of 5.635 ns, corresponding to a frequency of about 208.4 MHz, as shown in Fig. 9.

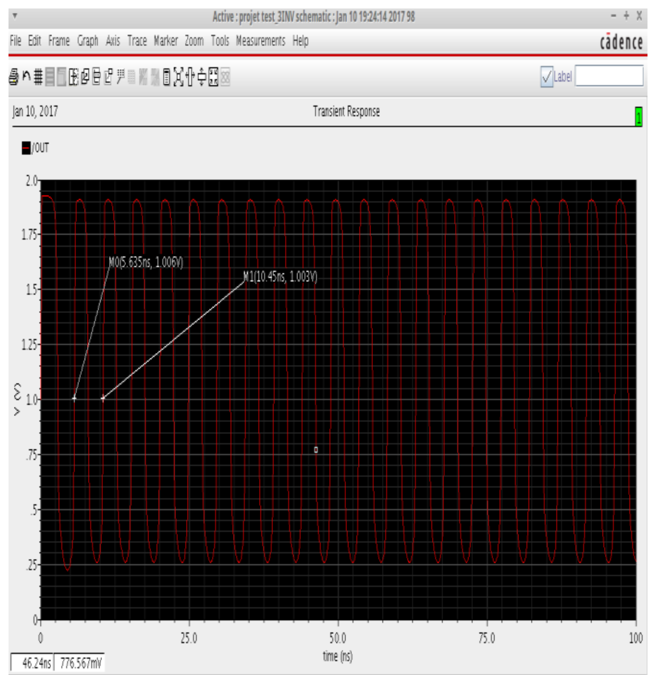

Fig. 9. Display of the period of a ring oscillator with three inverters.

4.3 Variation the frequency of the ring oscillator with five inverters

To observe the variation of the frequency of a ring oscillator as a function of the number of the inverters, we performed simulations for ring oscillators with five inverters at temperature of 77 ° C. The ring oscillator with five inverters is shown in Fig. 10.

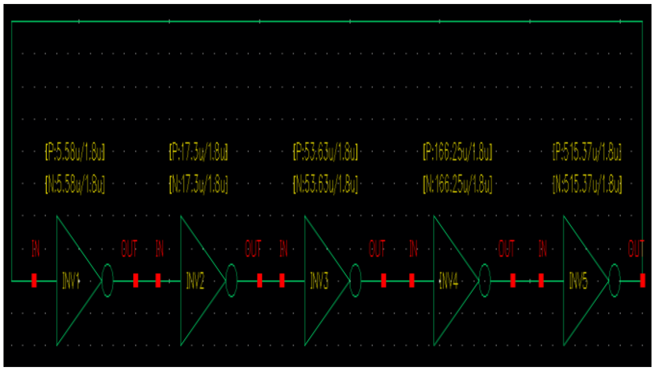

Fig. 10. Schematic ring oscillator with five inverters.

By simulating this ring oscillator of 5 inverters, we obtain a period of 12.7 ns, corresponding to a frequency of about 78.74 MHz, as shown in Fig. 11.

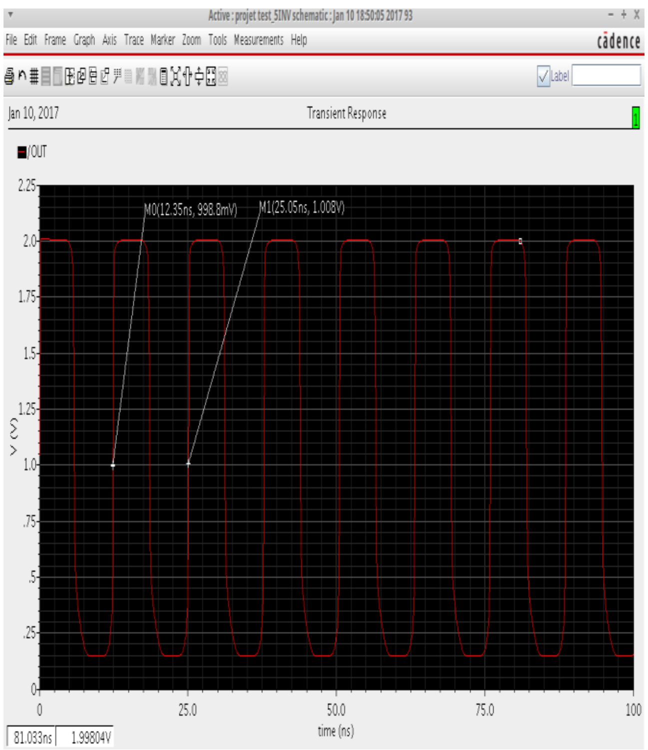

Fig. 11. Display of the period of a ring oscillator with five inverters.

4.3 Variation the frequency of the ring oscillator with seven inverters

To observe the variation of the frequency of a ring oscillator as a function of the number of the inverters, we performed simulations for ring oscillators with seven inverters at temperature of 77 ° C. The ring oscillator with five inverters is shown in Fig. 12.

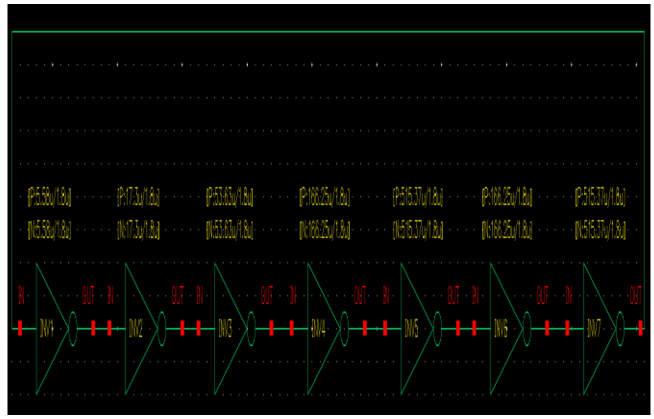

Fig. 12. Schematic ring oscillator with seven inverters.

By simulating this ring oscillator of 7 inverters, we obtain a period of 15.35 ns, corresponding to a frequency of about 61.16 MHz, as shown in Fig. 13.

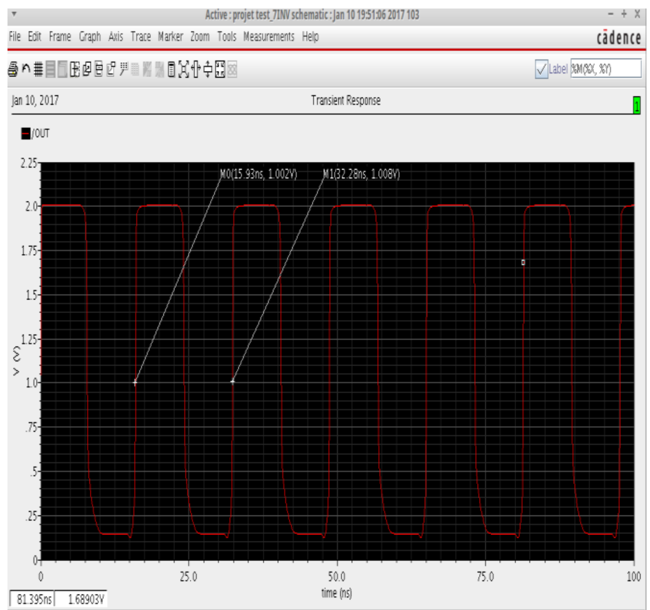

Fig. 13. Display of the period of a ring oscillator with seven inverters.

After these simulations, here is a summary in the form of an array of values found by varying the number of inverters:

Table 1: Variation of the frequency as a function of the number of inverters

Number of inverters in the RO	***Obtained frequency***
3	208.4 Mhz
5	78.74 Mhz
7	61.16 Mhz

It is seen from the table. 1 that the more we increase the number of inverters, the lower the frequency. All the simulations have been done correctly and logically, now if we compare these findings with the results of the graph which is proposed by [16], and displaying in section 2 of this paper that temperature 77 ° C has our complex module corresponds to approximately 78 MHz (see Fig. 2). This perfectly corresponds to our simulation which is made for the ring oscillator with 5 inverters (see the Table. 1) which clearly presents this result.

5. CONCLUSIONS

One of the important issues in the field of thermal problems of complex systems and microsystems is how to perform thermal monitoring with a minimum number of inverters used in a single ring oscillator, to indicate overheating situations. The traditional approach is to place many sensors based on a large number of inverters all over the chip and then their output can be read simultaneously and compared to the reference voltage recognized as the overheating level. The idea of the new method proposed is to predict the local temperature and gradient along the distance given in only a few places on the monitored surface and to evaluate the information obtained in order to predict the temperature of the heat source with a minimum of Inverters in single ring oscillator, in our complex system we need just five inverters for controlling a temperature has 77 ° C. The good benefit of our proposal is that in most cases more complex electronic systems, overheating occurs only in one place.

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