

# Integrated Sensors' Modelling via Different Circuit Simulators

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**Abstract** – This paper presents approaches for modelling the characteristics of integrated sensors. The methodology can be applicable to data flow graphical programming tools as Simulink, schematic capture and simulation applications as Multisim and hardware description languages such as Verilog. The proposed models are running on different technical computing environments as Cadence Verilog-A, MathWorks MATLAB® & Simulink® and National Instruments Multisim™.

**Keywords** – AD22103, Integrated sensor, MATLAB, Multisim, Verilog-A.

## I. INTRODUCTION

Sensors have been used in many applications and because of their integration still have many potential applications into numerous devices and environments.

The purpose of a sensor is to respond to some kind of an input physical property (stimulus) and to convert it into an electrical signal that is compatible with electronic circuits. This signal further is converted into a form that can be processed, stored, and acted upon. In this sense sensors are part of the interface between the physical the digital worlds. However the sensor does not function by itself, it is always a part of a larger system that may incorporate many other detectors, signal conditioners, signal processors, memory devices, data recorders, and actuators. These complex technical systems and higher levels of integration of electronic circuits lead new requirements on the design process of modern sensor systems, especially on modelling and simulation.

The most of stimuli are not electrical, from an input to the output, a sensor may have several energy conversion steps before it produces and outputs an electrical signal. An ideal or theoretical input-output (stimulus-response) relationship exists for every sensor. Because of this the sensor could be considered as a “black box” where the main concern are

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relationships between its output electrical signal and input stimulus. If the input-output function is time invariant it is commonly called transfer function. This function contains information about the sensitivity and the offset at the output and usually is used to predict the behaviour of the sensor.

Simulation is a mathematical way of emulating the behaviour of a circuit. With simulation can be determined much of circuit's performance before physically constructing the circuit or using actual test instruments. Because of the complex theory, the modelling with equivalent circuits is a complicated process, which requires efficient device models.

## II. MODELS OF THE INTEGRATED SENSORS

The main objective of the model is to simulate output signal as a response to an input physical phenomena. This is accomplished by block *Transfer Function*, which generates the output voltage in accordance with the algebraic expression, being given by manufacturer. In Fig. 1 the proposed general model is illustrated, which can be applied to voltage output sensors.

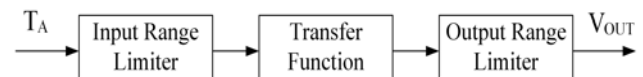


Fig. 1. A simplified model of an integrated sensor

The transfer function represents the relation between stimulus  $s$  and response electrical signal  $S$  produced by the sensor. This relation can be written as  $S = f(s)$ . Normally, stimulus  $s$  is unknown while the output signal  $S$  is measured. An inverse  $f^{-1}(S)$  of the transfer function is required to compute the stimulus from the sensor's response  $S$ . The value of  $S$  that becomes known during the measurement is a number that represents the value of stimulus  $s$  [4].

In the developed model the functional relationship between output voltage  $V_{OUT}$  and temperature  $T_A$  is stated as [8, 9]:

$$V_{OUT} = \frac{V_S}{V_{Snom}} (V_{offset} + S.T_A) \quad (1)$$

In Eq. 1,  $V_S$  is the supply voltage and  $V_{Snom}$  is the nominal supply voltage.

The input and output blocks are range limiters, used to restrict the values according sensor's specifications [8].

### III. SIMULATION RESULTS

For the needs of current paper is used a monolithic temperature sensor with on-chip signal conditioning AD22103. It can be operated over the temperature range 0°C to +100°C using a single +3.3 V supply. The output voltage is proportional to the temperature times the supply voltage (ratiometric). The output extends from 0.25 V at 0°C to +3.05 V at +100°C. The AD22103 is especially well suited to providing a low cost temperature measurement capability for microprocessor/microcontroller based systems. The modelled transfer function has the following expression, specified by the manufacturer:

$$V_{OUT} = \frac{V_s}{3.3V} \left( 0.25V + \frac{28mV}{^{\circ}C} \times T_A \right) \quad (2)$$

#### A. MathWorks MATLAB® and Simulink®

Figure 2 shows the model of AD22103 sensor. Main blocks of the proposed model are the source blocks as Ramp, Constant and Step. The Ramp block generates a signal that starts at a specified time and value and changes by a specified rate. The block's Slope, Start time, and Initial output parameters determine the characteristics of the output signal. The slope of the transfer function is a product of Constant and Ramp sources. The Step Vs block provides a step between two definable levels at a specified time. According to specification the output signal of Step Vs source is divided by 3.3 with a Gain block. The Output Range Limiter from figure 1 is performed by Saturation block, which limits the maximum output voltage [10, 11].

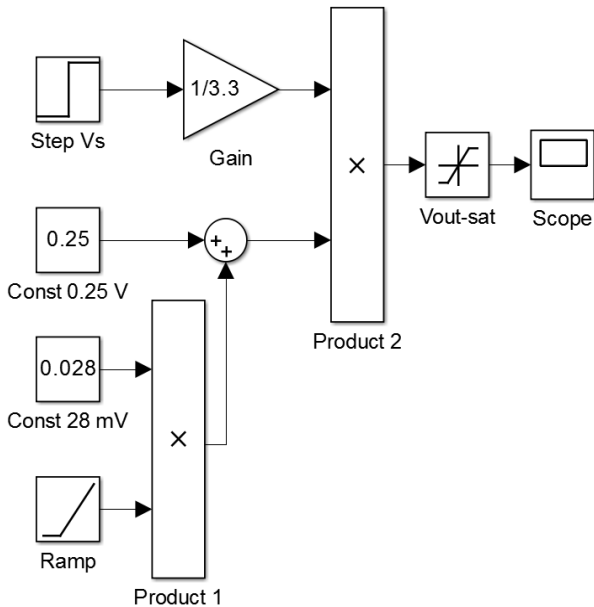


Fig. 2. Simulink model of the transfer function of temperature sensor AD22103

Figure 3 illustrates simulation results of the transfer function of the chosen temperature sensor. Full scale characteristic of the sensor is limited at 3.05 V for the guaranteed operating temperature, according to sensor's specifications. The span of the temperature is from 0°C to +100°C. The characteristic has offset 0.25 V and slope 28 mV/°C.

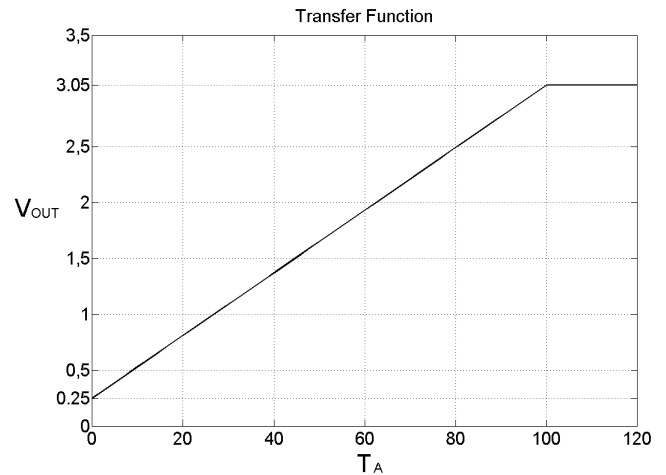


Fig. 3. Simulation results in Matlab and Simulink

#### B. National Instruments Multisim™

There are several sections in the Multisim software that are closely tied to the simulation process: setting up the circuit to be simulated, setting up the simulation parameters, performing the simulation, and analyzing the results [6].

Figure 4 shows the developed model in the schematic capture and simulation application of National Instruments Circuit Design Suite – Multisim. The temperature range is transferred into voltage by Voltage Limiter block A2. The slope of the transfer function is given by Voltage Gain block A5. The offset of the characteristic is provided by DC Power source block Voff. The Divider block A4 represents the multiplier from Eq. 2 [5, 7].

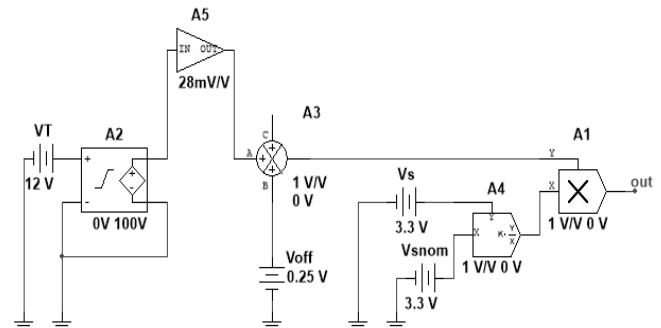


Fig. 4. Multisim model of the transfer function of temperature sensor AD22103

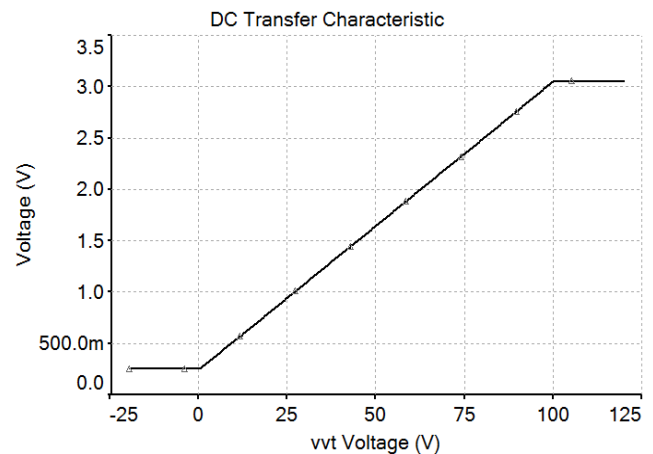


Fig. 5. Simulation results in Multisim

The results of the DC simulation are shown on Fig. 5.

C. Cadence Verilog-A

Hardware description languages such as Verilog are different from language to describe software, because they include methods for describing the spreading of signals depend on the time and signal level (sensitivity). The first application of the language appeared recently in version of Cadence, who had worked on their Spectre simulator. At this moment Cadence was the first to launch the application of this new language in a product which combines Verilog and Spectre simulators. Nowadays, all simulators support Verilog-A language and every bigger trader offers a mixed signal simulators. Once described model by Verilog-A that helps designers to better understand and verify their design through the use of simulator. Since Verilog is an open platform has a number of free software that can simulate the model, which is with description using Verilog language [1].

Simulation environment of Cadence Virtuoso® Spectre® Circuit Simulator allows analysis of SPICE level of analog, radio frequency and mixed-signal circuits [12]. Using module for setting analog simulation environment in Cadence we can undergo to analysis any circuit, in practically all conditions of input-output signals, temperature, time intervals and variations in the accuracy of the technological processes. The available languages for modeling are Verilog A and Verilog AMS, which have their own system files and this files are embedded in the relevant cell, which they describe [3]. This allows on each designer to describe a structure and using simulation model.

For the purpose of this paper we will use a behavioral description language Verilog-A and simulation environment Cadence [12]. To simulate the behavior of the sensor first have to code its behavior. To create a new symbol in Cadence, which corresponds to the temperature sensor AD22103 then for the simulation is using the newly created symbol.

In Fig. 6 is shown the circuit of the sensor from environment Cadence.

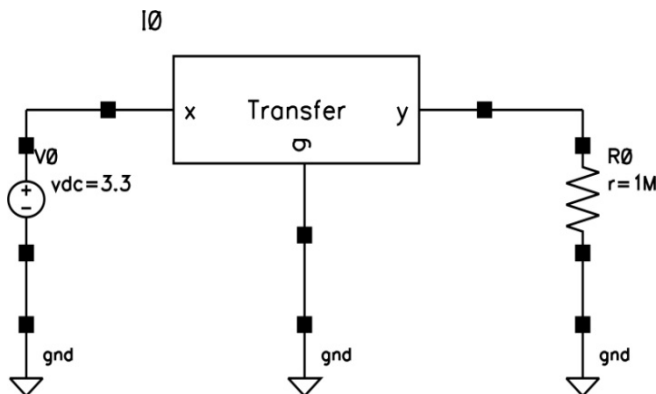


Fig. 6. Cadence model of the transfer function of temperature sensor AD22103

In Fig. 7 is shown part of the code of Verilog-A, where are coded the sensor and are set the value of its parameters, and the relationship between them [2].

```

// VerilogA for Sensor, Transfer, verilogA
#include "constants.h"
#include "discipline.h"

module Transfer (x, y, g);
inout g, x, y;
electrical Vin, Vout, g, x, y;
parameter real S = 0.028;
parameter real Ta = 25;
parameter real Vs = 3.3;
parameter real Vsnom = 3.3;
parameter real Voffset = 0.25;

analog
begin
V(Vin) <+ V(x, g);
//V(y) <+ Vs/Vsnom*(Voffset+S*Ta);

if (Ta < 0)
    V(y) <+ 0.25;

else if (Ta > 100)
    V(y) <+ 3.05;

[else
    V(y) <+ Vs/Vsnom*(Voffset+S*Ta);

end
endmodule
    
```

Fig. 7. Verilog-A code described the sensor.

Property	Value	Display
Library Name	Sensor	off
Cell Name	Transfer	off
View Name	symbol	off
Instance Name	I0	value
User Property		
partName	Transfer	off
vendorName		off
CDF Parameter of view		
S	0.028	both
Ta	25	both
Vs	3.3	both
Vsnom	3.3	both
Voffset	0.25	both

Fig. 8. Edit properties in Cadence

Used environment and description language for simulation allows in the original description to be introduced all parameters and from what they are dependent. It can be introduced values for the parameters, if are known their values, but later when users starting the

simulation could easily set the new values and the simulation can be done with them.

Figure 8 shows the window in which can be easier entered new values for the parameters defined in the model before.

In Fig. 9 is shown the result of the simulations in Cadence, there is shown a dependency of the output voltage versus the temperature change. The output voltage is changed in a range from 0.25 to 3.05 V, when the temperature is changed from 0° to 100° C.

The obtained results are identical with those obtained in the other two environments for simulation.

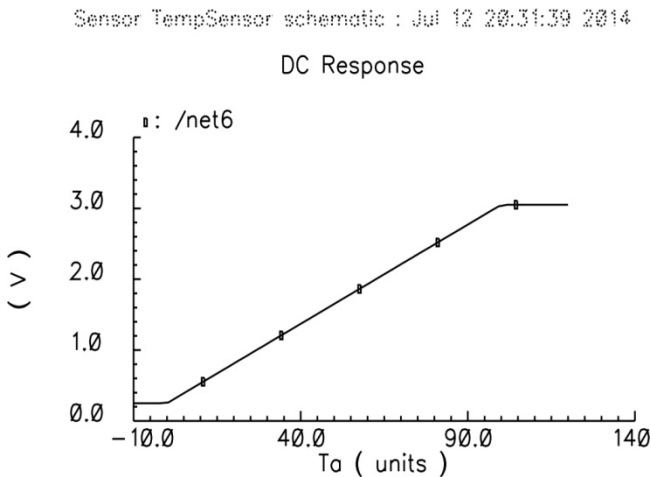


Fig. 9. Simulation results in Cadence

#### IV. SUMMARY

In this paper the transfer function is simulated of the temperature sensor AD22103 by Analog Devices. The simulations were performed on modern software environments for computer modelling and complex analysis as MathWorks MATLAB and Simulink, National Instruments Multisim and Cadence Verilog-A. As it can be seen the results are identical regardless of simulation environment. The difference in the modelling approach is the way of describing the sensor's parameters and his operation principle.

#### V. CONCLUSION

In general the proposed methodology for analysis of sensors' characteristics can be applied to different type of sensors. Furthermore, the developed models with minor changes can be used for various sensors. Because of the identical results, the used software environment for simulation depends on user's preferences and his requirements for further work.

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