NEW CONCEPTS OF MODELING AND COMPLEX SIMULATION OF ELECTRONIC CIRCUITS FOR INTERFACING TACTILE SENSORS IN CYBER-MECHATRONIC SYSTEMS

Anghel CONSTANTIN[1], Gheorghe Ion GHEORGHE[1, 2]

[1]National Institute of Research and Development in Mechatronics and Measurement Technique,

Bucharest, Romania

[2]Valahia University of Targoviste, Romania- Faculty of Materials Engineering and Mechanics

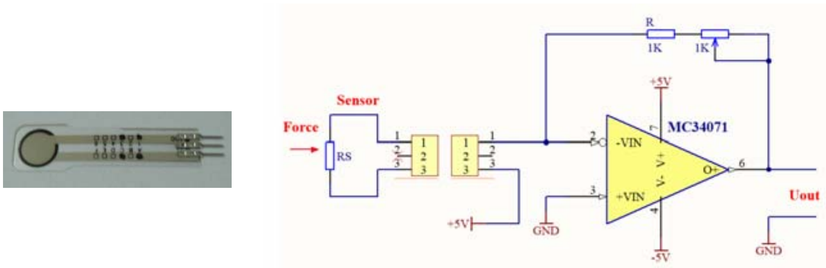
E-mail: anghel.constantin@incdmtm.ro, geocefin@yahoo.com

Abstract. The paper presents an original concept for interfacing tactile force sensors in modern cyber-mechatronic systems. The authors show the results and conclusions of a PSPICE simulation of an original patented circuit. In the simulations, in models used were introduced some circuit components corresponding to the physical implementation for a practical mechatronic system which has already been used for the analysis of human walking. After these simulations were revealed important aspects of dynamic behavior and was proposed an optimal variant of the interface circuit as a non-typically instrumentation differential circuit spitted in two parts, one near to the sensor, and the second far from the sensor and close to an A/D converter of the data acquisition system. For electrical links between the two parts can be used low cost cable without important loss of the signal / noise ratio.

Keywords: PSPICE, simulation, tactile sensor, interface

1. INTRODUCTION

This paper presents recent research about the optimal design [1] of an electronic interface circuit between a tactile force sensor and the data acquisition system. Thus it is continued an original patented idea and an electronic schematic topology which is discussed in another article [2]. Based on practical observations, it was designed an optimization schematic by PSPICE simulation using complex models that approximates physical reality in the real working environment. In the researched application the used sensor is a FlexiForce type – see Fig 1 a. The classical interface circuit is to introduce the sensor in a conductance-voltage converter circuit. In this case, can de achieved a calibration method for converting the output signal in measuring units for the force. The diagram which is recommended by the producer [3] is using a classical circuit like in Fig 1 b.

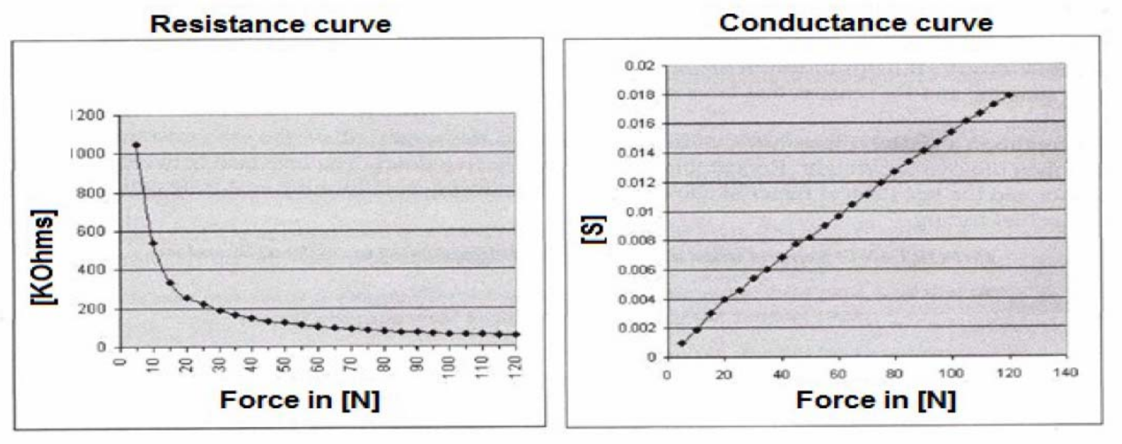


a) b)

Fig.1 – a) Tactile sensor FLEXIFORCE and b) Classical schematic interface

FlexiForce sensor is made by laminating two flexible and polyester / polyamide thin films (thickness: 0.008 inch), each of them being re-covered with a silver film which serves as a conductor on the one hand and, on the other hand, playing the role of electrodes that define the geometry of the sensitive area. Between the two circular silver electrodes is inserted a pressure sensitive layer made of special ink. When the sensor is unloaded its resistance is very high (1 ÷ 2 MΩ). That is the first observation [4].

If a force is applied on the sensor, its strength decreases, as shown in Fig. 2; the sensor is sensitive and have quasilinear behaviour.



a) b)

Fig.2 – a) Tactile sensor resistance b) Tactile sensor conductance

The classic circuit presents a great disadvantage in terms of common mode noise analyzed in detail in [2]. Fig. 3 shows the original patented circuit which has the advantage of drastically reducing the common mode noise and providing very good linearity. The tactile sensor is placed as variable conductance on the position that sets the gain of an instrumentation amplifier circuit excited with a greater stability DC voltage made by a precision reference source.

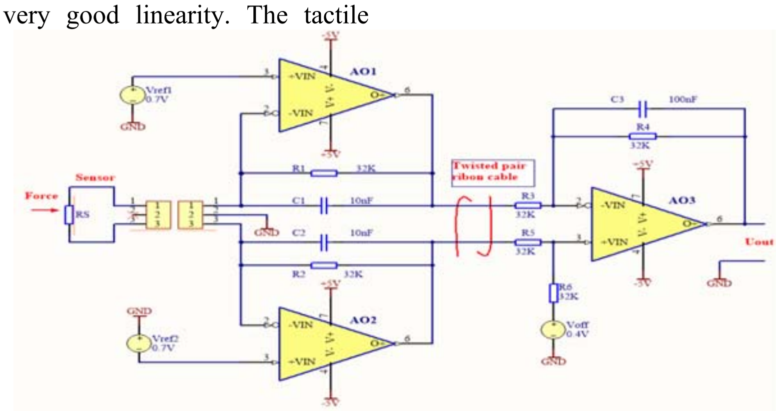


Fig.3 – Original circuit with high linearity and high common mode perturbation rejection

2. PSPICE MODELING AND SIMULATION

For optimal design of the interface circuit were investigated multiple circuits topologies for simulation and modeling of components with values close to reality as physical circuit. Thus, for the sensor was designed a model based on linear sources in order to create a voltage controlled conductance. This allows the complex simulations and analysis such as the indicial step response (transient analysis), linearity, frequency response, Monte Carlo analysis and others. The symbol for voltage controlled conductance is shown in Fig4.

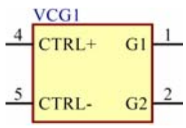


Fig.4 – Symbol for Voltage Controlled Conductance

Where: CTRL+ and CTRL- represent the connections for control voltage used in range 0-10V, and G1, G2 are the two connections of the controlled conductance with real range of the sensor.

The model for voltage controlled conductance is presented in the standard PSPICE in TABLE 1:

TABLE 1 – The PSPICE model code

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***********VOLTAGE CONTROLLED CONDUCTANCE *****
***************PSPICE MODEL SUBCIRCUIT ************
* CONDUCTANCE - 1, 2     CONTROL - 4, 5                *
*******************************************************
.SUBCKT VCConductance 1 2 4 5
ERES    1   3   VALUE = {I (VSENSE)*100K/ (V (4, 5) +0.001)}
VSENSE 3   2   DC 0V
.ENDS VCConductance
```

2.1 Circuit Simulations Results

Fig. 5 shows the schematic circuit used for simulation. Actually, it is the diagram in Fig. 3 to which were added new circuit components such as parasitic capacitances of the connections wires between the sensor and the circuit (C6) and between the differential input of the circuit and single ended output circuit U1B. Because U1B and U1C are placed remotely and are connected with U1B, with a twisted pair ribbon cable which has parasitic capacitances (C3, C4 and C5) nanofarads values. The spitted instrumentation circuit is part of the original idea for transmitting analog signals remotely (1m) in a differential mode with the multiple advantages derived from it. The input circuit is symmetric and placed near the sensor, and the differential outputs are transmitted at approx. 1m from where they are differentiated and this operation improves global signal to noise ratio.

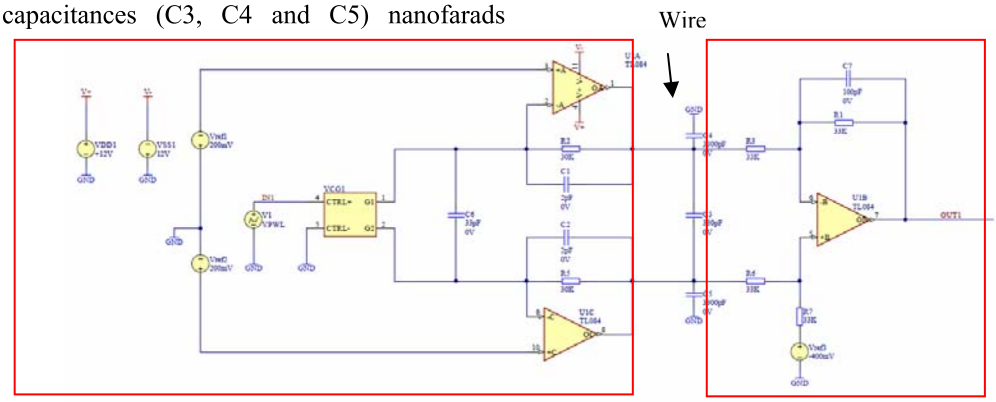

Fig.5 – Simulation circuit with parasitic capacitance models

Running the Transient Analysys and AC Analysis we determined the signal step response and the frequency response feature of the sensor interface circuit - considering that the variable frequency source is V1 as the range of forces applied is of 0 - 100N (the sensor resistance varies from the 5MOhms to 1Kohm). In Fig. 6 are depicted the settings used as PSPICE directives analysis in Altium Designer software. For the Transient Analysis was checked the option "Use initial conditions" and for capacitors was considered the null voltage as the initial status [5].

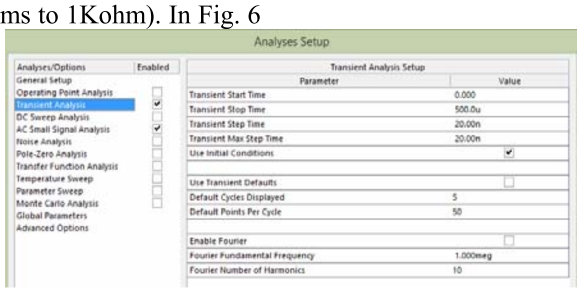

Fig.6 – Simulation options in Altium Designer

The simulations results are showed in the following charts. Fig. 7 shows the Transient Analysis step response with signal sensor in the range 0 - 100N. The resistors of the schematic circuit were calculated for a maximum output signal does not exceed 2.5V well the maximum input voltage allowed from the acquisition system used. Fig. 8 shows the result of AC Analysis simulation for frequency behavior.

Observe that the circuit has a frequency characteristic as a Low Pass Filter (LPF) with a bandwidth about 10KHz but both simulations show an instability with null load (equivalent resistance of the sensor is high - about 5MOhms) hereby parasitic oscillations with a frequency around 300KHz occur.

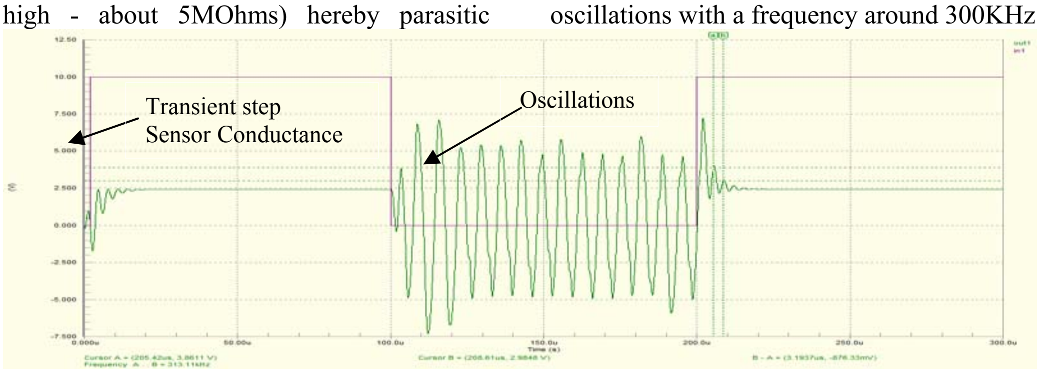

Fig.7 – Simulation results of Transient Step Response

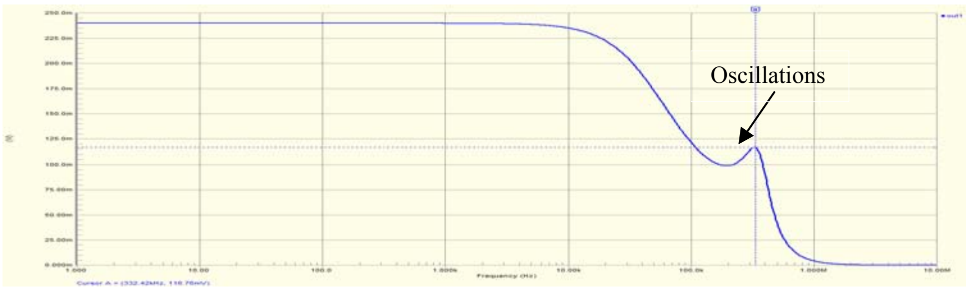

Fig.8 – Simulation results of AC Analysis response

2.2 Circuit Simulations Results after Optimisations

Analyzing the causes of unwanted oscillations that occur when the force pushes a little bit the sensor (the conductance is very small and equivalent resistance is very high) found in datasheet of the operational amplifiers (OPAMPS) does not accept a capacitive loads exceeding 100pF [6]. But the wire capacitancehave nanofarads values and can not be reduced by simple methods. A good idea is to place the resistors R3 and R6 near the outputs of the amplifiers U1A and U1C and after this connecting the wires to remote input of the amplifier U1B. The new topology scheme was modeled and simulated as shown in Figure 9.

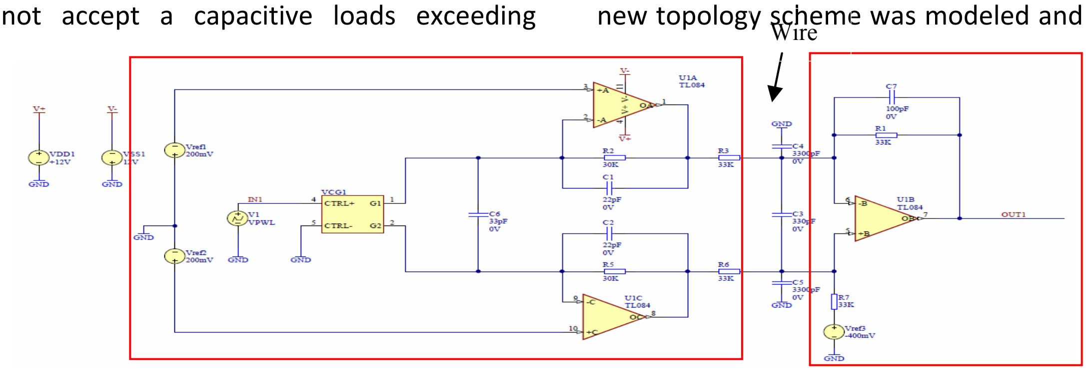

Fig.9 – Optimal topology of the circuit interface

Fig. 10 shows the result of the Transient Analysis simulation indicial response. The disappearance of the unwanted oscillations are observed even at very null load of the tactile sensor The rise time and the fall time is the same because of the symmetry of the input circuit.

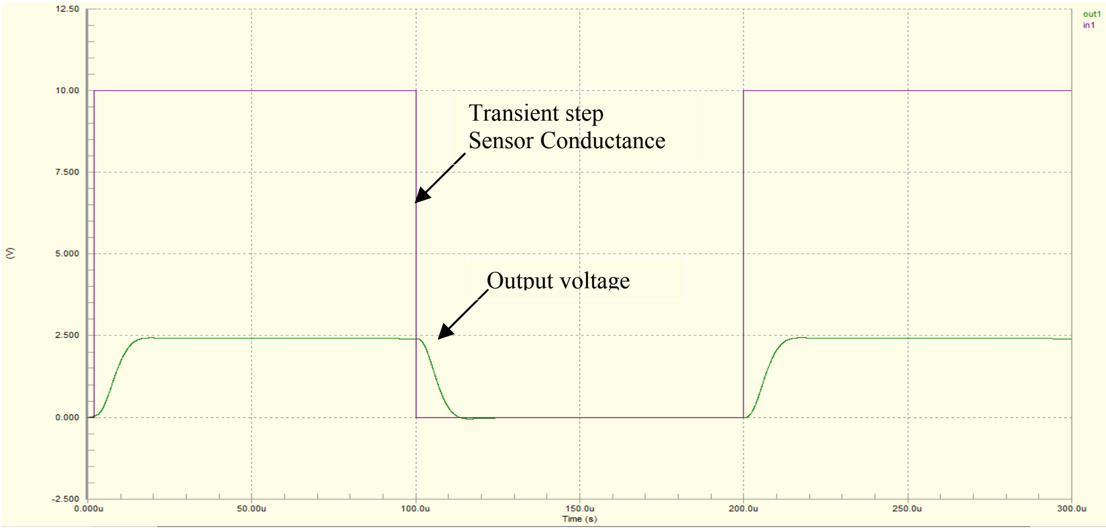

Fig.10 – Simulation results of Transient Step response

Fig. 11 shows the simulation results of the characteristic frequency of the entire interface circuit and sensor. Here is obvious the disappearance of the oscillations and in general, it represents a characteristic of a second order LPF with cutting frequency (Cuttoff Frequency) around 46KHz

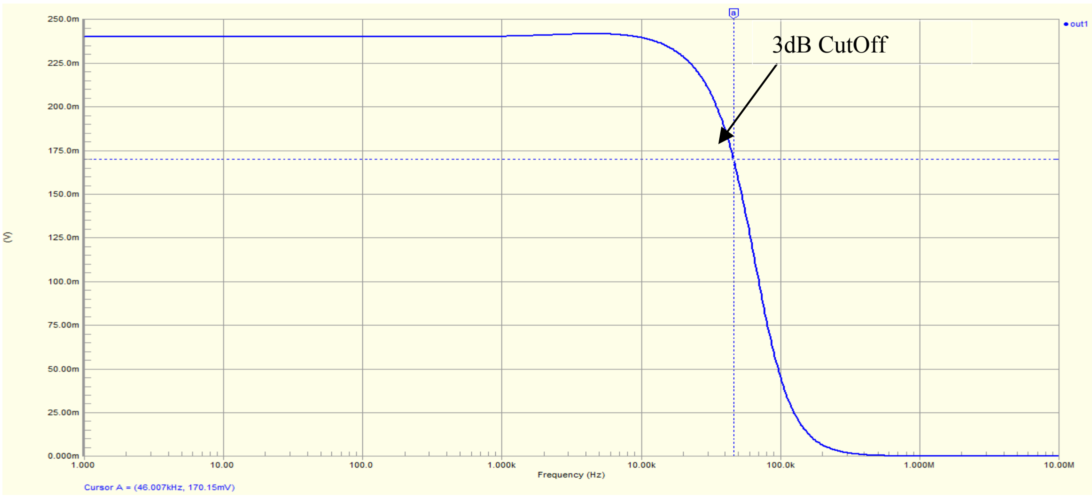

Fig.11 – Simulation results of AC Analysis response

3. CONCLUSIONS

By complex modeling of the real elements of connections (wires) between the sensor and the circuit interface on the one hand and the input interface with the remote circuit at 1 m distance on the other hand were obtained remarkable results confirmed by the experiments: linearity, stability and immunity to disturbances [7].

Thus it is noted that by placing resistors R3 and R6 near the output amplifiers U1A and U1C (basically in series with connection wires between blocks) can be minimized the capacitive loading of the outputs which eliminates the unwanted oscillations due to instability.

Also, R3C4 and R6C5 together with C3 form an additional LPF filter that improves the noise immunity.

The Bandwidth of the circuit around 40KHz is enough to use the tactile sensors in the cyber-mechatronic systems for vibration analysis up to 20KHz bandwidth (according to Shannon Theorem) [8,9].

Increasing the values of C1, C2 and C7 can decrease to the minimum allowable Bandwidth until the band reaches the useful frequency of sensor signal.

The circuit is optimal but other issues may be discussed yet concerning the choice of operational amplifier circuits and their power for remote or local.

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