Modeling and Simulation of Hall Elements

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Abstract: **In this paper, some Hall element models in view of their applicability for simulation testing in different operation modes are presented. The theoretical-experimental and PSpice structural models of a Hall element have been developed. The conversion characteristics of the discrete semiconductor Hall elements have been simulated. Simulated characteristics have been compared with experimental ones and the results obtained have been discussed**

Keywords **– Hall elements, model, PSpice simulation.**

I. INTRODUCTION

The wide practical application of Hall elements operating as magnetic field sensors in areas such as electronics, automatics, medicine, automobile industry, etc., requires studying and gaining knowledge about their characteristics and parameters (Hall voltage, control current, magnetic field variation range, and temperature dependences). This is an objective prerequisite for developing suitable models of the elements in view of their applicability for simulation testing of their operation in different operation modes.

The main conversion characteristic of Hall sensors is the dependence of Hall voltage (U_H) on magnetic flux density (B) and the current flowing through the element (I_S), i.e. $U_H=f(I_S,B)$. Object of research interest is the simulation modeling of this characteristic depending on D.C. operation mode and the applied magnetic field.

It is well known [3, 4, 5, 6, 7] that the voltage of discrete semiconductor Hall elements can be described in terms of the dependence

$$U_H = -G\frac{r_H I_S B}{qnd}, \qquad (1)$$

where: **G** - coefficient showing the effect of the geometric dimensions of the element and its recording electrodes, $\mathbf{r_H}$ - Hall coefficient; **d** - depth of the semiconductor plate; **n** - charge carrier density; **q** - electron charge.

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II. PRESENTATION

The presence of design and engineering parameters in the mathematical model, which are normally unknown, limits its application in engineering practice. In this respect, the theoretical-experimental models which are synthesized according to characteristics measured at the elements outputs are more correct. To obtain such a model, the planned experiment approach has been applied [1, 2], the control current I_S and flux density B being chosen as factors affecting Hall voltage.

Complete factor experiments of the type $N=2^n$ have been conducted for 4 types of Hall elements (type VHE101, type L1, type D1 and type D2), three observations being carried out in each point [1, 2, 4]. The variation levels of the factors have been determined on the basis of conducted preliminary single-factor experiments for obtaining the conversion characteristics of the Hall elements and they guarantee nominal operation mode. The following values have been assigned for the lower and the upper variation level of the two chosen factors: for I_S – lower level 1mA and upper level 10mA, and for B – 0.1T and 1.5T, respectively.

After the experimental results for the four types of Hall elements have been processed using the methodology in [1, 2], the following general theoretical-experimental model has been obtained

$$U_H = AI_S^a B^b, \qquad (2)$$

Where: **A**, **a** and **b** are constants whose values depend on the type of the specific element and its D.C. operation mode (Table 1).

TABLE I

Hall element	**A**	**a**	**b**
VHE101	399,7903	0,7519	0,8560 - 0,0111.ln(Is)
L1	462,5437	0,7175	0,4539 - 0,0133.ln(Is)
D1	482,1914	0,7057	0,4767 - 0,0139.ln(Is)
D2	233,7463	0,7002	0,1985 - 0,0441.ln(Is)

The theoretical-experimental model has been modified in view of its compatibility with the CAD systems of the electronic circuits. For this purpose a simulation modeling approach has been applied on the basis of structural units whose operation is described using suitable analytic dependences. For simulation of the Hall elements conversion

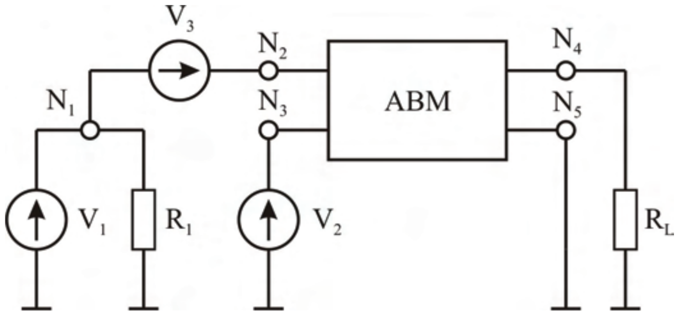

Fig. 1. PSpice structural model of a Hall element

characteristics, an analogue functional block /AFB/ has been used as a structural unit, and for its modeling – a non-linear dependent voltage source is used, which is controlled by the current flowing through the element I_S and by voltage proportional to magnetic flux density B. The generalized PSpice structural model of a discrete semiconductor Hall element is presented in Fig. 1.

The non-linear transfer function of AFB in PSpice format is modeled in the following manner:

Ename N+ N- VALUE = {functional dependence}, Where **Ename** is an arbitrary name of the non-linear dependent voltage source, **N+** and **N-** – node numbers (in sequence +, -), between which the source is connected, **VALUE** – a mandatory key word, after which an analytical dependence is assigned that defines the output voltage of the dependent source as a function of the control quantities, i.e. the non-linear dependence U_H = f (I_S, B). This voltage is actually the Hall voltage.

With view to forming library files with PSpice models of various types of Hall elements, the latter are presented in the form of sub-circuits according to the following general version:

```
.SUBCKT HALLTYPE N1 N3 N4 N5
Ehall N4 N5 VALUE = {A*Ia(V3)*Vb(N3)}
V3 N1 N2 0
.ENDS HALLTYPE
```

The specific type of Hall element is assigned by means of **HALLTYPE**, and the operation of all modeled elements is based on the non-linear dependence described by equation (2). The source V3 has a zero voltage, i.e. it is fictitious. Its existence in the model is justified by the PSpice requirement that the control currents for the dependent sources be defined as currents flowing through voltage sources.

The control current I_S in the structural model in Fig.1 is simulated by means of the D.C. voltage source V_1 and resistor R_1, while the magnetic flux density is simulated by means of voltage source V_2.

To simulate the conversion characteristics of the discrete semiconductor Hall elements, PSpice modules of the following type have been developed:

```
Hall Characteristics
.TEMP 25
R1 N1 0 VALR1
V1 N1 0 VALV1
.STEP V1 LIST <V1_VALUES>
V2 N2 0 DC 0
.DC V2 V2START V2STOP V2STEP
RL N4 0 VALRL
.LIB HALL.LIB
X1 N1 N3 N4 0 HALLTYPE
.PROBE
.END
```

Simulated conversion characteristics for the 4 types of Hall elements have been compared with conversion characteristics obtained experimentally in different operation modes using the possibilities provided by the PSpice integrated medium – Matlab, in order to assess the adequacy of the functional PSpice model. For this purpose the results simulated using the model, which are automatically set up in file filename.out, are edited and saved as a data file filename.dat. This file is set up in Matlab, and its data are read using either the command textread or load. A file containing the experimental results is also set up in Matlab. The two types of results, simulation and experimental ones, corresponding to the same operation mode for a specific element, are processed and visualized. This technology for processing and visualization of the characteristics, allowing the conduction of a precise assessment regarding the correctness of the simulation model, is presented by means of the generalized flow chart in Fig. 2.

Fig. 3 shows simulated and experimental characteristics U_H=f(B) for an element of the type VHE101 in a common coordinate system for 4 different control currents.

III. Conclusion

The results show that

- The experimental conversion characteristics and the ones simulated using the functional PSpice model, vary in the same manner.
- Both the Hall voltage and the characteristics steepness rise with the rise in the control current when B=const. Fig. 2 shows that when the flux density B = 0.05T and the control current changes from I_S=0.5mA to I_S= 10mA, i.e. when it increases 20-fold, the ratio between the output voltage obtained through simulation and the output voltage obtained by experiment is almost the same. When control current I_S=0.5mA, the ratio is 1.468, while for I_S = 10mA, it is 1.212, respectively. Under the same conditions, but for B = 0.1T, these ratios are 1.286 and 1.091.
- In case of small and large values of the control current, below 1mA and above 6mA, respectively, the experimental results and the ones simulated using the functional model are very close, and even coincide completely in case of small currents. This statement is proved not only by the graphical dependences in Fig. 3, but also by the one in Fig. 4, which illustrates the variation in the mean-square error obtained through the processing of the measured conversion characteristics and the simulated ones. As can be seen in Fig. 4, when the current flowing through the Hall element

increases up to a certain value, the error increases, after which it decreases. The error is the least (0.03261) for current I_S=0.5mA, and it is the greatest (0.11912) for I_S=5.25mA.

- Considering the fact that Hall elements practically operate in a relatively narrow area of flux density variation, it follows that the accuracy of both the theoretical-experimental model and the PSpice model is really much greater.
- The results are an indisputable proof for the adequacy of the functional PSpice model and the possibility of its practical application for simulation study of Hall elements characteristics and parameters.
- The synthesized model can be used to determine the optimal operation modes of discrete semiconductor Hall elements relative to both control current and magnetic flux density, which is an important foundation for the design of precise sensors.

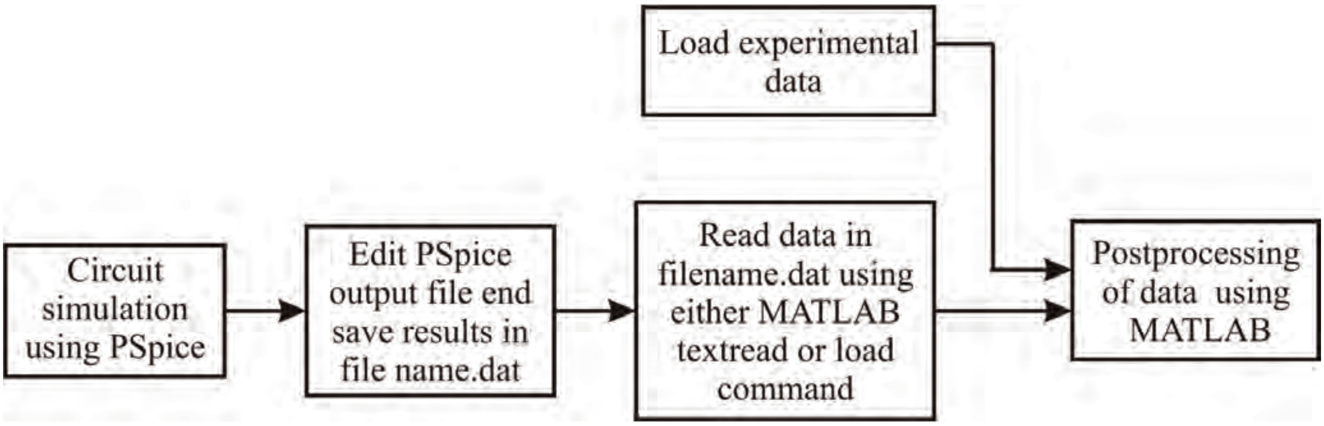

Fig. 2. Flowchart of circuit simulation using PSpice and postprocessing by Matlab

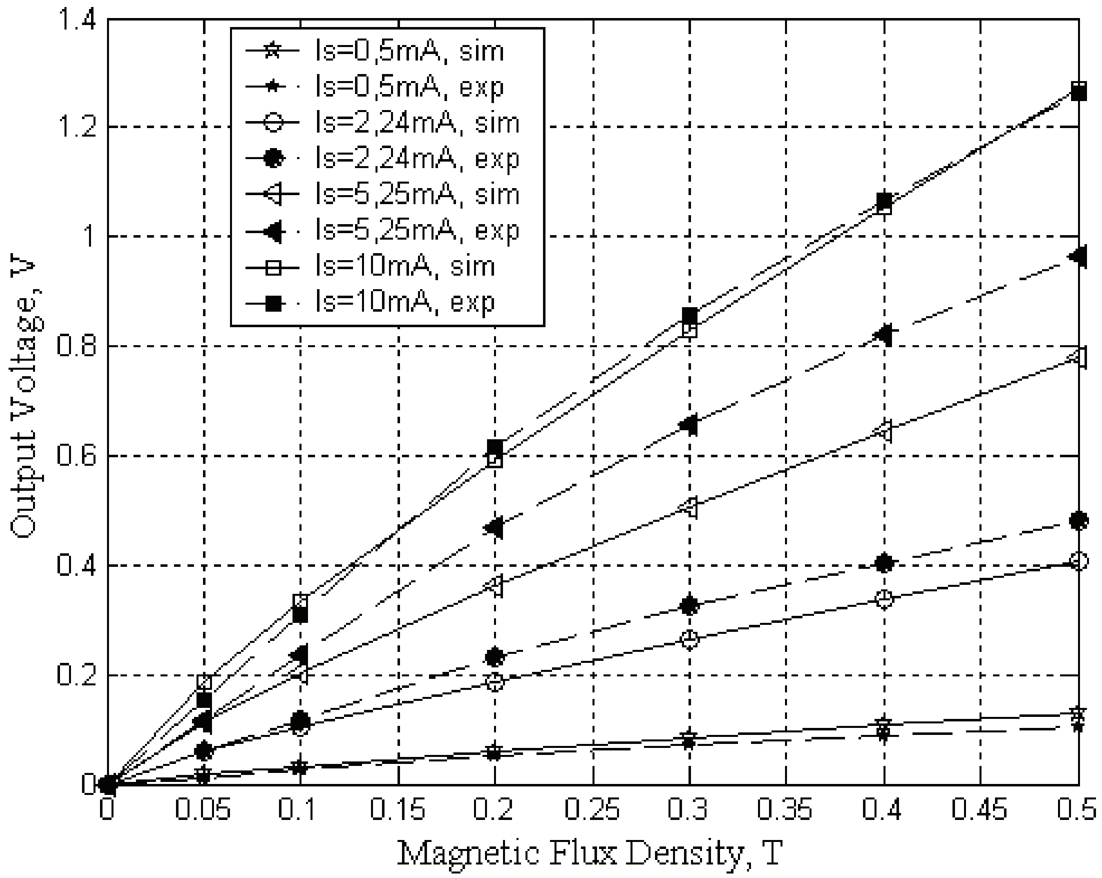

Fig. 3. Simulated and experimental conversion characteristics for element VHE101

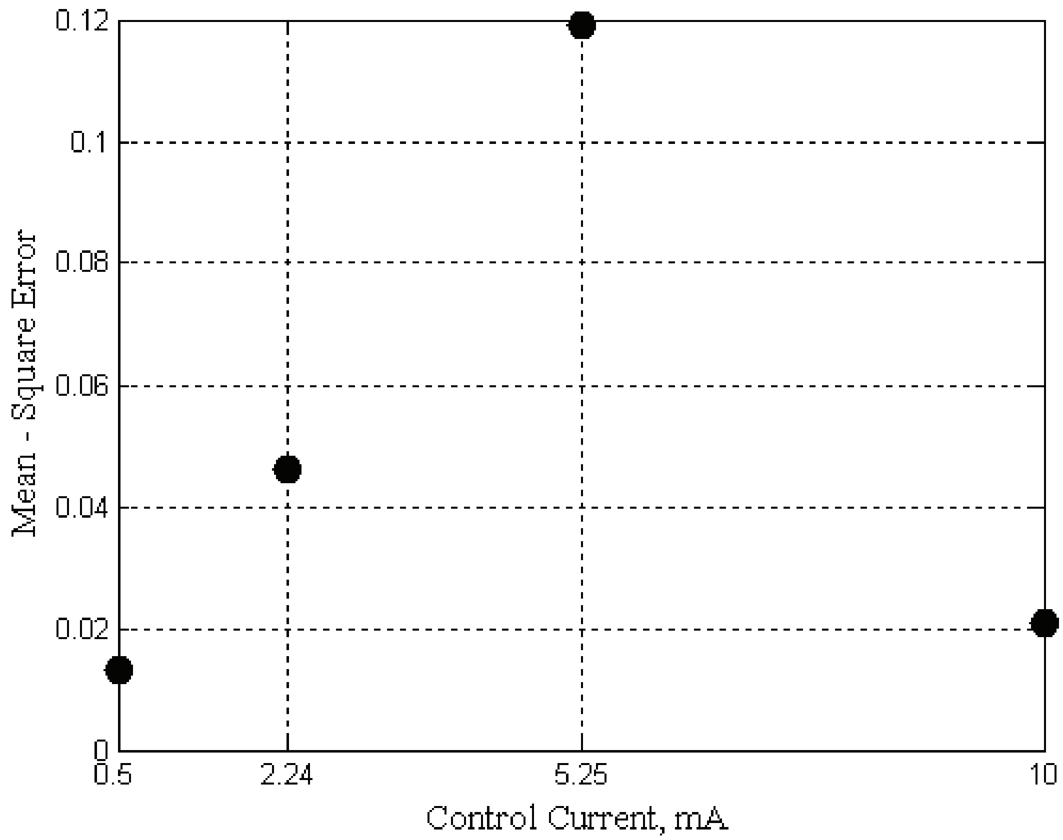

Fig. 4. Mean-square error depending on the control current

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