Journal of Engineering Science and Technology Review
Special Issue on Telecommunications, Informatics, Energy and Management 2019

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

Conference Article

Analog-Behavioural Approach for Modelling a Dual-Collector Magnetotransistor in a Static Mode of Operation

Anatolii Aleksandrov[1], Dimitrios Kazolis[2], Goran Goranov[1] and Ivaylo Belovski[4]

[1]*Technical University-Gabrovo, Gabrovo, Bulgaria*
[2]*Department of Electrical Engineering, Eastern Macedonia and Thrace Institute of Technology, Kavala, Saint Loukas 65404 Greece*
[3] *Technical University-Gabrovo, Gabrovo, Bulgaria*
[4]*"Prof. Dr. Assen Zlatarov'' University, Burgas, Bulgaria*

Received 29 September 2019; Accepted 29 February 2020

Abstract

The present paper views to an analogue-behavioural approach to modelling a dual-collector bipolar lateral magnetotransistor in static mode. A model of the magnetotransistor is proposed in two versions - schematic and text format, which are compatible with PSpice-based simulators. The particularities of the models are clarified, both in terms of their structures and in terms of their possibilities for simulation of the volt-ampere and tesla-ampere characteristics.

Keywords: Dual-collector magnetotransistor, analogue-behavioural modelling, schematic model, model in text format.

1. Introduction

The development of modern magneto-electronics is closely related to the application of an wide variety of galvano-magnetic elements. Of particular interest are bi-directional magnetotransistors, which have the highest current magnitudes and linear characteristics within a wide range of magnetic field variations [1, 2, 3, 4, 5].

Particularly relevant in the field of magnetotransistor sensory electronics is the problem related to the simulation modeling of the characteristics of the dual collector magnetotransistors under different modes of operation. This is a problem that is not sufficiently solved from a theoretical point of view.

The requirements that have to be met by the models are limited to: Accuracy of reproduction of the characteristics within the permissible range of variations of the magnetotransistor parameters. Also, the supply voltage, the magnetic field induction and the ambient temperature.

For the study of electronic circuits under different modes of operation, many software simulators are used in engineering practice [6, 7, 8, 9-12]. Depending on their approach, the models that are used are formal, physical, behavioural and mixed.

Specifically, according to the mode of operation of the magnetotransistor, the models can be divided into two groups: non-linear (DC, temperature and dynamic) and linear (low frequency, medium and high frequency).

There are many known simulations of the static characteristics of the dual-collector magnetotransistor [13, 14, 15, 16, 17], which are based on the injection pattern of Ebers-Moll [18, 19, 20]. These models are formed in the form of sub circuits in accordance with the requirements of the PSpice simulator. Due to the presence of non-linear (polynomial) current-controlled current sources, there is a need to determine the coefficients of the approximating polynomials, which on the one hand is a relatively labour-intensive task and on the other leads to inaccuracies.

2. Material and method

2.1 Description of the problem

The aim of the present work is the implementation of an analogue-behavioural approach [21,22] for modelling of a dual-collector magnetotransistor in static mode of operation. That can be performed by the means of PSpice-based program simulators such as PSpice [6, 12]. Cadence [7], NI Multisim [10], OrCAD [8, 9, 11].

Analogue Behavioural Modelling of semiconductor elements and integrated circuits [23, 24] is based on the extended versions of the traditional PSpice voltage controlled sources, the E source, which is a voltage-controlled voltage source (VCVS), and the G source, a voltage-controlled current source (VCCS). These types of sources are much more powerful than linear and polynomial ones because the control parameter in them is a ratio between currents and voltages. That can be done in the form of an analytical expression that contains both all the nodal voltages, the branches that are available in the structure of the model currents, and a large set of mathematical and logical functions and operators. An analogue-behavioural approach to modelling a dual-collector magnetotransistor can be implemented in accordance with the block diagram which is represented in Fig. 1.

* E-mail address: dkazolis@teiemt.gr
ISSN: 1791-2377 © 2020 School of Science, IHU.

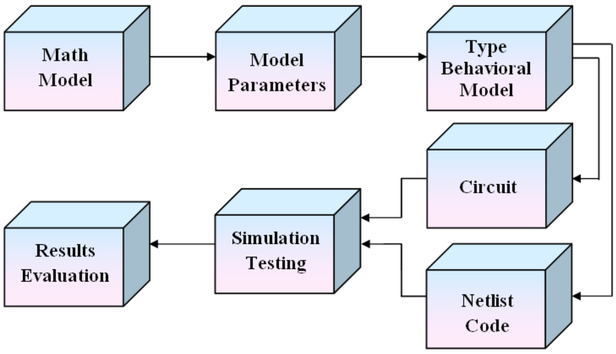

Fig 1. Stages of behavioural simulation modelling of dual-collector magnetotransistor.

Each of the blocks performs a certain stage of the overall modelling process. The aggregated operations that are realized through the individual blocks are limited to:

1. The basic equations of the magnetotransistor are formed depending on the mode of operation, static or dynamic.
2. It defines the set of model parameters that appear in the equations.
3. A variant of a behavioural model of the magnetotransistor, a schematic that is implemented through ABM blocks or descriptive as a text file that describes the element as a sub-circuit according to the syntax of the simulator that used.
4. The characteristics corresponding to the operation mode of the magnetotransistor, are simulated.
5. The results are analyzed and the model is evaluated.

In order to form a static characterization model of a dual-collector magnetotransistor, the first three steps of the aforementioned sequence of operations are performed.

2.2 Mathematical models for determining the bipolar transistors

Regardless of the approach used in the modelling and operation of the magnetotransistor, in the absence of a magnetic field (B = 0), the models can be synthesized on the basic non-linear models of the bipolar transistors, such as the Linvill [18, 20] model of Ebers-Moll [18, 19, 20], model of Gummel-Poon [19, 20, 25] and others. Based on the Ebers-Moll injection model for a bipolar junction transistor and the features of the double collector magnetotransistor [2, 3, 4, 5, 26-28], the currents through the two collectors (C1, C2) and emitter (E) of the magnetotransistor can be represented by the following equations:

$$I_{C1} = -I_{C1S}\left(e^{\frac{U_{B'C1}}{M_{C1}U_T}} - 1\right) + a_{N1}I_{ES}\left(e^{\frac{U_{B'E}}{M_E U_T}} - 1\right) + S_{I1}B \quad (1)$$

$$I_{C2} = -I_{C2S}\left(e^{\frac{U_{B'C2}}{M_{C2}U_T}} - 1\right) + a_{N2}I_{ES}\left(e^{\frac{U_{B'E}}{M_E U_T}} - 1\right) - S_{I2}B \quad (2)$$

$$I_E = I_{ES}\left(e^{\frac{U_{B'E}}{M_E U_T}} - 1\right) - a_{I1}I_{C1S}\left(e^{\frac{U_{B'C1}}{M_{C1}U_T}} - 1\right) - a_{I2}I_{C2S}\left(e^{\frac{U_{B'C2}}{M_{C2}U_T}} - 1\right) \quad (3)$$

where I_{c1s}, I_{c2s}, I_{Es} - leakage saturation currents of both collector and emitter junction; M_{c1}, M_{c2}, M_E - leakage emission coefficients of collector and emitter junction; α_{N1}, α_{N2} - forward common base (CB) current gains; α_{I1}, α_{I2} - inverse common base (CB) current gains; s_{I1}, S_{I2} - current magnetic sensitivity; UT - thermal voltage;
$U_{B'C1}$, $U_{B'C2}$, $U_{B'E}$, - control voltages (B'- internal base).

By the first term in the equations (1) and (2), the injection currents are modelled through the two collector transitions. The second collectible is the influence of the injection current of the emitter junction on the currents through the two collectors, and by the third is the influence of induction of the applied magnetic field on both collector currents. Similarly, the injection current of the emitter transition is modelled by the first collectable in equation (3) and by the second and the third collectable influence of the injection currents of the dual-collector transitions on the current, flowing through the emitter.

The set of model parameters that appear in equations (1), (2) and (3) is respectively: I_{c1s}, I_{c2s}, I_{Es}, M_{c1}, M_{c2}, M_E, α_{N1}, α_{N2}, α_{I1}, α_{I2}, S_{I1}, S_{I2}.

The three equations for the currents through the actual external terminals (C_1, C_2, E) of the magnetotransistor fully meet the modelling conditions with ABM type G blocks in which specific voltages are controlled. Moreover, they are also suitable for forming a text file in which basic elements are also VCCSs, and the functional dependencies of their respective currents from the control voltages are set by analytical expressions.

Regardless of the type of behavioural model (schematic or descriptive), modelling the two current components k_{I1B}, k_{I2B} in the presence of a magnetic field **(**$B \neq 0$**)** an external supply voltage source can be used, whose voltage is proportional to the induction B of the applied magnetic field.

Based on equations (1), (2) and (3) and the extended possibilities of the G-type dependent sources, a static nonlinear model of a double collector magnetotransistor has been developed. This has been done in two variants - schematic and text format. Both versions contain component information (component types and their model parameters) and topological information (component attachment point) for the structure of the model.

2.3 Schematic model

The basic elements, with which the model represented in Fig. 2 is synthesized, are ABM blocks type G.

Through each of the three sources (G1, G2, GB1 and G3, G4, GB2), represent the currents through the collectors C1 and C2 respectively, according to equations (1) and (2). Similarly, sources G5, G6, G7 represent the three constituents of the emitter's current, according to equation (3). The resistance RBB1 between the real base B and the internal (model) base B1 is the resistivity of the base region of the magnetotransistor and is a model parameter.

The model of Fig. 2 can be substantially simplified by merging the sources G1, G2, GB1, collector C2, respectively G3, G4, GB2, as well as the sources G5, G6, G7, respectively connected to the collector C1. The modified simplified model is shown in Fig. 3.

The difference between the two configurations of the model is that, at the expense of the simplification of the scheme of Fig. 3, the analytical dependencies are complicated by which, the settings of the three sources are set. On the other hand, the configuration of Fig. 2 gives a much better idea of the current components of the two collectors and the emitter.

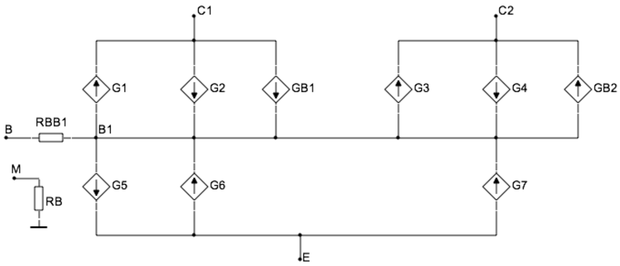

Fig.2. Schematic analogue behavioural model of a double-collector magnetotransistor.

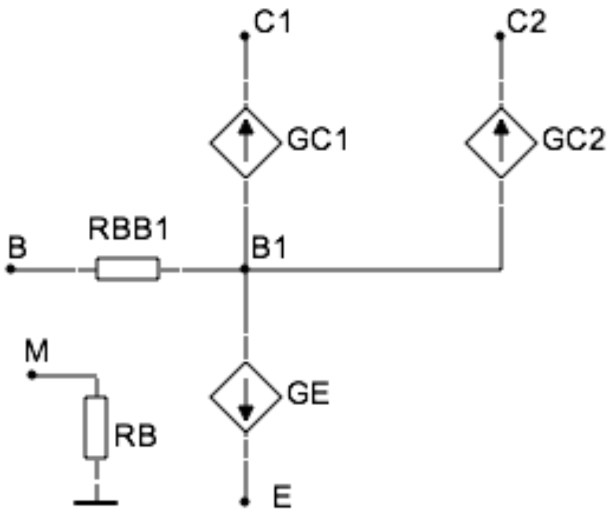

Fig.3. Simple schematic analogue behavioural model of a dual-collector magnetotransistor.

2.4 Model in text format

The modelling of the double collector magnetotransistor in this case is limited to the creation of a file in a text format (a net list code), in which the non-linear dependencies between the transistor terminal currents and the control voltages (mainly the transient stresses) are set by means of an analogue behavioural type G. The format, defining these sources is as follows:

GNAME N+ N- VALUE = {(expression)}

where: *GNAME*: modelling source name (required beginning with the letter G), *N+, N-* : the number of the terminals (nodes) between which the source is connected, *VALUE*: operator, which sets the functional dependence between the current and the control voltages.

This dependence is written in the form of an expression {(expression)}, which is a combination of control voltages, mathematical operations and model parameters.

In accordance with the above-mentioned features, the schematic models of Fig. 2 and Fig. 3 can be replaced by sub circuits in text PSpice format, as shown in Fig. 4(a) and 4(b), respectively.

In Fig. 4, the MODEL DCMT1 corresponds to the schematic model of Fig. 2, and the MODEL DCMT2, corresponds to the schematic model of Fig. 3.

For multiple use purposes, the two proposed model variants (schematic and text format) of a dual-collector magnetotransistor can be stored in libraries.

The approach to simulation of the static characteristics (volt-ampere and tesla-ampere) of a magnetotransistor depends, in principle, on the type of model used. In both cases, the characteristics that have to be simulated must be defined. This requirement is directly related to the type and location of the triggering signal sources.

When selecting a schematic model, the model is loaded into the simulator working environment and the corresponding signal sources are connected to it. The ABM blocks are setting in the form of analytical expressions in which unknown variables are the control voltages only. This means that all the other variables that appear in the analytical dependencies must be calculated in advance.

The simulation environment requirements are set through the simulator menus. If the simulation is done by a model in the form of a net list, the source and the simulation environment requirements are described in a text PSpice file, which also feeds the subchapter.

For the model in text format it is possible to set the values of the model parameters of the magnetotransistor in the indefinite file itself and to automatically calculate all the quantities necessary for describing the dependent current sources. Therefore, in this case, the need for preliminary computational procedures is eliminated.

.SUBCKT DCMT1 B C1 C2 E M	.SUBCKT DCMT1 B C1 C2 E M

```
*------------------------------------------------------------
                    *SUBCIRCUIT NODES
*------------------------------------------------------------
   *B –  BASE                  *B1 – INTERNAL BASE
   *C1 – FIRST COLLECTOR       *C2 – SECOND COLLECTOR
   *E –  EMITTER               *M –  FICTIOUS NODE
*------------------------------------------------------------
                    *MODEL PARAMETERS
*------------------------------------------------------------
 .PARAM ME = VALUE, ISE = VALUE, MC1 = VALUE, MC2 = VALUE,
 +ISC1 = VALUE, ISC2 = VALUE, ALN1 = VALUE, ALN2 = VALUE,
 +ALI1 = VALUE, ALI2 = VALUE, SI1 = VALUE, SI2 = VALUE
*------------------------------------------------------------
                    * THERMAL VOLTAGE
*------------------------------------------------------------
                    .PARAM UT = VALUE
*------------------------------------------------------------
                    * COEFFICIENTS
*------------------------------------------------------------
 .PARAM k1 = {1/(ME*UT)}, k2 = {1/(MC1*UT)}, k3 = {1/(MC2*UT)},
 +k4 = {ALN1 *ISE}, k5 = {ALN2 *ISE}, k6 = {ALI1 *ISC1}, k7 = {ALI2 *ISC2}
*------------------------------------------------------------
                    *MODEL DESCRIPTION
*------------------------------------------------------------
```

```
* MODEL DCMT1
*------------------------------------------
*FIRST COLLECTOR JUNCTION
*------------------------------------------
G1   B1 C1 VALUE = {ISC1*(exp (V(C1,B1)/k2)-
+    1)}
G2   C1 B1 VALUE = {k4*(exp(V(E,B1)/k1)-1)}
GB1  C1 B1 VALUE = {SI1*V(M)}
*------------------------------------------
*SECOND COLLECTOR JUNCTION
*------------------------------------------
G3   B1 C2 VALUE = {ISC2*(exp (V(C2,B1)/k3)-
+    1)}
G4   C2 B1 VALUE = {k5*(exp(V(E,B1)/k1)-1)}
GB2  B1 C2 VALUE = {SI2*V(M)}
*------------------------------------------
*EMITTER JUNCTION
*------------------------------------------
G5 B1 E VALUE = {ISE*(exp (V(B1,E)/k1)-1)}
G6 E B1 VALUE = {k6*(exp(V(B1,C1)/k2)-1)}
G6 E B1 VALUE = {k7*(exp(V(B1,C2)/k3)-1)}
*------------------------------------------
RBB1 B B1 VALUE
*------------------------------------------
RB M 0 VALUE
*------------------------------------------
.ENDS DCMT1
```

```
* MODEL DCMT2
*------------------------------------------
*FIRST COLLECTOR JUNCTION
*------------------------------------------
GC1 B1 C1 VALUE = {ISC1*
+ (exp (V(C1,B1)/k2)-1)
+ -k4*(exp(V(E,B1)/k1)-1) -SI1*V(M)}
*------------------------------------------
*SECOND COLLECTOR JUNCTION
*------------------------------------------
GC2 B1 C2 VALUE = {ISC2*
+ (exp (V(C2,B1)/k3)-1)
+ -k5*(exp(V(E,B1)/k1)-1) + SI2*V(M)}
*------------------------------------------
*EMITTER JUNCTION
*------------------------------------------
G5 B1 E VALUE = {ISE*(exp (V(B1,E)/k1)-1)-
+     k6*(exp(V(B1,C1)/k2)-1)-
+     k7*(exp(V(B1,C2)/k3)-1)}
*------------------------------------------
RBB1 B B1 VALUE
*------------------------------------------
RB M 0 VALUE
*------------------------------------------
.ENDS DCMT2
```

Fig.4. An analogue-behavioural model of a dual-collector magneto transistor in text format

3. Conclusions

The comparative evaluation of the two proposed static model variants (schematic and text format) of a dual-collector magnetotransistor leads to the following more important conclusions:

1. The proposed varieties of a static model have the same functionality.
2. The schematic version gives a considerably better view of the constituent currents through the terminals of the magnetotransistor.
3. For the schematic version of the model it is necessary to calculate in advance all the coefficients that connect the dependent currents and their controlling voltages and which depend on the model parameters of the magnetotransistor.

Any change in the value of even one parameter requires a repeat of the computation process.

In this respect, the text version of the model is preferable because the calculation of the necessary coefficients is done automatically in the model itself. This means that the model can be used to change the values of the model parameters without the need for user intervention.

Acknowledgements
The Authors are grateful for the support provided by the National Science Fund of Bulgaria under grand DN 07/18, 15.12.2016.

References

1. Alexandrov, A.T. Semiconductor elements and integrated circuits. Gabrovo, Express, 2012.
2. Vikulin, I., Vikulin F., Stafeev V., Magnetosensitive Transistors Overview.Physics and Technology of Semiconductors. Academy of Communications of Ukraine .Vol. 35, no. 1, pp. 3-11, 2001.
3. Tikhonov R.Dual-collector lateral bipolar magnetotransistor: negative sensitivity and galvanomagnetic effects. Open Electrical & Electronic Engineering 2, 14-26, 2008.
4. Lenz J., Edelstein A., Magnetic Sensors and Their Applications. IEEE sensors journal, Vol. 6, No. 3, 2006.
5. Korvink J., Paul O., MEMS: A Practical Guide of Design, Analysis, and Applications. Springer USA, 2010.
6. Attia., J. O. PSPICE and MATLAB for Electronics. An Integrated Approach. CRC Press, 1st Edition, 2002.
7. Chao. Y., M. Hoseini. CADENCE TUTORIAL. ECE 423/623, North Dakota State University, Spring 2007.
8. Goody R. OrCAD PSpice for Windows Volume II: Devices, Circuits and Operational Amplifiers (3rd Edition), Prentice Hall, 2000.
9. Fitzpatrick D., Analog Design and Simulation Using OrCAD Capture and PSpice. Second Edition, 2017.
10. www.multisim.com
11. www.orcad.com
12. www.pspice.com
13. Salim A., Manku T., Nathan A., Modeling of magnetic field sensitivity of bipolar magnetotransistors using HSPICE. IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems Volume: 14 , Issue: 4 , 1995.
14. Vinal A., Masnari N.Operating principles of bipolar transistor magnetic sensors. IEEE Transactions on Electron Devices. 1486 – 1494, 1984.
15. Masud A., Islam S., Khosru Q. Modified Ebers-Moll model of magnetic bipolar transistor. IEEE International Conference on Electron Devices and Solid-State Circuits (EDSSC). 2015.
16. Petrova, P.D., Alexandrov AT, Todorov PJ. Effect of asymmetry of collector currents on parameters of the static model of the double collector magnetotransistor. Fourth National Scientific-applied Conference "Electronic Equipment ET'95", Sozopol, pp. 170-175.
17. Andreou, A.G., C.R. Westgate. A. C. Characterization and modeling of lateral bipolar Magnetotransistors IEDM. San Francisco Calif.,Dec.9-12,84 Techn. Dig," New York",1984.
18. Vinal A., Masnar N. Transactions on Electron Devices .IEEE Volume: 31, Issue: 10 , Oct 1984.
19. Park J., Jung Y., Butler K. Quick-start guide for first-principles modeling of semiconductor interfaces. Journal of Physics: Energy, 2018.
20. Tang C., Demeester L., Mathematical Models in Integrated-Circuit Manufacturing: A Review. Kluwer Academic Publishers 1993.
21. Abidi A., Behavioral modeling of analog and mixed signal IC's. Proc. of Custom Integrated Circuits Conference, pp. 443-450, 2001.
22. Filseth, E., T. Roullier. Build Analog Behavioral Models in Six Easy Steps, Electronic Design, vol. 38, pp. 105-119. 1990.
23. Jüngel, A. Qualitative behavior of solutions of a degenerate nonlinear drift-diffusion model for semiconductors. Math. Mod. and Meth. in Appl. Sci., (5):497–518, 1995.
24. Karimi, Gh. R., S. Mirzakuchaki. Behavioral Modeling and Simulation of Semiconductor Devices and Circuits Using VHDL-AMS. Iranian Journal of Electrical & Electronic Engineering, Vol. 4, pp 165-175, 2008.
25. Xiaochong Cao, Mcmacken J., Stiles K.; Layman P., Liou J., Oritz-Conde A., Moinian S., Comparison of the new VBIC and conventional Gummel-Poon bipolar transistor models. IEEE Transactions on Electron Devices, Volume: 47 , Issue: 2 , 2000.
26. Lozanova, S., Ivanov, A., Roumenin, C. The device design as enhancing sensitivity tool in hall elements, Comptes Rendus de L'Academie Bulgare des Sciences Volume 65, Issue 4, pp. 519-526, 2012.
27. Lozanova, S, Noykov, S., Ivanov, A., Roumenin, C. High sensitive dual-collector N+-P-N+ magnetotransistor. Comptes Rendus de L'Academie Bulgare des Sciences, Volume 61, Issue 7, pp. 933-938, 2008.
28. Lozanova, S., Roumenin, C. MOS magnetoresistor sensor, Comptes Rendus de L'Academie Bulgare des Sciences, Volume 61, Issue 6, pp. 795-800, 2008.