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SIMULATION STUDY OF STATIC MAGNETOELECTRIC CHARACTERISTICS OF A DUAL-COLLECTOR MAGNETOTRANSISTOR

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ABSTRACT

A simulation approach is applied to study the static magnetoelectric characteristics of a dual-collector bipolar lateral magnetotransistor. A simulation setting is proposed for obtaining the characteristics in PSpice based environments using an analog-behavioral model of the magnetotransistor. Static magnetoelectric characteristics were obtained for a sample of a dual-collector magnetotransistor 2T1MP1 connected in a common emitter circuit. Analysis and evaluation of the results was carried out.

INTRODUCTION

In recent decades, galvanomagnetic sensors have been increasingly used in various fields of engineering [1, 2,3,4, 5,6,7,8]. They consist of a sensing element and an electronic circuit that provides optimal power supply, amplification and formation of the type and parameters of the output signal, temperature compensation and zero drift elimination. Ones of the most commonly used galvanomagnetic elements [1,9,10,11,12] are magneto-transistors of which the dual-collector bipolar magnetotransistors are of highest interest. In these, the magnetic field causes a redistribution of injected current carriers between the two collectors. That is the reason they are characterized by high sensitivity and linearity of the conversion characteristic [10,11,13], which predetermines their wide application in variety of constructive solutions.

A major parameter of dual-collector magnetotransistors (DCMs) is the magnetic sensitivity, which is defined as absolute or relative (conversion efficiency) [12,14].

The absolute magnetic current sensitivity SI and the voltage sensitivity SU are described accordingly with the following relationships:

$$S_I = \frac{\partial(I_{C1} - I_{C2})}{\partial B} \approx \frac{\Delta I_C}{\Delta B}, \ A/T \tag{1}$$

$$S_U = \frac{\partial(U_{C1} - U_{C2})}{\partial B} \approx \frac{\Delta U_C}{\Delta B}, \ V/T \tag{2}$$

where I_{C1}, I_{C2}, U_{C1}, U_{C2} are the currents and voltages measured respectively on the first and second collectors of the dual-collector magnetotransistor and B is the induction of the magnetic field.

The ratio between the absolute magnetosensitivity and the supply current ICC determines the relative magnetosensitivity - current sensitivity γ_I and voltage sensitivity γ_U :

$$\gamma_I = \frac{S_I}{I_{CC}}, \ 1/T \tag{3}$$

$$\gamma_U = \frac{S_U}{I_{CC}}, \ V/AT \tag{4}$$

The dependencies related to the current magnetic sensitivity characterize the DCM, and those related to the voltage magnetic sensitivity characterize the magnetic sensitivity of the circuit in which the transistor is connected.

Depending on the specifics of the structure of the element, the specific marginal conditions and the mode of operation, the dual-collector bipolar magnetotransistors are characterized by different magnetic sensitivity in the range (10-2 ÷ 4) 1 / T. This is due to the combined effect of such sensing mechanisms as [12,15]: deviation of the non-majority carriers due to the Lorentz force effect on the base in the depleted layer of the base-collector junction and in the low alloyed collector area, the magnetotransistor Hall effect and the magnetoconcentration effect, etc. Although these major galvanomagnetic effects work simultaneously, yet in a given mode of operation and a certain geometry, one of them prevails over the others.

The features of dual-collector bipolar magneto-transistors with respect to the physical processes taking place in them and the variety of constructive solutions are explained in detail in [1,12,13,16,17]. At the same time, information on the electrical and magnetoelectric characteristics and parameters of this type of elements is incomplete and insufficient, both in terms of their

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application in engineering practice and for the purposes of automated design and testing of circuits based therefrom. Therefore, the problem related to the study of the characteristics, parameters and modes of operation of DCM is relevant and significant, both in theoretical and practical aspects. To solve this problem, two main approaches are applied - experimental and simulative [8,13,15-24]. In both cases, a number of conditions must be considered, such as: manufacturer-defined acceptable parameters, operating mode (static or dynamic), connection mode, magnetic field impact, limitations resulting from the specific application of the tested magnetotransistor. With the development and implementation in engineering of computer-aided design (CAD) systems in electronics, especially PSpice-based integrated environments such as MicroSim Design Lab [25,26], OrCAD [27,28,29], Cadence [30], NI Multisim [31], etc., the simulative approach has become dominant for the study not only of circuits and devices but also of components.

A necessary condition for the simulation study of a dual-collector magnetotransistor, regardless of the programming environment in which it is carried out, is the availability of a suitable model for the element. However, the model should be as simple and accurate as possible. In principle, the choice of model for each element depends on the specific task and is made by the design engineer.

The purpose of the present work is a simulation study of the basic static magnetoelectric characteristics that provide information on the behavior of DCM in a magnetic field using a PSpice based analog-behavioral model.

EXPOSITION

Investigation of static magnetoelectric characteristics

To achieve the objective defined above, a sequence of operations is applied that is analogous to the generalized procedure proposed in [24] concerning static voltage-current characteristics, taking into account both the influence of the magnetic field ($B \neq 0$), as well as the specific features and requirements with respect to the stimulating signal sources (connection type, signal type, sweep priority) and the ability to obtain the characteristics (directly or through further processing).

Simulation setting

The study of static magnetoelectric characteristics for DCM in a common emitter (CE) circuit was performed using the simulation setting proposed in Fig.1. The setting meets the requirements of PSpice based simulators and can be quickly and easily converted to work from one simulation environment to another.

The signal sources VB, VC1, VC2 and VE connected in the simulation circuit of Fig. 1, have zero voltages and are used to measure the currents flowing through the respective circuit branches. The sources VC1 and VC2 take into account the currents $I_{C1} = I(VC1)$ and $I_{C2} = I(VC2)$ by means of which the difference in the test conditions $\Delta I_C = I_{C1} - I_{C2}$ is also determined. The influence of the magnetic field is recorded by means of VM source, assuming that its voltage is proportional to the field induction B. The parameters of stimulus sweeps (DC sources VBE, VC1E, VC2E, VM and IB) are defined depending on the specific characteristics studied. Supplying stimulus current (source IB) or stimulus voltage (source VBE) to the base circuit of the magnetotransistor in this simulation setting, which also depends on the type of characteristics tested, is done with switch S (when S is in position 1, a stimulus is connected to the base voltage, and when in position 2 - stimulus current is supplied). In the simulation study of the magnetoelectric characteristics, instead of the block "Analog-Behavioral Model of DCM", a schematic or text-based analog-behavioral model of the magnetotransistor is used, variants of which are proposed in [23]. All variants of the model are implemented with only one type of dependent sources (G-type dependent sources with extended capabilities [25]) and can be used in different PSpice-based simulation environments.

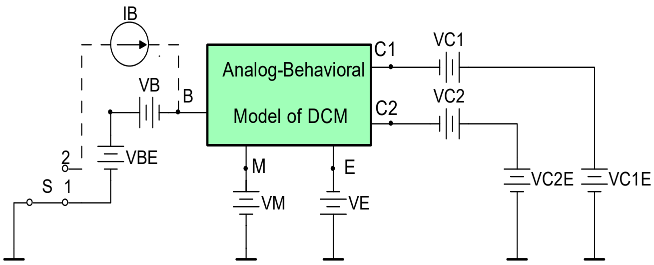

Fig. 1. Simulation setting for studying of static magnetoelectric characteristics of a dual-collector magnetotransistor using analog-behavioral model

Magnetoelectric characteristics

With the proposed simulation setting have been examined the static magnetoelectric characteristics of a sample dual-collector lateral magnetotransistor type 2T1MP1 [32] in Design Lab and Multisim environments.

a) Tesla-ampere characteristics

$\Delta I_C = f(B)$ at I_E = const

Simulation setting requirements:

1. Switch S - in position 2.
2. Stimulus source VM (sets the variation of the first variable - the induction B of the magnetic field, assuming that the induction coincides with the voltage of the VM source) - in main sweep mode with linear variation of the voltage.
3. Stimulus source IB (sets the variation of the second variable – current I_E, by setting current I_B values so that the desired values of I_E are achieved, which are measured as current passing through the source VE) works in nested sweep mode with linear variation of I_B.
4. Stimulus sources VC1E and VC2E - with constant voltage values, such as $U_{C1E} = U_{C2E}$.

The family of static tesla-ampere characteristics $\Delta I_C = f(B)$ obtained at the so defined conditions at I_E = const is presented in Fig. 2.

b) Tesla-ampere characteristics

$\Delta I_C = f(B)$ at $U_{BE} = const$ and $U_{CE} = const$

Simulation setting requirements:

1. Switch S - in position 1.
2. Stimulus source VM (sets the variation of the first variable - the induction B of the magnetic field, assuming that the induction coincides with the voltage of the VM source) - in main sweep mode with linear variation of the voltage.
3. Stimulus source VBE (sets the variation of the second variable - the voltage U_{BE}) - in nested sweep mode with linear variation of U_{BE}.
4. Stimulus sources VC1E and VC2E - with constant voltage values such as $U_{C1E} = U_{C2E}$ and $U_{C1E} = U_{C2E}$.

Figure 3 shows the obtained tesla-ampere characteristics for four combinations of voltage values U_{BE} and U_{CE}.

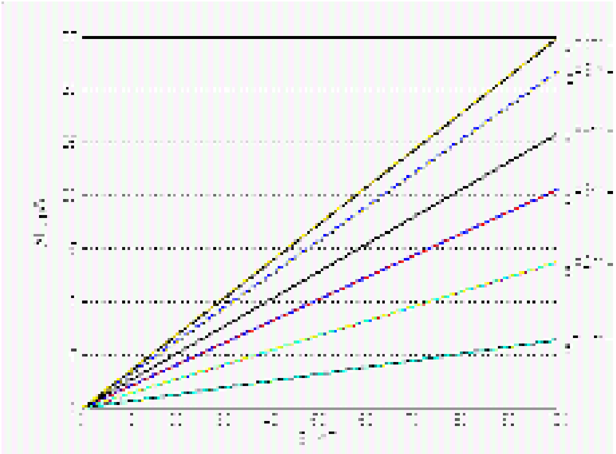

Fig. 2. Tesla-ampere characteristics at $\Delta I_C = f(B)$ at $U_{C1E} = U_{C2E} = 4V$

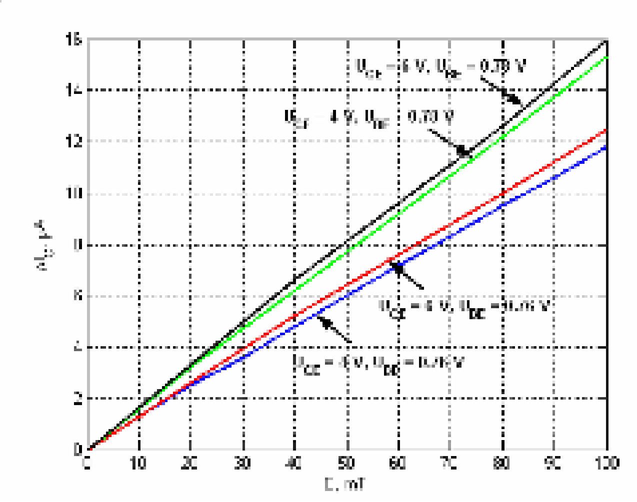

Fig. 3. Tesla-ampere characteristics $\Delta I_C = f(B)$ at $U_{BE} = 0.76V;\ 0.78V$ and $U_{CE} = 4V;\ 6V$

As can be seen from Fig. 2 and Fig. 3, the obtained tesla-ampere characteristics are linear in the operating interval $(B \le 100mT)$. As the direction of the magnetic field changes, the characteristics shift to the III quadrant and are symmetric with respect to the beginning of the coordinate system. From the Tesla-ampere characteristics of Fig. 2 and Fig. 3 it follows that the difference ΔI_C between the collector currents depends essentially on the selected DC operating point of the magnetotransistor (I_E, U_{CE} in Fig. 2 and U_{CE}, U_{CE} in Fig. 3). For example, at $U_{CE} = 4V$ and $B = 80mT$ ΔI_C changes from $5{,}156\mu A$ at $I_E = 1mA$ to $25{,}313\mu A$ at $I_E = 5mA$. The analysis of Tesla-ampere characteristics of Fig. 3 shows that the influence of the voltage U_{CE} on the current difference ΔI_C is greater than that of voltage U_{CE}. At induction value of the magnetic field $B = 80mT$ and $U_{BE} = 0{,}76V$ increasing the voltage from 4V to 6V leads to current difference ΔI_C increase by only $0{,}429\ \mu A$, while a change to voltage U_{CE} from 0.76V to 0.78V at $B = 80mT$ and $U_{CE} = 4V$, causes the current difference ΔI_C to increase by $2{,}572\mu A$.

Current Transfer Characteristics $\Delta I_C = f(I_E)$ at $B = const$

Simulation setting requirements:

1. Switch S - in position 2.

2. Stimulus source IB (sets the variation of the first variable - the current I_E, by setting current I_B values so that the desired values of I_E can be obtained, which are measured as current through the source VE) works in main sweep mode with linear variation of I_B.

3. Stimulus source VM (sets the change of the second variable - induction B of the magnetic field, assuming that the induction coincides with the voltage of the source VM) works in nested sweep mode, with voltage values included in a list.

4. Incentive sources VC1E and VC2E - with constant voltage values, such as $U_{C1E} = U_{C2E}$.

Figure 4 shows how the collector current difference ΔI_C varies depending on the emitter current I_E $(\Delta I_C = f(I_E))$ at $U_{CE} = const$ and $B = const$. The family of characteristics $\Delta I_C = f(I_E)$ are obtained at $U_{CE} = 4V$ for three values of magnetic field induction: $B = 50mT, 100mT\ u\ 125mT$. It can be seen that as the magnetic field induction increases, the difference between the collector currents ΔI_C increases as well, resulting in the characteristics turning left relative to the start of the coordinate system. In addition, before $B = 100mT$ the obtained graphical dependences are linear and then, at $B = 125mT$, the characteristic $\Delta I_C = f(I_E)$ becomes nonlinear. This is indisputable evidence that the recommended value of magnetic field induction, which guarantees the high linearity and sensitivity of the investigated magnetotransistor, should be $B = 100mT$.

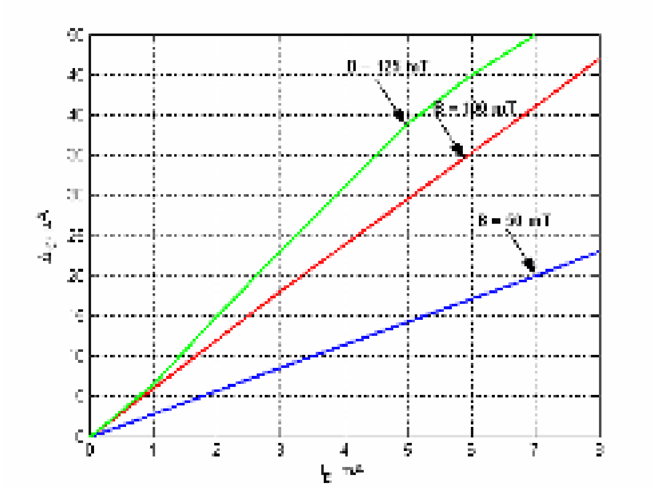

Fig. 4. Current transmission characteristics $\Delta I_C = f(I_E)$ at $B = 50mT,\ 100mT,\ 125mT$

Based on the results in Fig. 4 and equation (1) the functional dependence of the current magnetosensitivity on the emitter current $(S_I = f(I_E))$ at $B = const$ can be determined.

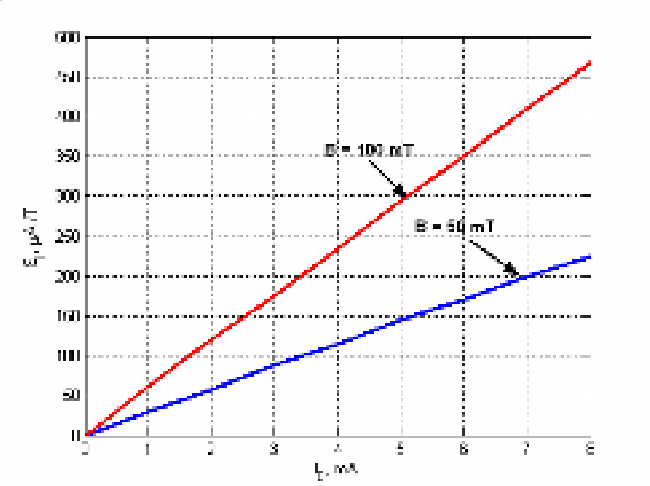

Fig. 5. Dependences of the current magnetosensitivity on the emitter current at $B = 50mT$ u $100mT$

In Fig. 5, the dependence $S_I = f(I_E)$ for $B = 50mT$ u $100mT$, is shown. It is obvious that in the chosen interval of change of magnetic induction, which is actually the operating interval, the dependence $S_I = f(I_E)$ is linear. From the presented characteristics it follows that from $29{,}545\mu A/T$ at $I_E = 0{,}5mA$ current magnetic sensitivity increases up to $409{,}09\mu A/T$ at $I_E = 7mA$.

CONCLUSION

The analysis of the static magnetoelectric characteristics and parameters, obtained by simulation study of a dual-collector magnetotransistor in a CE configuration, leads to the following more important conclusions:

1. The tesla-ampere characteristic of the investigated sample of a dual-collector magnetotransistor is linear in the operating range of the magnetotransistor, which is up to $B = 100\,mT$ while at $B > 100\,mT$ the characteristic becomes non-linear.
2. At a fixed value of the magnetic field induction, the difference between the currents in the two collectors of the magnetotransistor increases when voltages U_{BE} and U_{CE} go up.
3. Static characteristics obtained in PSpice based Multisim NI and Design Lab simulation environments, using, respectively, schematic and textual analog-behavioral model of a dual-collector magnetotransistor are identical, meaning that the models have the same functionality.
4. The results of the simulation satisfy the manufacturer's defined limitations for the basic parameters of the tested magnetotransistor, which is a guarantee of the adequacy and reliability of the analog-behavioral model variants used.

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