ISSN 1392 – 1215 *ELECTRONICS AND ELECTRICAL ENGINEERING* 2011. No. 3(109)

ELEKTRONIKA IR ELEKTROTECHNIKA

T 171 *MICROELECTRONICS*

MIKROELEKTRONIKA

The Magneticreactive Effect in Transistors for Construction Transducers of Magnetic Field

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Introduction

One of perspective scientific directions in development of transducers offered in this work, is usage dependence of reactive properties and negative resistance of semiconductor devices from influence of exterior physical quantities and making on this basis a new class of radiomeasuring microelectronic transducers of a magnetic field. In devices of such type there is the transformation of a flux density to a frequency signal, that allows to establish transducers on integrated technique and enables to boost speed, accuracy and reliability, to expand the range of measurands, to improve reliability, noise stability and long-time parameter stability [1–3]. Besides the join single-crystal of transducer with the circuits of an information handling enables makings “intellectual” devices. Usage as information parameter of frequency allows to avoid application of amplifying devices and analog-to-digital converters at an information handling, that reduces the cost price of monitoring systems and control [4]. Thus, on the agenda already today become necessity of development it is qualitatively of the new theoretical approaches to making radiomeasuring microelectronic transducers, development of their circuits and constructions, experimental research of their performances, metrology parameters, implantation them in production.

Theoretical and experimental researches of magneticreactive effect in transistor structures

For build-up of transducers of a magnetic field it is necessary to develop elements of the theory of magneticreactive effect for sensitive elements as bipolar and field-effect transistors of transducers. Under the above mentioned effects understand dependence of a complete resistance bipolar and field-effect transistors from an operation of a magnetic field. For determination in an analytical aspect of dependence of a complete resistance of sensitive elements from induction of a magnetic field it is necessary to receive the decision of the equation of transport and Poisson equation for alternating-currents as allocation of injected carriers of a charge in of base area of bipolar and channel of field-effect transistors, which depends on induction of a magnetic field.

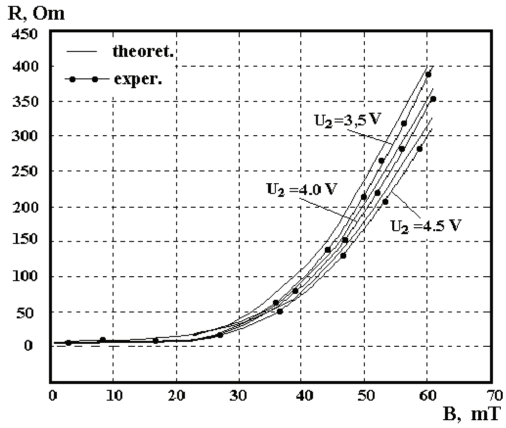
By viewing the magneticreactive effect in magnetic-sensitive elements on the basis of field-effect transistors it is necessary to define a complete resistance on electrodes a source - drain at an arrangement of a sensitive elements in a transversal magnetic field. In this case there is the magnetoresistance, which reduces in dependence of a channel current on a flux density. At usage of a field-effect transistor as the Hall element the potential distribution in the channel and determination of Hall voltage can be received on the basis of the decision of Puasson equation, which enables to optimize an arrangement of contacts, from which is dumped the Hall voltage. The carried out calculations have allowed to receive a complete resistance of a magneticsensitive element.

On the basis of a nonlinear equivalent circuit of the bipolar transistor [5] the analytical dependence of complete resistance on electrodes the emitter - collector bipolar magnetictransistor is obtained which is featured by (1)

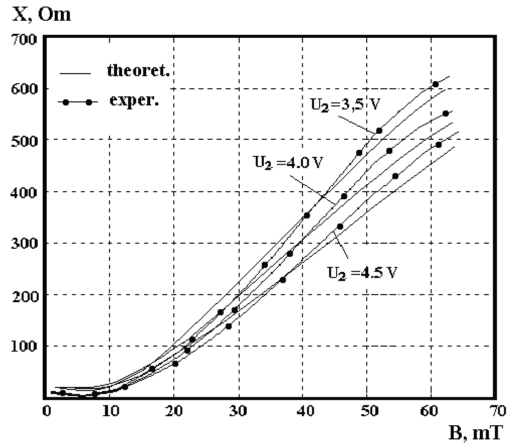
$$\begin{aligned} Z = {} & \Bigg[U_2 \Bigg(A_1 A_2 \left(A_4 - j\frac{1}{\omega C_{bc}(B)} \right) + \frac{A_1}{\omega^2 C_{bc}^2(B)} + \\ & + j\frac{2A_3 R_b(B)}{\omega C_{bc}(B)} - A_3^2 \left(A_4 - j\frac{1}{\omega C_{bc}(B)} \right) + j\frac{2A_3 R_b(B)}{\omega C_{bc}(B)} - \\ & - A_2 R_b^2(B) \Bigg) \Bigg] \Big/ \Bigg[A_1 \left(U_2 - I_{p1} A_5 \right) \left(A_4 - j\frac{1}{\omega C_{bc}(B)} \right) + \\ & + j\frac{A_1 \left(j\dfrac{I_{p1}}{\omega C_{bc}(B)} - A_4 I_{p2} \right)}{\omega C_{bc}(B)} - R_b^2(B) \left(U_2 - I_{p1} A_5 \right) - \\ & - A_3 R_b(B) \left(j\frac{I_{p1}}{\omega C_{bc}(B)} - A_4 I_{p2} \right) + \\ & + j\frac{R_b(B) \left(U_1 - I_{p1} \left(\dfrac{1}{j\omega C_{be}(B)} + R_b(B) \right) \right)}{\omega C_{bc}(B)} - \\ & - \left(A_4 - j\frac{1}{\omega C_{bc}(B)} \right) A_3 \left(U_1 - I_{p1} \left(R_b(B) - j\frac{1}{\omega C_{be}(B)} \right) \right) \Bigg], \end{aligned} \tag{1}$$

where $A_1 = Z_{R1} + R'_b + j\omega L_b + R_b(B) - j/\omega C_{be}(B) + $
$+ R_e(B) + R'_e + j\omega L_e, A_2 = R_c(B) + R'_c + j\omega L_c - j/\omega C_{bc}(B) -$
$- j/\omega C_{be}(B) + R_e(B) + R'_e + j\omega L_e, A_3 = R_e(B) + R'_e +$
$+ j\omega L_e - j/\omega C_{be}(B)$, $A_4 = R_b(B) - j/\omega C_{bx}(B)$,
$A_5 = -j/\omega C_{bc}(B) - j/\omega C_{be}(B)$,
$I_{p1} = I_{be2}(B) + I_{be1}(B)/\beta_F(B) + (I_{be1}(B) - I_{bc1}(B))/Q_b$,
$I_{p2} = I_{bc2}(B) + I_{bc1}(B)/\beta_R(B) - (I_{be1}(B) - I_{bc1}(B))/Q_b$,

where U_1 – voltage base–emitter; U_2 – voltage a collector – emitter. The dependence of active and reactive components complete resistance bipolar magnetictransistor from magnetic induction on Fig. 1 is shown.



a)



b)

Fig. 1. Dependence of active and reactive components of complete resistance of bipolar magnetictransistor from magnetic induction

On the basis of a nonlinear equivalent circuit of the field-effect transistor [6–8] in view of operation of a magnetic field the complete resistance is determined which is featured by (2)

$$Z = -U_1\left[Z_1^2 A_2\left(R_{ds}(B) - j\frac{1}{\omega C_{bg}(B)} + Z_2\right) - 2R_{ds}(B)Z_1A_3 \times\right.$$
$$\times\left(\frac{j}{\omega C_{bg}(B)} - Z_2\right) - A_1A_2\left(R_{ds}(B) - j\frac{1}{\omega C_{bg}(B)} + Z_2\right)A_4 +$$
$$+R_{ds}^2(B)A_1A_2 + A_3^2A_4\left(R_{ds}(B) - j\frac{1}{\omega C_{bg}(B)} + Z_2\right) - R_{ds}^2(B)A_3^2 +$$
$$\left.+A_1A_4\left(\frac{j}{\omega C_{bg}(B)} - Z_2\right)^2 - Z_1^2\left(\frac{j}{\omega C_{bg}(B)} - Z_2\right)^2\right] \Big/ \left[Z_1^2(U_1 + \right.$$
$$+y_1 - y_2)\left(\frac{j}{\omega C_{bg}(B)} - Z_2\right) - Z_1^2A_2(-y_4 - y_1 + y_2) - Z_1A_3 \times$$
$$\times\left(\frac{j}{\omega C_{bg}(B)} - Z_2\right)(y_5 + y_2 + y_4) + A_1A_2A_4(-y_4 - y_1 + y_2) -$$
$$-R_{ds}(B)A_3^2(y_5 + y_2 + y_4) - A_2R_{ds}(B)Z_1(U_2 - y_3) -$$
$$-A_3^2(-y_4 - y_1 + y_2)A_4 + A_2R_{ds}(B)A_1(y_5 + y_2 + y_4) + (U_1 +$$
$$+y_1 - y_2)R_{ds}(B)Z_1A_3 + A_3\left(\frac{j}{\omega C_{bg}(B)} - Z_2\right)A_4(U_2 - y_3) -$$
$$\left.-(U_1 + y_1 - y_2)A_1A_4\left(\frac{j}{\omega C_{bg}(B)} - Z_2\right)\right], \qquad (2)$$

where $Z_1 = \dfrac{R_{gs}(B)}{1 + \omega^2R_{gs}^2(B)C_{gs}^2(B)} - j\dfrac{\omega R_{gs}^2(B)C_{gs}(B)}{1 + \omega^2R_{gs}^2(B)C_{gs}^2(B)}$,

$Z_2 = \dfrac{R_b(B)}{1 + \omega^2R_b^2(B)C_{bs}^2(B)} - j\dfrac{\omega R_b^2(B)C_{bs}(B)}{1 + \omega^2R_b^2(B)C_{bs}^2(B)}$,

$A_1 = R_g(B) + Z_1 + R_s(B) + R'_s + j\omega L_s$,

$A_2 = R_d(B) + R'_d + j\omega L_d - j\dfrac{1}{\omega C_{bg}(B)} + Z_2 + A_3$,

$A_3 = R_s(B) + R'_s + j\omega L_s$, $A_4 = R_{ds}(B) - j\dfrac{1}{\omega C_{gd}(B)} + Z_1$,

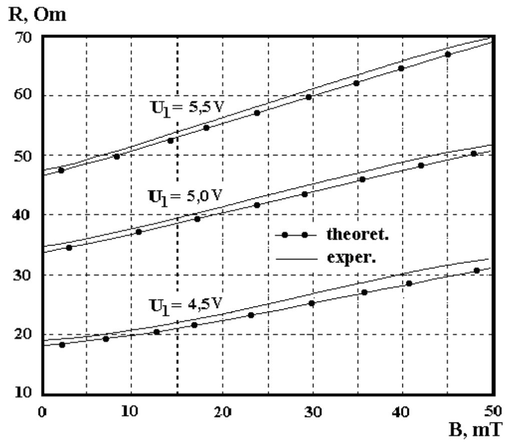
$y_1 = \dfrac{-j(I_{bg} - I_{bs} - I_{DS}(B)}{\omega C_{bg}(B)}$, $y_2 = Z_1((I_{bs} - I_{bg} + I_{DS}(B))$,

$y_3 = Z_2((I_{bs} - I_{bg} + I_{DS}(B))$, $y_5 = Z_1((I_{bg} - I_{bs} - I_{DS}(B))$,

$y_4 = ((I_{bs} - I_{bg} + I_{DS}(B))R_{ds}(B)$,

where U_1 – voltage a drain – source, U_2 – voltage a gate – source. The dependence of active and reactive components complete resistance of the field–effect magnetictransistor from magnetic induction on Fig. 2 is shown.

The variation reactive part from a magnetic induction for a field magneticsensitive element makes 0,6 Ohms/mT, and for a bipolar magneticsensitive element – 12,5 Ohms /mT.



a)

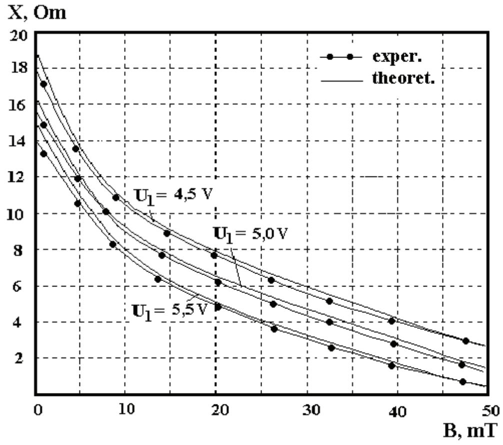


Fig. 2. Dependence of active and reactive party of complete resistance of the field magnetictransistor from magnetic induction

Thus, the analysis of obtained theoretical calculations of dependence of reactive component a complete resistance of magneticsensitive elements displays that this dependence is essential from induction of a magnetic field, that confirms the opportunity of operational use of these effects for making microelectronic transducers.

Microelectronic radiomeasuring transducers of magnetic induction

It is also possible to utillize as sensitive elements frequency transducers MOS transistors. The electric circuit of the transducer is shown on Fig. 3.

The analytical expression of function of transformation has a view

$$F_0=\frac{\sqrt{2}\sqrt{\dfrac{A_1-\sqrt{A_1^2+4L_1C_{GD}(B)R_{DS}^2(B)C_{GS}^2(B)}}{L_1C_{GD}(B)R_{DS}^2(B)C_{GS}^2(B)}}}{4\pi}, \qquad (3)$$

where $A_1=R_{DS}^2(B)C_{GD}(B)C_{GS}(B)+R_{DS}^2(B)C_{GS}^2(B)-L_1C_{GD}(B)$.

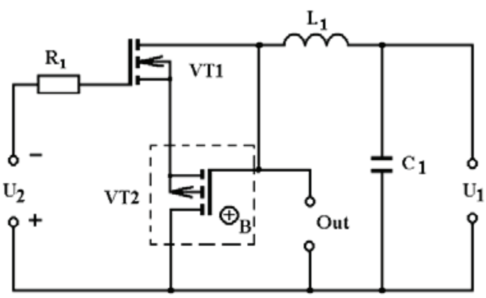


Fig. 3. An electric circuit of the frequency transducer of a magnetic field on the basis MOS of transistors

The pictorial dependence of function of transformation is submitted on Fig. 4. The sensitivity of the frequency transducer of a magnetic field is determined on the basis of expression (3) and is featured by the equation

$$\begin{aligned}
S_B^{F_0}=&-\frac{1}{8}\sqrt{2}\Bigg(R_{DS}^5(B)C_{GS}^5(B)\left(\frac{\partial C_{GD}(B)}{\partial B}\right)+R_{DS}^3(B)C_{GD}^2(B)\times\\
&\times C_{GS}(B)\left(\frac{\partial C_{GS}(B)}{\partial B}\right)\sqrt{A_2}+C_{GD}^3(B)R_{DS}^5(B)C_{GS}^2(B)\times\\
&\times\left(\frac{\partial C_{GS}(B)}{\partial B}\right)+C_{GD}^2(B)R_{DS}^5(B)C_{GS}^3(B)\left(\frac{\partial C_{GS}(B)}{\partial B}\right)+C_{GD}(B)\times\\
&\times R_{DS}^5(B)C_{GS}^4(B)\left(\frac{\partial C_{GD}(B)}{\partial B}\right)+C_{GD}(B)R_{DS}^3(B)C_{GS}^3(B)L_1\times\\
&\times\left(\frac{\partial C_{GD}(B)}{\partial B}\right)-2C_{GD}^3(B)R_{DS}^2(B)C_{GS}^2(B)L_1\left(\frac{\partial R_{DS}(B)}{\partial B}\right)-\\
&-3C_{GD}^3(B)R_{DS}^2(B)C_{GS}(B)L_1\left(\frac{\partial C_{GS}(B)}{\partial B}\right)+2C_{GD}^2(B)\times\\
&\times R_{DS}^2(B)C_{GS}^3(B)L_1\left(\frac{\partial R_{DS}(B)}{\partial B}\right)+2C_{GD}^2(B)R_{DS}^3(B)\times\\
&\times C_{GS}^2(B)L_1\left(\frac{\partial C_{GS}(B)}{\partial B}\right)+R_{DS}^3(B)C_{GS}^3(B)\sqrt{A_2}\left(\frac{\partial C_{GD}(B)}{\partial B}\right)-\\
&-2\left(\frac{\partial R_{DS}(B)}{\partial B}\right)\sqrt{A_2}C_{GD}^2(B)C_{GS}(B)L_1-2\left(\frac{\partial C_{GS}(B)}{\partial B}\right)\times\\
&\times R_{DS}(B)C_{GD}^2(B)\sqrt{A_2}+2\left(\frac{\partial R_{DS}(B)}{\partial B}\right)\sqrt{A_2}C_{GD}^3(B)C_{GS}(B)\times\\
&\times L_1^2+2\left(\frac{\partial C_{GS}(B)}{\partial B}\right)C_{GD}^3(B)C_{DS}(B)L_1^2\Bigg)\Bigg/\Bigg(\pi\sqrt{A_2}L_1\times\\
&\times C_{GD}^2(B)R_{DS}^3(B)C_{GS}^3(B)\sqrt{-\frac{A_3-\sqrt{A_2}}{L_1C_{GD}(B)R_{DS}^2(B)C_{GS}^2(B)}}\Bigg), \qquad (4)
\end{aligned}$$

where $A_2=R_{DS}^4(B)C_{GS}^2(B)C_{GD}^2(B)+2R_{DS}^4(B)C_{GS}^3(B)\times$ $\times C_{GD}(B)-2R_{DS}^2(B)C_{GS}(B)C_{GD}^2(B)L_1+R_{DS}^4(B)C_{GS}^4(B)+$ $+2L_1R_{DS}^2(B)C_{GS}^2(B)+L_1^2C_{GD}^2(B)$, $A_3=-R_{DS}^2(B)C_{GS}(B)C_{GD}(B)-$ $-R_{DS}^2(B)C_{GS}^2(B)+L_1C_{GD}(B)$.

As it is visible from the graph, sensitivity and linearity of function of transformation increase with a heightening of the supply voltage. There are optimum magnitudes of the supply voltage and control, which make 4 V and 3,5 V.

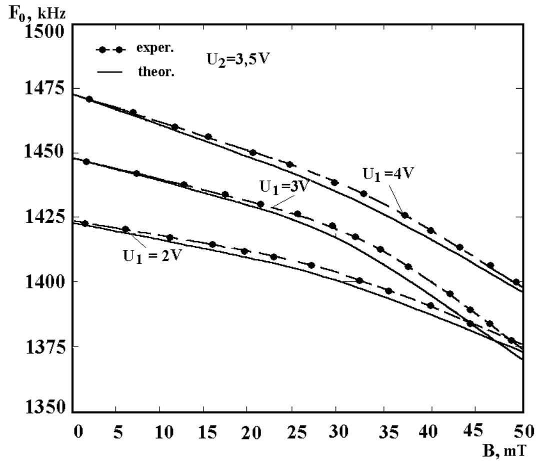


Fig. 4. Dependence of frequency of generation on the induction of a magnetic field

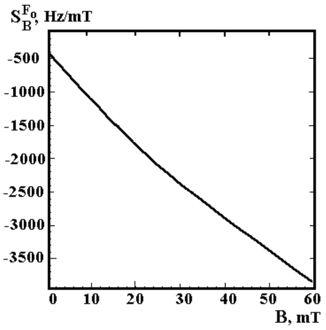


Fig. 5. Dependence of sensitivity on the induction of a magnetic field

The adequacy to designed model in matching with experiment is determined as a relative accuracy and does not exceed 5%. Magneticsensitivity (Fig. 5) and function of transformation were calculated by a numerical method on a PC, according to the formulas (3) and (4). Sensitivity of the transducer on frequency 1418 kHz at the supply voltage 4 V makes 3 kHz/mT.

Conclusions

The method of build-up of radiomeasuring transducers of a magnetic field on a basis magneticreactive effect in bipolar and field-effect transistors is offered. It is shown, that change of a reactive component of a complete resistance from induction density on electrodes a source - drain of a field-effect transistor makes 0,6 Ohm/mT, and for the bipolar transistor on electrodes the emitter-collector - 12,5 Ohm/mT. Such changes of reactive components of a complete resistance are essential, that confirms an opportunity of practical application of these effects for making microelectronic radiomeasuring transducers. The circuit of the transducer of a magnetic field on field-effect transistors which sensitivity makes from 510 up to 3500 Hz/mT is offered.

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Received 2011 01 05

V. S. Osadchuk, A. V. Osadchuk. The Magneticreactive Effect in Transistors for Construction Transducers of Magnetic Field // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 3(109). – P. 119–122.

In the given article the method of build-up of radiomeasuring transducers of a magnetic field on a basis magneticreactive effect in bipolar and field-effect transistors is offered. It is shown, that change of a reactive component of a complete resistance from induction density on electrodes a source - drain of a field-effect transistor makes 0,6 Ohm/mT, and for the bipolar transistor on electrodes the emitter-collector - 12,5 Ohm/mT. Such changes of reactive components of a complete resistance are essential, that confirms an opportunity of practical application of these effects for making microelectronic radiomeasuring transducers. The circuit of the transducer of a magnetic field on field-effect transistors which sensitivity makes from 510 up to 3500 Hz/mT is offered. Ill. 3, bibl. 8 (in English; abstracts in English and Lithuanian).

V. S. Osadchuk, A. V. Osadchuk. Magnetinio lauko įtakos tyrimas taikant lauko tranzistorių magnetoreaktyvinį efektą // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 3(109). – P. 119–122.

Pasiūlytas magnetinio lauko stiprumo matavimo metodas sąlygojamas magnetoreaktyvinio efekto pasireiškimu bipoliariuose ir lauko tranzistoriuose. Parodyta, kad reaktyvinės dedamosios pokytis priklauso nuo indukcijos tankio. Nustatyta, kad lauko tranzistoriuose tarp ištakos ir santakos elektrodų reaktyviosios dedamosios jautris yra 0,6 Ω/mT, o bipoliariuose tranzistoriuose tarp emiterio ir kolektoriaus – 12,5 Ω/mT. Tokie reaktyviosios dedamosios pokyčiai yra svarbūs ir patvirtina, kad galima gaminti tokius radijo matavimams skirtus keitiklius. Il. 3, bibl. 8 (anglų kalba; santraukos anglų ir lietuvių k.).