

The Frequency Transducer of Magnetic Induction

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Introduction

The frequency transducers have a series of advantages compare to amplitude, which consist in considerable increase of noise immunity, that allows to magnify the measurement accuracy, and also in an opportunity of deriving of major output signals. It creates premises of a refusal of amplifier devices in an aftertreatment of signals. Usage of a frequency signal as information allows to refuse A/D converters, that raises profitability of the measuring equipment.

In the given time the intensive research on learning properties of analog microelectronic transducers [1-3] are carried on, though the research of frequency transducers of magnetic induction on the basis of reactive properties of transistor structure with negative resistance is in an incipient state. Therefore given article is devoted to research of the main parameters of frequency transducers of magnetic induction on the basis of such structures in a range of low temperatures.

Theoretical and Experimental Research

The electric circuit of the transducer is presented in Fig.1. It represents a hybrid integrated circuit, which consists of three bipolar transistors with different types of admittance, which establishes premises of making of the auto generating device. The magnetic sensitive diode is connected in a circuit of positive feedback.

On electrodes collector-collector of transistors VT1 and VT2 a complete resistance exists, active component of which has a negative value, and reactive – capacitive character. The hook up of active inductance on the basis of the transistor VT3 and series circuit C2R7 to a collector VT1 establishes a tuning circuit, the power losses in which are cancelled by negative resistance [4]. Thus, the resonance frequency of a tuning circuit depends on action of a magnetic induction on magnetic sensitive diode VD1. Origin inductive properties in bipolar structure are related

with the final velocity of the moving charge carriers in base area.

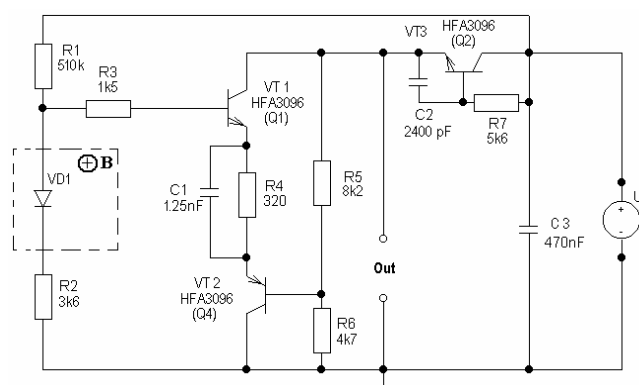


Fig. 1. An electric circuit of the frequency transducer of magnetic induction

The signal fed to emitter can not appear on collector junction while charge carriers pass the base with the delay in time, which has got the name of time of the stairwell. Thereby, current of the collector lags behind in time from voltage on emitter, which is the source of this current that corresponds to the inductive reaction on electrode emitter-collector of the bipolar transistor. The value of inductances and quality factor is defined on base of the nonlinear model of the inductive transistor, founded on models of Ebers-Moll, which is obtained from the general mathematical model of the transistor. Output data for given models is a system of the main equations, which describe the behaviour of the charge carriers in semiconductor material, as well as mathematical correlations, which characterize the behaviour p-n junction. The Inductance in theoretical model depends on electro-physical parameters: semiconductor material of the base, regime of the power supply (constant and alternating voltages), as well as geometric dimensions of the transistor, that allows to control the values of its electrical and technological parameters. The external parameters of

the transistor, which directly are not related with process of the carrying the charge carriers, such as capacitive barrier in emitter-collector junction, ohmic resistance of the base area, inductances of electrodes greatly influence the value of the inductances, which appear in process of the carrying the charge carriers in the base area. External R7C2-circuit connected to transistor VT4 allows to increase both inductance and quality factor of active element on the one hand, but on the other hand – completely implement both active inductive element and entire device using integral technology. In Fig. 2 the experimental dependences of the voltage of magnetic sensitive diode on the value of a magnetic induction are presented at temperature 77 K and 293 K. The connection of a branch circuit R4C1 to emitter circuit of transistors VT1 and VT2 allows to improve considerably the thermocompensation of properties of the device.

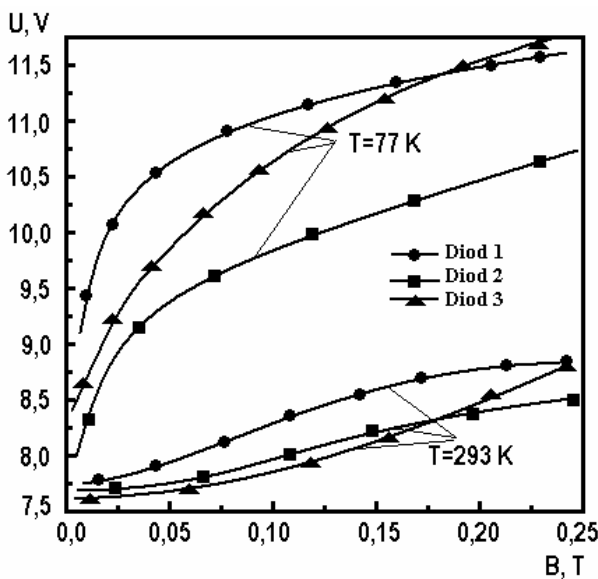


Fig. 2. Dependence of a voltage on magnetic sensitive diode on value of a magnetic induction

As it can be seen from presented theoretical and experimental research [5], the application of p-n junction as magnetic sensitive element does not yield advantage compare to magnetoresistors. For increasing magnetic sensitivity it is necessary to utilize a diode crystal with lengthy bases, in which the part of the voltage drops on p-n junction and part on the base area [6]. When using classical allocation of injected carriers in base area [2]

$$p(x) = p_n + p_n [\exp(qU_e / kT) - 1] e^{-x/L_p}, \quad (1)$$

where p_n - concentration of minority carriers in n-base area, U_e - drop of a fixed supply voltage on p-n junction, L_p - diffusion length injected of vacant electron sites. If the current through the diode will be in an interval [5]

$$AI_w < I < AI_w \exp(W/L_p), \quad (2)$$

where $A = bn_n / p_n(b+1) + 1$, $b = \mu_n / \mu_p$. The resistance of base area of the lengthy diode has an aspect [5]

$$R_B = \frac{W}{q\mu_n n_n S} \left(1 + \frac{L_p}{W} \ln \frac{AI_w + I}{AI_w} \right), \quad (3)$$

where W – length of the base area of the diode. The resistance p-n of junction in this case is featured by the formula [2]

$$R_e = \frac{kT}{qI}. \quad (4)$$

The diffusion capacitance, which is connected in bridge to the resistance of p-n junction, is calculated [6]

$$C_e = \frac{q}{kT} I \tau_p. \quad (5)$$

Let's transfer the determination of dependences of resistance of basis, diffusion capacity and resistance p-n of junction from a magnetic induction. The transversal magnetic field reduces in propagation of resistance of the lengthy diode for such parents: at first, the resistance p-n of junction owing to reduction of a reverse current increases; secondly, the resistance of bases increases at the expense of reduction of its electrical conductivity, that is stipulated by influence both fundamental, and minority carriers of a charge. Reduction of an electrical conductivity at the expense of majority carriers the charge is coupled to reduction of movability of electrons μ_n . The reduction of an electrical conductivity at the expense of minority carriers of a charge is explained by reduction of their length of diffusion displacement L_p as at the expense of reduction μ_p , and τ_p . The action of a magnetic field on resistance of a semi-conductor is featured by expression

$$R_B = R_{B0}(1 + c\mu_p^2 B^2), \quad (6)$$

where R_A , R_{A0} – accordingly resistance of the base area of the diode at action of magnetic field and without it, c – coefficient, which characterizes how magnetic induction depends on the mechanism of a scatter and geometrical dimensions of the diode, B – magnetic induction. Substituting expressions (3) in (6) we shall receive

$$R_B = \frac{W}{q\mu_n n_n S} \left(1 + \frac{L_p}{W} \ln \frac{AI_w + I}{AI_w} \right) \cdot (1 + c\mu_p^2 B^2). \quad (7)$$

For similar purpose, we shall define dependence of resistance of p-n junction when magnetic induction is present

$$R_e = R_{e0}(1 + c\mu_p^2 B^2) = \frac{kT(1 + c\mu_p^2 B^2)}{qI_w e^{\frac{qU_e}{kT}}}. \quad (8)$$

The diffusion capacity of the semiconductor lengthy diode depends on a magnetic field according to the formula

$$C_e = \frac{qI_w e^{\frac{qU_e}{kT}} \tau_p}{kT(1 + c\mu_p^2 B^2)}. \quad (9)$$

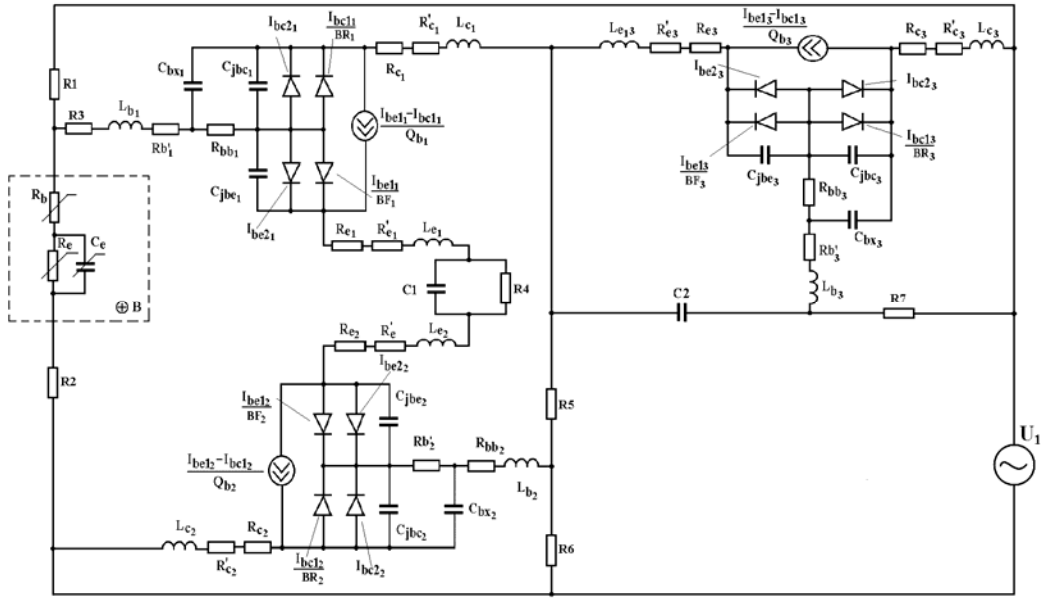


Fig. 3. An equivalent circuit of the frequency transducer of a magnetic induction

Thus, by receiving dependences of elements of a magnetodiode equivalent circuit on the action of a magnetic field we shall transfer the determination of function of transformation, which represents dependence of frequency of generation on magnetic induction. For this purpose it is necessary to calculate a complete resistance of electrodes collector-collector of transistors VT2 and VT3.

The equivalent circuit of the frequency transducer of a magnetic induction is represented on Fig.3. It takes into account nonlinear properties of the circuit, as the self-excited oscillator can work as in linear, and nonlinear modes.

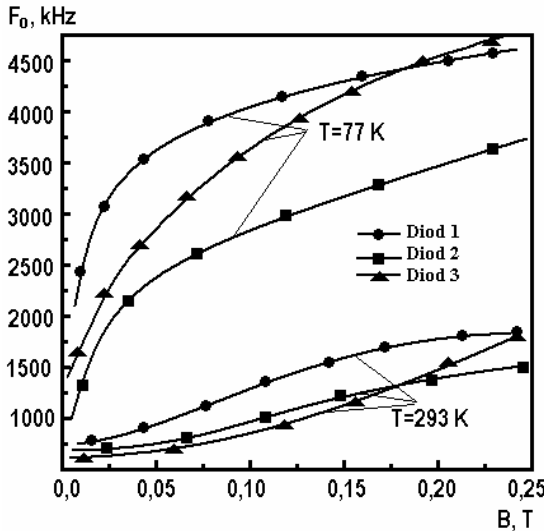


Fig. 4. Dependence of frequency of generation frequency the transducer from value of a magnetic induction

On the basis of this circuit according to a method Lapunov [7] the function of transformation of the device is defined. The analytical dependence of function of transformation is expressed as

$$F_0 = \frac{1}{2\pi} \sqrt{\frac{A_1 + \sqrt{A_1^2 + 4L_{ekv}C_{jbc1}(C_e(B)R_B(B))^2}}{2L_{ekv}C_{jbc1}(R_B(B)C_e(B))^2}}, \quad (10)$$

where $A_1 = L_{ekv}C_{jbc1} - (C_e(B)R_B(B))^2 - C_{jbc1}C_e(B)R_B^2(B)$; L_{ekv} – active inductance of VT3 basis and series C2R7 circuit; C_{jbc1} – capacitance of the junction basis-collector of the transistor VT1.

The illustrated dependence of function of transformation is presented in Fig.4. The sensitivity of the frequency transducer of magnetic induction is defined on the basis of expression (10) and is expressed by equation

$$\begin{aligned} S_B^{F_0} = & -0.0198 \left(-2C_e(B)R_B^3(B)C_{jbc1} \left(\frac{\partial C_e(B)}{\partial B} \right) \sqrt{A_1 + 2A_2} - \right. \\ & - 2C_e^2(B)R_B^3(B) \left(\frac{\partial C_e(B)}{\partial B} \right) - 2C_e^3(B)R_B^2(B) \left(\frac{\partial R_B(B)}{\partial B} \right) - \\ & - 3C_e(B)R_B^3(B)C_{jbc1} \left(\frac{\partial C_e(B)}{\partial B} \right) - 2C_{jbc1}C_e^2(B)R_B^2(B) \times \\ & \times \left(\frac{\partial R_B(B)}{\partial B} \right) + 8C_e^2(B)L_{ekv}R_B^3(B)C_{jbc1} \left(\frac{\partial C_e(B)}{\partial B} \right) + \\ & + 8L_{ekv}C_{jbc1}C_e^2(B)R_B^2(B) \left(\frac{\partial R_B(B)}{\partial B} \right) + 4L_{ekv}C_{jbc1}R_B(B) \times \\ & \times \left(\frac{\partial C_e(B)}{\partial B} \right) \sqrt{A_1^2 + 2A_2} + 4R_B(B) \left(\frac{\partial C_e(B)}{\partial B} \right) L_{ekv}C_{jbc1} + \\ & + 4C_e(B)L_{ekv}C_{jbc1} \left(\frac{\partial R_B(B)}{\partial B} \right) \sqrt{A_1^2 + 2A_2} + 4L_{ekv}C_{jbc1}C_e(B) \times \\ & \times \left(\frac{\partial R_B(B)}{\partial B} \right) \left. \right) / \left(\left(2\sqrt{A_1 + \sqrt{A_1^2 + 2A_2}} / A_2 \right) \times \right. \\ & \times L_{ekv}C_{jbc1}C_e^3(B)R_B^3(B)\sqrt{A_1^2 + 2A_2} \left. \right), \quad (11) \end{aligned}$$

where $A_2 = 2L_{ekv}C_{jbc1}(C_e(B)R_B(B))^2$.

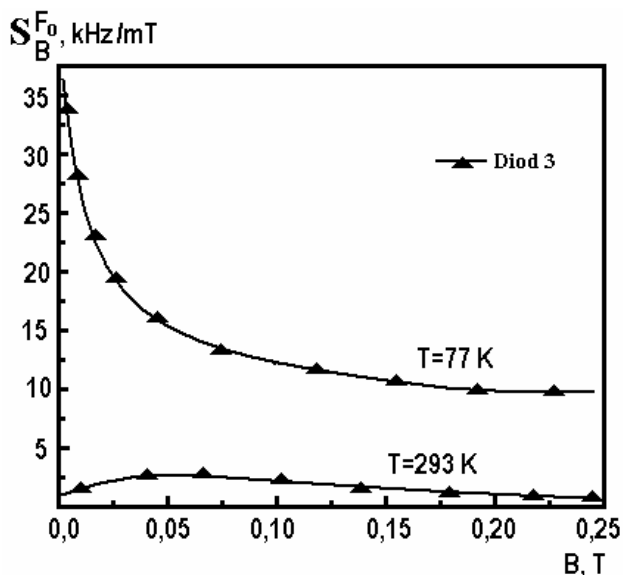


Fig. 5. Dependence of sensitivity on value of magnetic induction

Conclusions

In the given article research of the transducer of magnetic induction with a frequency output signal is presented on the basis of usage of reactive properties of transistor structures with negative resistance in the field of temperatures 77 K and 293 K. The analytical dependences of function of transformation and equation of sensitivity

are obtained. The theoretical and experimental research has shown, that the sensitivity of the transducer makes a 1,5 - 2,25 kHz/mT, and at temperature 77 K increases approximately 10 times.

References

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Research the transducer of magnetic induction with a frequency output signal is represented on the basis of usage of reactive properties of transistor structures with negative resistance in the field of temperatures 77 K and 293 K. The analytical dependences of function of transformation and equation of sensitivity are obtained. The theoretical and experimental research has shown, that the sensitivity of the transducer makes a 1,5-2,25 kHz/mT, and at temperature 77 K increases approximately 10 times. Ill. 5, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

В. С. Осадчук, А. В. Осадчук, В. В. Чабаненко. Частотный преобразователь магнитной индукции // *Электроника и электротехника*. – Каунас: Технология, 2007. – № 3(75). – С. 57–60.

Представлены исследования преобразователя магнитной индукции с частотным выходным сигналом на основе использования реактивных свойств транзисторных структур с отрицательным сопротивлением в области температур 77 К и 293 К. Получены аналитические зависимости функции преобразования и уравнение чувствительности. Теоретические и экспериментальные исследования показали, что чувствительность преобразователя составляет 1,5–2,25 кГц/мТ, причем при температуре 77 К возрастает в 10 раз. Ил. 5, библи. 7 (на английском языке, рефераты на английском, русском и литовском яз.).

V. S. Osadčiuk, A. V. Osadčiuk, V. V. Čabanenko. Dažninis magnetinės indukcijos keitiklis // *Elektronika ir elektrotechnika*. – Kaunas: Technologija, 2007. – Nr. 3(75). – P. 57–60.

Pateikti magnetinės indukcijos keitiklio su dažnio išėjimo signalu tyrimų, atliktų remiantis neigiamą varžą turinčių reaktyviųjų tranzistoriaus struktūrų savybėmis 77 K ir 293 K temperatūrų zonose, rezultatai. Gautos analitinės transformacijos funkcijos ir jautrio lygties išraiškos. Teoriniai ir eksperimentiniai tyrimai parodė, jog keitiklio jautris yra 1,5–2,25 kHz/mT ir padidėja apie 10 kartų, kai temperatūra pasiekia 77 K. Il. 5, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).