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FREQUENCY OPTICAL TRANSDUCER BASED ON DUAL-GATE MOSFET AND PHOTORESISTOR

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Purpose. To describe the properties of the frequency optically transducer consists of oscillator, based on DUAL-GATE MOSFET (metal-oxide-semiconductor field-effect transistors), and photoresistor as a photosensible sensor is necessary to develop a mathematical model by which are depending, active and reactive components of the impedance structure, sensitivity, generation frequency from optical power as information parameter, perform experimental studies confirming the validity theoretical positions. The goal is to determine the transform function and equation of sensitivity, describing the operation of the transducer. **Methodology.** We have determined impedance of the transistor structure by solving equations Kirchhoff, composed for equivalent circuit of frequency optically transducer. Characteristics, which describe dependences of reactive and active component of the impedance converter oscillator, on optical power has been obtained by computer simulation using the MATLAB numerical computing environment. **Results.** We have developed the mathematical model for description properties of frequency optically transducer. The transducer has a high sensitivity in the range of low values of optical power. It makes possible to measure even low optical signals. The proposed model describes the dependence of the impedance transistor structure, basing the transducer, on optical power. Also the analytical equations of the transform function and relative sensitivity was estimated to describe the action of transducer. The values of relative sensitivity are equal to 0,5 – 4 kHz/ microwatt/sm^2. A comparison of simulation results with experimental data shows excellent agreement. Accuracy of developed mathematical model is $\pm 5\%$. **Originality.** The mathematical model of frequency optical transducer was improved. Such model considers the impact of illumination on the elements of nonlinear equivalent circuits of transducer based on transistor's structure with negative resistance. **Practical value.** As a result of mathematical modeling, the analytical expressions for the transform function and sensitivity of optical transducer was designed. It can be used for engineering calculation of the primary optical transducers. References 16, figures 7.

Key words: optical transducers, frequency transducers, negative resistance, photoresistor.

ЧАСТОТНИЙ ОПТИЧНИЙ ПЕРЕТВОРЮВАЧ НА ОСНОВІ ДВОЗАТВОРНИХ МОН-ТРАНЗИСТОРІВ ТА ФОТОРЕЗИСТОРА

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Наведено модель частотного оптичного перетворювача на основі МОН-транзисторів та фоторезистора в якості фоточутливого елементу. Перетворювач володіє високою чутливістю в діапазоні низьких значень потужності оптичного випромінювання, що дає можливість достовірно вимірювати навіть слабкі оптичні сигнали. Запропоновано модель, що описує залежність повного опору транзисторної структури, яка лежить в основі перетворювача від потужності оптичного випромінювання. Наведено залежності реактивної та активної складової повного опору автогенератора перетворювача, отримані за допомогою комп'ютерного моделювання з використанням програмного пакету MatLab. Отримано аналітичні вирази для функції перетворення та чутливості. Результати моделювання підтверджено експериментальними даними. Похибка розробленої математичної моделі становить $\pm 5\%$.

Ключові слова: оптичні перетворювачі, частотні перетворювачі, від'ємний опір, фоторезистор.

PROBLEM STATEMENT. Optical transducers are widely employed to automate any industrial processes, in the robotics, systems of the control, processing and mounting. The transducers are installed in the systems of automatic lighting control, remote control devices, applied in security systems [1–5]. At present, the level of development and research of transducers of optical radiation requires new approaches to create primary transducesr of optical radiation. It can be achieved by converting electric signals into informative frequency signals, especially in the extremely high frequency range [6, 7].

A promising research area is to develop and create the transducers based on reactive properties of semiconductor structures with negative resistance. Such transducers implement the principle of transformation «optical power – frequency». The application of frequency transducers allows to exclude the analog-to-digital transducers from its designs, reduce the cost of management systems, and create a «smart» transducers as a result of the combination data processing circuit and the primary device on a single chip [8, 9].

The practically simultaneous processing, filtering, compression and updating of the measured data takes place in addition to obtaining one. The advantages of using a frequency informative signal of primary transducers compared with the analog voltage or current form are based on simplicity and accuracy of the frequency transformation to a digital code, its high noise immunity during transmission, and switching efficiency in multichannel measurement systems [10, 11].

The optical frequency transducers have a high susceptibility to measure parameters, low weight and dimensions, information, technological and structural compatibility with microelectronic information processing devices [12].

Application of negative resistance and reactive properties of semiconductor devices is capable of improving the sensitivity and accuracy of measuring optical radiation by converting optical signal into frequency [13, 14].

This transformation can be carried out using semiconductor structure comprising auto generating device. The auto generating device was implemented as a circuit consisting of a dual gate MOS-transistors. The photoresistor is employed as a photosensible element in the frequency transducers.

To study the properties of the optical frequency transducer is necessary to develop a mathematical model, which enables obtain the dependence of active and reactive components of the impedance of the structure, the sensitivity, the generation frequency on power of optical radiation [15, 16]. Also experimental studies are needed to confirm the validity of theoretical propositions.

The aim of the study is to determine the transform function and equation of sensitivity for transducer, based on equivalent circuit composed by solving Kirchhoff's equations.

EXPERIMENTAL PART AND RESULTS OBTAINED. The circuit of frequency optical transducer on the basis of dual gate field-effect transistors with photoresistor as the sensing element is shown in Fig. 1.

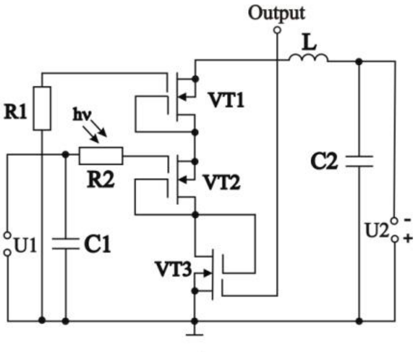

Figure 1 – Circuit of frequency optical transducer based on MOSFET: $U1$ – control voltage; $U2$ – supply voltage

The equivalent capacity of oscillator circuit is formed by the capacitive component of the impedance on such electrodes as drain and source of MOS field-effect transistors VT1 and VT3.

To determine the impedance of the oscillator equivalent circuit for alternating current have been made (Fig. 2).

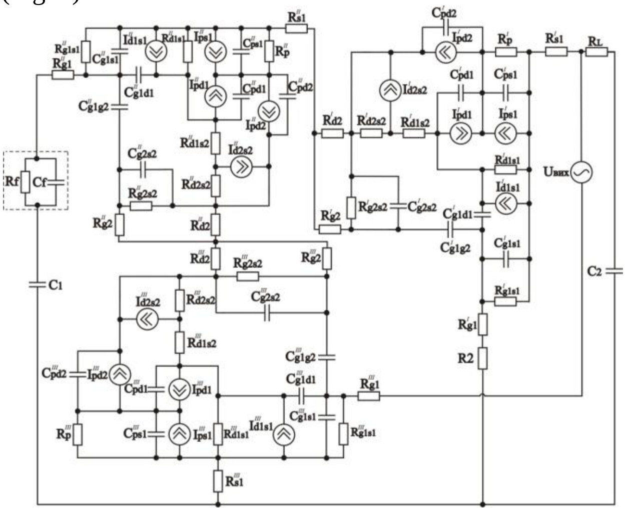

Figure 2 – Equivalent circuit for AC of frequency optical transducer

The equivalent circuit (Fig. 2) uses the following symbols: R_f – photoresistor resistance R_1; R^{I}_{g1}, R^{II}_{g1}, R^{III}_{g1} – bulk resistances of gates of VT1, VT2 and VT3 transistors respectively; R^{I}_{g1s1}, R^{II}_{g1s1}, R^{III}_{g1s1} та R^{I}_{g2s2}, R^{II}_{g2s2}, R^{III}_{g2s2} – bulk resistances of gate-source MOS transistors VT1, VT2 and VT3; R^{I}_{d1s1}, R^{II}_{d1s1}, R^{III}_{d1s1}, R^{I}_{d1s2}, R^{II}_{d1s2}, R^{III}_{d1s2}, R^{I}_{d2s2}, R^{II}_{d2s2}, R^{III}_{d2s2} – resistances of drain-source MOS transistors VT1, VT2 and VT3; R^{I}_{s1}, R^{II}_{s1} , R^{III}_{s1} – bulk resistances of source of MOS transistors VT1, VT2 and VT3; R^{I}_{d2}, R^{II}_{d2}, R^{III}_{d2} – bulk resistances of drain of MOS transistors VT1, VT2 та VT3; R^{I}_{g1}, R^{II}_{g1} R^{III}_{g1}, R^{I}_{g2}, R^{II}_{g2}, R^{III}_{g2} – bulk resistances of first and second gates of MOS transistors VT1, VT2 та VT3; R^{I}_{p} , R^{II}_{p}, R^{III}_{p} – resistances of bodies of MOS transistors VT1, VT2 та VT3; C_f – capacity of photoresistor R_1; C^{I}_{g1s1}, C^{II}_{g1s1}, C^{III}_{g1s1}, C^{I}_{g2s2}, C^{II}_{g2s2}, C^{III}_{g2s2} – capacity of gate-source of MOS transistors VT1, VT2 та VT3; C^{I}_{g1d1}, C^{II}_{g1d1}, C^{III}_{g1d1} – capacity of gate - drain of MOS transistors VT1, VT2 and VT3; C^{II}_{ps1}, C^{II}_{ps1}, C^{II}_{ps1} – capacity body- source of MOS transistors VT1, VT2 and VT3; C^{I}_{pd1}, C^{II}_{pd1}, C^{III}_{pd1}, C^{I}_{pd2}, C^{II}_{pd2}, C^{III}_{pd2} – capacity body-drain of MOS transistors VT1, VT2 and VT3; C^{I}_{g1g2}, C^{II}_{g1g2}, C^{III}_{g1g2} – capacity between first and second gates MOS transistors VT1, VT2 and VT3; C_1 and C_2 – capacity of capacitors C_1 and C_2 respectively.

The circuit (Fig. 2), transformed into more convenient for calculations is presented in Fig. 3

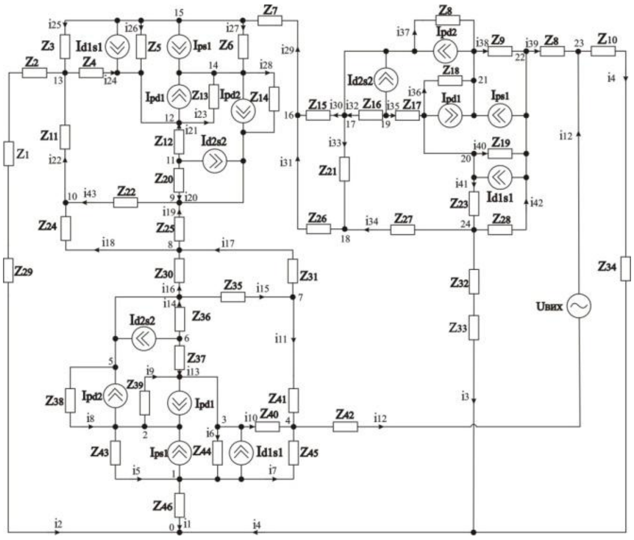

Figure 3 – Transformed equivalent circuit for AC of frequency optical transducer

The following symbols are used to convert the equivalent circuit (Fig. 3):

$$Z_1 = \frac{R_f}{1+\omega^2 R_f^2 C_f^2} - j\frac{R_f^2 \omega C_f}{1+\omega^2 R_f^2 C_f^2};\; Z_2 = R_{g1}^{II};$$

$$Z_3 = R_{g1s1}^{II} /(1+\omega^2 (R_{g1s1}^{II})^2 (C_{g1s1}^{II})^2) -$$
$$- j\left((R_{g1s1}^{II})^2 \omega C_{g1s1}^{II} /(1+\omega^2 (R_{g1s1}^{II})^2 (C_{g1s1}^{II})^2)\right);$$
$$Z_4 = -j/\left(\omega C_{g1d1}^{II}\right);\;\; Z_5 = R_{d1s1}^{II};$$

$$Z_6 = R_p^{II} /(1+\omega^2 (R_p^{II})^2 (C_{ps1}^{II})^2) -$$
$$- j\left((R_p^{II})^2 \omega C_{ps1}^{II} /(1+\omega^2 (R_p^{II})^2 (C_{ps1}^{II})^2)\right);$$

$$Z_7 = R_{s1}^{II};\;\; Z_8 = -j/\left(\omega C_{pd2}^{I}\right);$$

$$Z_9 = R_p^{I} /(1+\omega^2 (R_p^{I})^2 (C_{ps1}^{I})^2) -$$
$$- j\left((R_p^{I})^2 \omega C_{ps1}^{I} /(1+\omega^2 (R_p^{I})^2 (C_{ps1}^{I})^2)\right);$$

$$Z_{10} = j\omega L;\; Z_{11} = -j/\omega(C_{g1g2}^{II});\; Z_{12} = R_{d1s2}^{II};$$

$$Z_{13} = -j/\left(\omega C_{pd1}^{II}\right);\; Z_{14} = -j/\left(\omega C_{pd2}^{II}\right);\; Z_{15} = R_{d2}^{I};$$

$$Z_{16} = R_{d2s2}^{I};\;\; Z_{17} = R_{d1s2}^{I};\; Z_{18} = -j/\left(\omega C_{pd1}^{I}\right);\;\; Z_{19} = R_{d1s1}^{I};$$

$$Z_{20} = R_{d2s2}^{II};$$

$$Z_{21} = R_{g2s2}^{I} /(1+\omega^2 (R_{g2s2}^{I})^2 (C_{g2s2}^{I})^2) -$$
$$- j\left((R_{g2s2}^{I})^2 \omega C_{g2s2}^{I} /(1+\omega^2 (R_{g2s2}^{I})^2 (C_{g2s2}^{I})^2)\right);$$
$$Z_{22} = R_{g2s2}^{II} /(1+\omega^2 (R_{g2s2}^{II})^2 (C_{g2s2}^{II})^2) -$$
$$- j\left((R_{g2s2}^{II})^2 \omega C_{g2s2}^{II} /(1+\omega^2 (R_{g2s2}^{II})^2 (C_{g2s2}^{II})^2)\right);$$

$$Z_{18} = -j/\left(\omega C_{g1d1}^{I}\right);\; Z_{24} = R_{g2}^{II};\; Z_{25} = R_{d2}^{II};\; Z_{26} = R_{g2}^{I};$$

$$Z_{27} = -j/\left(\omega C_{pd2}^{I}\right); Z_{34} = -j/\left(\omega C_2\right)$$

$$Z_{28} = R_{g1s1}^{I} /(1+\omega^2 (R_{g1s1}^{I})^2 (C_{g1s1}^{I})^2) -$$
$$- j\left((R_{g1s1}^{I})^2 \omega C_{g1s1}^{I} /(1+\omega^2 (R_{g1s1}^{I})^2 (C_{g1s1}^{I})^2)\right);$$
$$Z_{29} = -j/(\omega C_1);\; Z_{30} = R_{d2}^{III};\;\; Z_{32} = R_{g1}^{I};\; Z_{33} = R_2;$$

$$Z_{35} = R_{g2s2}^{III} /(1+\omega^2 (R_{g2s2}^{III})^2 (C_{g2s2}^{III})^2) -$$
$$- j\left((R_{g2s2}^{III})^2 \omega C_{g2s2}^{III} /(1+\omega^2 (R_{g2s2}^{III})^2 (C_{g2s2}^{III})^2)\right)$$

$$Z_{36} = R_{d2s2}^{III};\;\; Z_{37} = R_{d1s2}^{III};\;\; Z_{38} = -j/\left(\omega C_{pd2}^{III}\right);$$

$$Z_{39} = -j/\left(\omega C_{pd1}^{III}\right);\; Z_{40} = -j/\left(\omega C_{g1d1}^{III}\right);$$

$$Z_{41} = -j/\omega(C_{g1g2}^{III});\; Z_{42} = R_{g1}^{III};$$

$$Z_{43} = R_p^{III} /(1+\omega^2 (R_p^{III})^2 (C_{ps1}^{III})^2) -$$
$$- j\left((R_p^{III})^2 \omega C_{ps1}^{III} /(1+\omega^2 (R_p^{III})^2 (C_{ps1}^{III})^2)\right);$$

$$Z_{44} = R_{d1s1}^{III};\;\; Z_{46} = R_{s1}^{III};$$

$$Z_{45} = R_{g1s1}^{III} /(1+\omega^2 (R_{g1s1}^{III})^2 (C_{g1s1}^{III})^2) -$$
$$- j\left((R_{g1s1}^{III})^2 \omega C_{g1s1}^{III} /(1+\omega^2 (R_{g1s1}^{III})^2 (C_{g1s1}^{III})^2)\right).$$

The Kirchhoff system of equation for AC has been obtained for the equivalent circuit shown in Fig. 3 (1):

$$\begin{cases}
I_{ps1} + I_{d1s1} = -\varphi_1(Y_1 + Y_5 + Y_6 + Y_7) + \varphi_2 Y_5 + \varphi_3 Y_6 + \\
+ \varphi_4 Y_7, \\
I_{pd2} - I_{pd1} - I_{ps1} = \varphi_1 Y_5 - \varphi_2(Y_5 + Y_8 + Y_9) + \varphi_5 Y_8, \\
I_{pd1} - I_{d1s1} = \varphi_1 Y_6 + \varphi_2 Y_9 - \varphi_3(Y_6 + Y_9 + Y_{10} + Y_{13}) + \\
+ \varphi_4 Y_{10} + \varphi_6 Y_{13}, \\
0 = \varphi_1 Y_7 + \varphi_3 Y_{10} - \varphi_4(Y_7 + Y_{10} + Y_{11} + Y_{12}) + \varphi_7 Y_{11} + \varphi_{23} Y_{12}, \\
- I_{pd2} - I_{d2s2} = \varphi_2 Y_8 - \varphi_5(Y_8 + Y_{14} + Y_{15} + Y_{16}) + \varphi_6 Y_{14} + \\
+ \varphi_7 Y_{15} + \varphi_8 Y_{16}, \\
I_{d2s2} = \varphi_3 Y_{13} + \varphi_5 Y_{14} - \varphi_6(Y_{14} + Y_{13}), \\
0 = \varphi_4 Y_{11} + \varphi_5 Y_{15} - \varphi_7(Y_{11} + Y_{15} + Y_{17}) + \varphi_8 Y_{17}, \\
0 = \varphi_5 Y_{16} + \varphi_7 Y_{17} - \varphi_8(Y_{16} + Y_{17} + Y_{18} + Y_{19}) + \varphi_9 Y_{19} + \varphi_{10} Y_{18}, \\
- I_{pd2} - I_{d2s2} = \varphi_8 Y_{19} - \varphi_9(Y_{19} + Y_{20} + Y_{28} + Y_{43}) + \\
\varphi_{10} Y_{43} + \varphi_{11} Y_{20} + \varphi_{14} Y_{28}, \\
0 = \varphi_8 Y_{18} + \varphi_9 Y_{43} - \varphi_{10}(Y_{18} + Y_{22} + Y_{43}) + \varphi_{13} Y_{22}, \\
I_{d2s2} = \varphi_9 Y_{20} - \varphi_{11}(Y_{20} + Y_{21}) + \varphi_{12} Y_{21}, \\
I_{pd1} - I_{d1s1} = \varphi_{10} Y_{22} - \varphi_{12}(Y_{23} + Y_{24} + Y_{26}) + \varphi_{13} Y_{24} + \\
+ \varphi_{14} Y_{23} + \varphi_{15} Y_{26}, \\
0 = \varphi_{10} Y_{22} + \varphi_{12} Y_{24} - \varphi_{13}(Y_2 + Y_{22} + Y_{24} + Y_{25}) + \varphi_{15} Y_{25}, \\
- I_{ps1} - I_{pd1} + I_{pd2} = \varphi_9 Y_{28} + \varphi_{12} Y_{23} - \\
- \varphi_{14}(Y_{23} + Y_{27} + Y_{28}) + \varphi_{15} Y_{27}, \\
I_{d1s1} + I_{ps1} = \varphi_{12} Y_{26} + \varphi_{13} Y_{25} + \varphi_{14} Y_{27} - \\
- \varphi_{15}(Y_{25} + Y_{26} + Y_{27} + Y_{29}) + \varphi_{16} Y_{29}, \\
0 = \varphi_{15} Y_{29} - \varphi_{16}(Y_{29} + Y_{30} + Y_{30}) + \varphi_{17} Y_{30} + \varphi_{18} Y_{31}, \\
- I_{d2s1} - I_{pd2} = \varphi_{16} Y_{30} - \varphi_{17}(Y_{30} + Y_{32} + Y_{33} + Y_{37}) + \\
+ \varphi_{19} Y_{32} + \varphi_{21} Y_{37}, \\
0 = \varphi_{16} Y_{31} + \varphi_{17} Y_{33} - \varphi_{18}(Y_{31} + Y_{33} + Y_{34}) + \varphi_{24} Y_{34}, \\
I_{d2s2} = \varphi_{17} Y_{32} - \varphi_{19}(Y_{31} + Y_{33} + Y_{34}) + \varphi_{17} Y_{32} + \varphi_{20} Y_{35}, \\
I_{pd1} - I_{d1s1} = \varphi_{19} Y_{35} - \varphi_{20}(Y_{35} + Y_{36} + Y_{40} + Y_{41}) + \\
+ \varphi_{21} Y_{36} + \varphi_{22} Y_{40} + \varphi_{24} Y_{41}, \\
I_{pd2} - I_{pd1} - I_{ps1} = \varphi_{17} Y_{37} + \varphi_{20} Y_{36} - \varphi_{21}(Y_{36} + Y_{37} + Y_{38}) + \\
+ \varphi_{22} Y_{38}, \\
I_{ps1} + I_{d1s1} - U_{\text{вих}} Y_{39} = \varphi_{20} Y_{40} + \varphi_{21} Y_{38} - \\
- \varphi_{22}(Y_{38} + Y_{39} + Y_{40} + Y_{42}) + \varphi_{24} Y_{42}, \\
0 = \varphi_4 Y_{12} - U_{\text{вих}}(Y_4 + Y_{12} + Y_{39}) + \varphi_{22} Y_{39}, \\
0 = \varphi_{18} Y_{34} + \varphi_{20} Y_{41} + \varphi_{22} Y_{42} - \varphi_{24}(Y_3 + Y_{34} + Y_{41} + Y_{42}),
\end{cases} \qquad (1)$$

The conductivity of the circuit branches are determined by the equations:

$$Y_1 = 1/Z_{46};\quad Y_2 = 1/(Z_1 + Z_2 + Z_{29});\quad Y_3 = 1/(Z_{32} + Z_{33});$$
$$Y_4 = 1/(Z_{10} + Z_{34});\quad Y_5 = Z_{43};\quad Y_6 = 1/Z_{44};\quad Y_7 = Z_{45};$$
$$Y_8 = 1/Z_{38};\quad Y_9 = 1/Z_{39};\quad Y_{10} = 1/Z_{40}; Y_{11} = 1/Z_{41};$$

$$Y_{12}=1/Z_{42};\quad Y_{13}=1/Z_{37};\quad Y_{14}=Z_{36};\quad Y_{15}=1/Z_{35};$$
$$Y_{16}=1/Z_{30};\quad Y_{17}=1/Z_{31};\quad Y_{18}=Z_{24};\quad Y_{19}=1/Z_{25};$$
$$Y_{20}=1/Z_{20};\quad Y_{21}=1/Z_{12};\quad Y_{22}=1/Z_{11};Y_{23}=1/Z_{13};$$
$$Y_{24}=1/Z_{4};\quad Y_{25}=1/Z_{3};\quad Y_{26}=1/Z_{5};\quad Y_{27}=1/Z_{6};$$
$$Y_{28}=1/Z_{14};\quad Y_{29}=1/Z_{7};\quad Y_{30}=1/Z_{15};\quad Y_{31}=1/Z_{26};$$
$$Y_{32}=1/Z_{16};\quad Y_{33}=1/Z_{21};\quad Y_{34}=1/Z_{27};\quad Y_{35}=1/Z_{17};$$
$$Y_{36}=1/Z_{18};\quad Y_{37}=1/Z_{8};\quad Y_{38}=1/Z_{9};\quad Y_{39}=1/Z_{8};$$
$$Y_{40}=1/Z_{19};\ Y_{41}=1/Z_{23};Y_{42}=1/Z_{28};\ Y_{43}=1/Z_{22}.$$

The system of equations (1) has been solved using Gauss's method in the software package MATLAB 8.1.

Calculated and experimental dependences of active and reactive component of the impedance on the optical power are shown in Fig. 4 and Fig. 5, respectively.

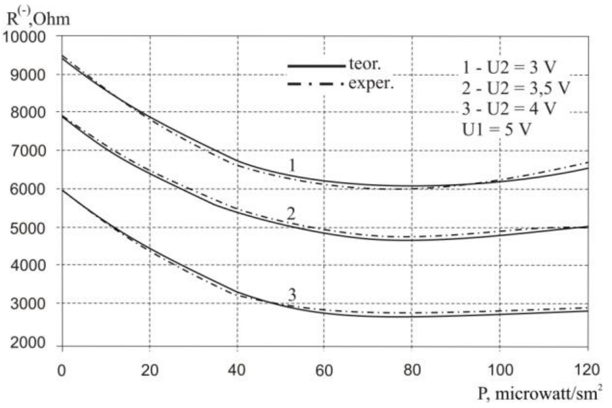

Figure 4 – Theoretical and experimental dependences of active component of the impedance on optical power

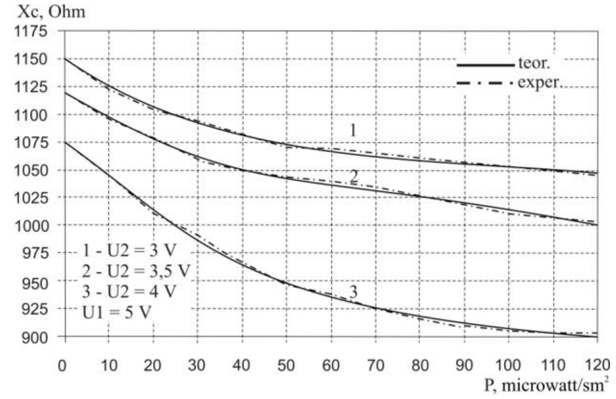

Figure 5 – Theoretical and experimental dependences of imaginary component of the impedance on optical power

The reactive component of the impedance has a maximum value for voltage 3 V and decreases with decreasing optical power.

In order to determine the transform functions, the dependence of generation frequency on optical power has been obtained by means of solution of the Kirchhoff system of equations (1) [14]. The estimated transform functions is described by formula

$$F=\frac{\sqrt{2}\sqrt{LC_4(-L_1C'_{pd2}+R_f^2(P)C_f^2+R_f^2(P)C_fC'_{pd2}+A)}}{2LC_fC'_{pd2}R_f(P)},$$

where

$$A_1=\sqrt{L^2(C'_{pd2})^2+2LC_f^2C'_{pd2}R_f^2(P)-2L(C'_{pd2})^2C_fR_f^2(P)+A_2},$$

$$A_2=R_f^4(P)C_f^4+2R_f^4(P)C_f^3C'_{pd2}+R_f^4(P)C_f^2(C'_{pd2})^2.$$

Dependence of generation frequency on optical power calculated by the formula (3) and determined experimentally for transducer (for transistors BF998 and photoresistor GL5528) is shown in Fig. 6.

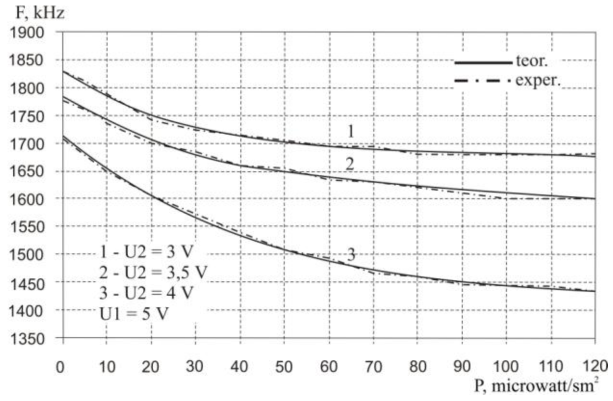

Figure 6 – Theoretical and experimental dependences of the oscillation frequency on the optical power for different operating points of the oscillator

The plots (Fig. 6) show frequency generation increasing with radiation power. The theoretic values agree to within better than ± 5% with experimental data.

The sensitivity of the frequency transducer is given by equation:

$$\begin{gathered}
S_P^F=\frac{1}{4}\sqrt{2}\left(2R_f(P)C_f^2\left(\frac{\partial}{\partial P}R_f(P)\right)+\right.\\
2R_f(P)C_fC'_{pd2}\left(\frac{\partial}{\partial P}R_f(P)\right)+\\
+\left(\frac{1}{2}\left(4LR_f(P)C'_{pd2}C_f^2\left(\frac{\partial}{\partial P}R_f(P)\right)-\right.\right.\\
-4LR_f(P)\left(C'_{pd2}\right)^2C_f\left(\frac{\partial}{\partial P}R_f(P)\right)+\\
+4R_f^3(P)C_f^4\left(\frac{\partial}{\partial P}R_f(P)\right)+8R_f^3(P)C_f^3C'_{pd2}\left(\frac{\partial}{\partial P}R_f(P)\right)+\\
\left.\left.+4R_f^3(P)C_f^2\left(C'_{pd2}\right)^2\left(\frac{\partial}{\partial P}R_f(P)\right)\right)\Big/\sqrt{B_1}\right)\Big/\\
\Big/\left(\sqrt{-LC'_{pd2}(B_2+\sqrt{B_1})}\right)\bigg)-\frac{1}{2}\sqrt{2}\times\\
\times\sqrt{LC'_{pd2}\left(B_2+\sqrt{B_1}\right)}\left(\frac{\partial}{\partial P}R_f(P)\right)\Big/\left(LC'_{pd2}C_fR_f^2(P)\right),
\end{gathered}$$

where

$$B_1 = L^2\left(C'_{pd2}\right)^2 + 2LC'_{pd2}C_f^2R_f^2(P) - 2L\left(C'_{pd2}\right)^2 C_f R_f^2(P) +$$
$$+ R_f^4(P)Cf + 2R_f^4(P)C_f^3C'_{pd2} + R_f^4(P)C_f^2\left(C'_{pd2}\right)^2;$$

$$B_2 = -LC'_{pd2} + R_f^2(P)C_f^2 + R_f^2(P)C'_{pd2}C_f \,.$$

The dependence of the sensitivity of the optical frequency transducer on optical radiation power is presented in Fig. 7.

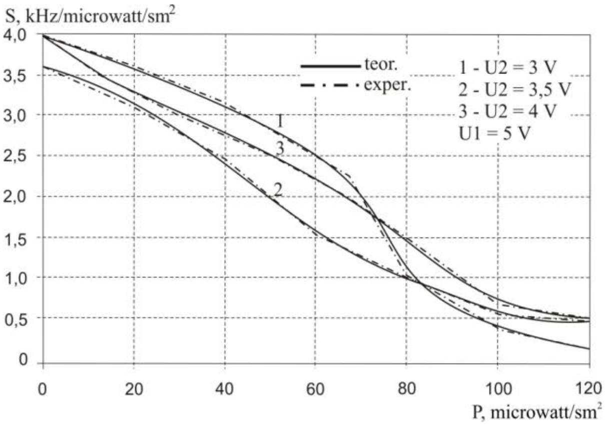

Figure 7 – The sensitivity of the optical frequency transducer based on dual-gate MOS field-effect transistors

CONCLUSIONS. The mathematical model of optical frequency transducer, based on oscillator with MOS transistors, with photoresistor as the sensing element was developed. The analytical expression for the transform function and sensitivity equation has been obtained using the mathematical model. The transducer has a high sensitivity in the range of low values of optical power. It makes possible to measure even low optical signals. The proposed model describes the dependence of the impedance transistor structure, basing the transducer, on optical power. Theoretical and experimental plots show that relative sensitivity is equal to 0,5 – 4 kHz/ microwatt/sm^2.

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ЧАСТОТНЫЙ ОПТИЧЕСКИЙ ПРЕОБРАЗОВАТЕЛЬ НА ОСНОВЕ ДВУХЗАТВОРНЫХ МОН-ТРАНЗИСТОРОВ И ФОТОРЕЗИСТОРА

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Представлена модель частотного оптического преобразователя на основе МОП-транзисторов и фоторезистора в качестве фоточувствительного элемента. Преобразователь обладает высокой чувствительностью в диапазоне низких значений мощности оптического излучения, что позволяет достоверно измерять даже слабые оптические сигналы. Предложенная на модель описывает зависимость полного сопротивления транзисторной структуры, лежащей в основе преобразователя, от мощности оптического излучения. Приведены зависимости реактивной и активной составляющей полного сопротивления автогенератора преобразователя, полученные с помощью компьютерного моделирования с использованием программного пакета MatLab. Получены аналитические выражения для преобразования и чувствительности. Результаты моделирования подтверждено экспериментальными данными. Погрешность разработанной математической модели составляет $\pm 5\%$.

Ключевые слова: оптические преобразователи, частотные преобразователи, отрицательное сопротивление, фоторезистор.

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