L. B. Lyschynska, Cand. Sc. (Eng.), Assist. Prof.; Ya. S. Rozhkova;

N. A. Filiniuk, Dc. Sc (Eng.), Prof.

"QUALITY" ANALYSIS OF ONE-CRYSTAL IMMITANCE CONVERTERS

The paper presents the development of mathematical models of generalized immitance converters (GIC) that take into account the dependence of their converted immitances on the physical parameters of transistors. $S^{Tk}_{\alpha i}$ *quality dependence on physical parameters of the above-mentioned transistors is investigated.*

Key words: *generalized immitance converter, unijunction transistor, bipolar transistor, field transistor, sensitivity coefficient, quality.*

Introduction

One of the requirements to generalized immitance converters (GIC) is stability of the conversion coefficient. Instability of this coefficient is usually characterized as sensitivity to GIC parameter variations that was named GIC "quality" [1]. The smaller GIC sensitivity is, the higher its quality will be.

Statement of the research problems

In order to determine GIC quality dependence on the physical parameters of unijunction (UT), bipolar (BT) and field (FT) transistors that provide the ability to control $S^{Tk}_{\alpha i}$ quality by changing physical parameters and connection circuits, it is necessary to solve the following problems:

– to develop mathematical models of the immitance converters based on UT, BT and FT that take into account the dependence of their converted immitances on the physical parameters of transistors;

– to investigate $S^{Tk}_{\alpha i}$ quality dependences on the physical parameters of transistors for real and ideal immitance converters.

Development of the mathematical models

Let us consider three types of converters based on unijunction transistor connected in the circuit with common base 1 (b*1*), bipolar transistor connected into the circuit with common collector (*c*) and on the basis of field transistor connected into the circuit with common drain (*d*).

To develop mathematical models of such converters that take physical parameters of transistors into account, their physical equivalent circuits are used [2 – 4].

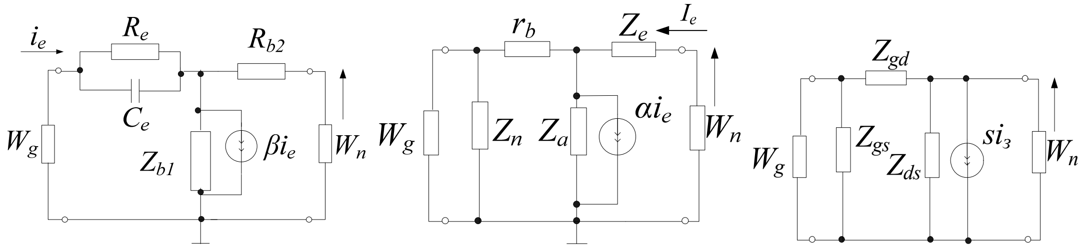


Fig. 1. Equivalent circuits of one-crystal converters on the basis of: a) UT; b) BT; c) FT

In the circuit 1a): β – UT current transfer coefficient; Z_{b1}, R_{b2} – resistances of base 1 and base 2; C_e and R_e – barrier capacitance and differential resistance of the emitter junction. In the circuit (fig. 1 b): α – BT current transfer coefficient; r_b – Ohmic resistance of the base resistance of the base, Z_e – total resistance of the emitter junction that is defined as $Z_e = r_e /(1+ j\omega r_e C_e)$;

$Z_a = 1/j\omega C_{k1}$, $Z_n = 1/j\omega C_{k2}$, where C_{k1} and C_{k2} – active and passive capacitances of the collector junction (fig. 1 b): Z_{gs}, Z_{gd} and Z_{ds} – complex resistances gate-source, gate-drain and drain-source of FT correspondingly; s – steepness of FT.

Physical equivalent circuits are obtained without parasitic elements, the case and the terminals being taken into account as the investigations are performed at relatively low frequencies. Parameters of the physical equivalent circuits are determined using the procedure described in [5].

To simplify calculations certain assumptions are made and namely: in the unijunction transistor emitter resistance at high currents $R_e \rightarrow 0$, and $Z_{b1} = 1/j\omega C_{b1}$.

Taking these assumptions into account we obtain mathematical expressions for Y-parameters of three physical equivalent GIC circuits.

The circuit conductance matrix (fig. 1 a) will have the form of:

$$[Y_{b1}] = \begin{bmatrix} \dfrac{R_{b2} + Z_{b1}}{R_{b2}\cdot(1-\beta) + Z_{b1}} & \dfrac{-1}{R_{b2}\cdot(1-\beta)} \\ \dfrac{-1}{R_{b2}} & \dfrac{1}{R_{b2}} \end{bmatrix}. \tag{1}$$

The circuit conductance matrix (fig. 1 b) will have the form of:

$$[Y_c] = \begin{bmatrix} \dfrac{Z_e + Z_a\cdot(1-\alpha)}{Z_e\cdot r_b + Z_a\cdot[r_e + r_b\cdot(1-\alpha)]} & -\dfrac{Z_e}{Z_e\cdot r_b + Z_a\cdot[r_e + r_b\cdot(1-\alpha)]} \\ \dfrac{Z_a}{Z_e\cdot r_b + Z_a\cdot[r_e + r_b\cdot(1-\alpha)]} & \dfrac{r_b + Z_a}{Z_e\cdot r_b + Z_a\cdot[r_e + r_b\cdot(1-\alpha)]} \end{bmatrix}. \tag{2}$$

The circuit conductance matrix (fig. 1 c) will have the form of:

$$[Y_d] = \begin{bmatrix} \dfrac{\Omega_s\cdot(\Omega_s + j)}{R_e} & -\dfrac{\Omega_s\cdot(\Omega_s + j)}{R_e} \\ -\dfrac{\Omega_s + s\cdot R_e + j\Omega_s\cdot(1 - sR_e)}{R_e} & \dfrac{\Omega_s + s\cdot R_e + j\Omega_s\cdot(1 - sR_e)}{R_e} \end{bmatrix}, \tag{3}$$

where $\Omega_s = \dfrac{\omega}{\omega_s}$, $\omega_s = \dfrac{1}{R_e C_{gs}}$; R_e – resistance of the source, C_{gs} – gate-source capacity; $\dot{\alpha} = \dfrac{\alpha_0}{1 + j\Omega_T}$, $\dot{\beta} = \dfrac{\beta_0}{1 + j\Omega_\beta}$, $\dot{s} = \dfrac{s_0}{1 + j\Omega_s}$.

Input and output converted conductances of the circuits under consideration are equal to [6]:

$$Y_{inp.} = Y_{11} - Y_{12}\cdot Y_{21}/(Y_{22} + Y_н), \tag{4}$$

$$Y_{out.} = Y_{22} - Y_{12}\cdot Y_{21}/(Y_{11} + Y_г). \tag{5}$$

where Y_n and Y_g – conductances to be converted.

Equation systems form mathematical models of one-crystal GIC and make it possible to investigate the quality dependences on the main parameters of the physical equivalent circuits of UT, BT and FT.

To determine the quality of one-crystal immitance converters based on (1) – (3), we find immitance converter coefficient T_c. For ideal GIC in all cases direct $T_{c.i}$ and inverse $T'_{c.i}$ conversion coefficients will be described by the expressions [7]:

$$T_{c.r} = \frac{Y_{11}}{Y_{22}}, \quad T'_{c.r} = \frac{Y_{22}}{Y_{11}}. \tag{6}$$

For real GIC direct $T_{c.p}$ and inverse $T'_{c.p}$ conversion coefficients with (4) and (5) taken into account will be equal to:

$$T_{c.p} = \frac{Y_{inp.}}{Y_n},\ T'_{c.p} = \frac{Y_{out.}}{Y_г}. \tag{7}$$

Using (6) and (7) analytical expressions are found for the quality of one-crystal immitance converters for direct and inverse conversion:

$$S_{\alpha_i}{}^{T_c} = \frac{\partial T_c}{\partial \alpha_i} \cdot \frac{\alpha_i}{T_c},\ S_{\alpha_i}{}^{T'_к} = \frac{\partial T'_c}{\partial \alpha_i} \cdot \frac{\alpha_i}{T'_c}, \tag{8}$$

where α_i – chosen physical parameter of the transistor.

Research results

Dependences of the quality coefficients of the above-mentioned GIC were considered for two cases: for the ideal and real converters.

For ideal converter sensitivity dependences of the direct $T_{c.i}$ and inverse $T'_{c.i}$ conversion coefficients on the main physical parameters of the equivalent UT circuit are presented in fig. 2 and 3.

Dependence of the real quality part on the resistance of base 2 (R_{b2}) has growing character and that of the imaginary part – descending character, though the influence of R_{b2} variations is not considerable. Increase of the transistor current transfer coefficient β_0 leads to the growth of the real part of the sensitivity and therefore to the converter quality reduction (fig.2b), the increase of the reduced Ω frequency leading to $S_{\beta 0}{}^{Tk}$ reduction. From the imaginary part of the dependence it can be concluded that neither current transfer coefficient β_0 of the transistor, nor reduced frequency Ω variations do not influence the quality. Dependences of sensitivity on resistance (R_{b1}) and capacitance (C_{b1}) of base 1 are so inconsiderable (10^{-14} – 10^{-15}) that they can be ignored.

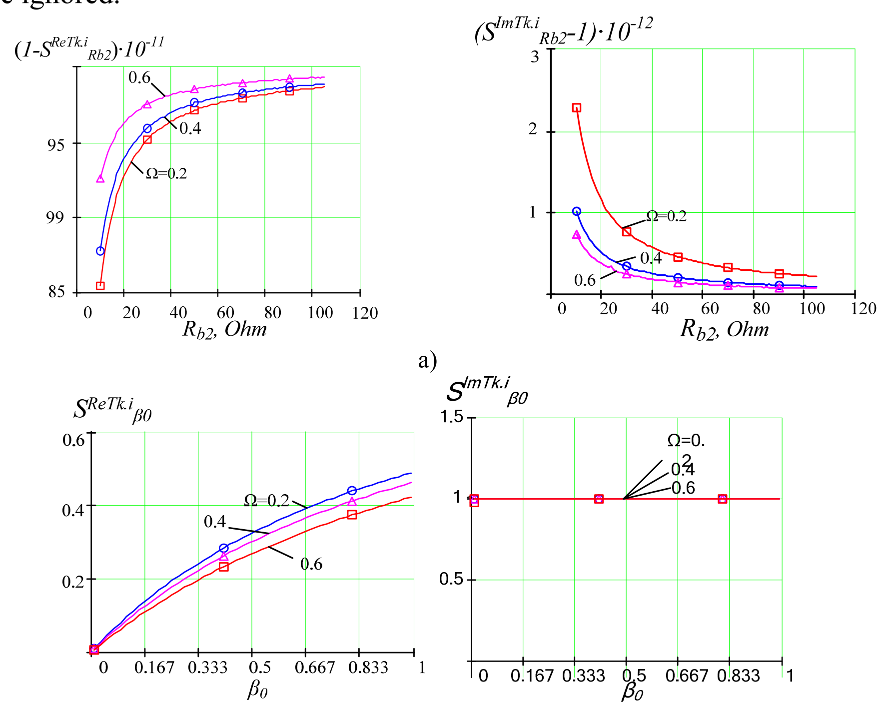
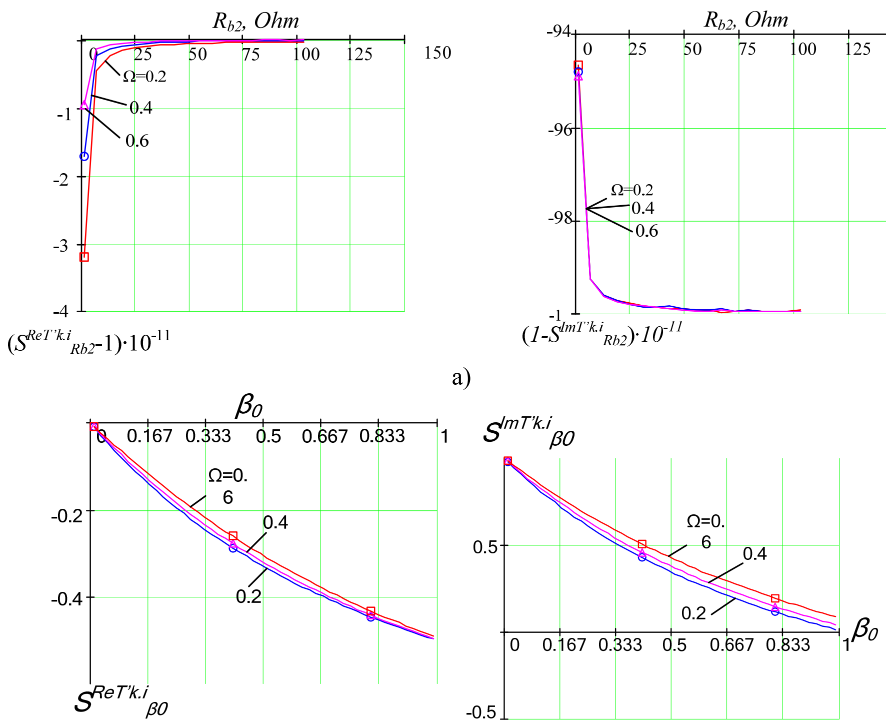


Fig. 2. Dependences of sensitivity for the direct conversion coefficient $T_{c.i}$ in the case of ideal GIC on the basis of UT on resistance R_{b2} of base 2 (a); transistor current transfer coefficient β_0 (b) for different reduced frequencies $\Omega = f/f_T$

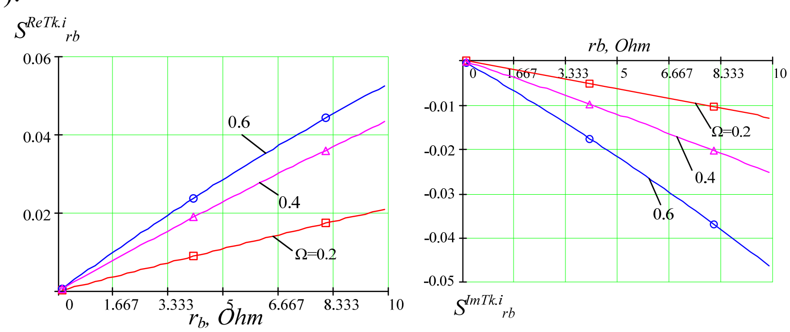


b)

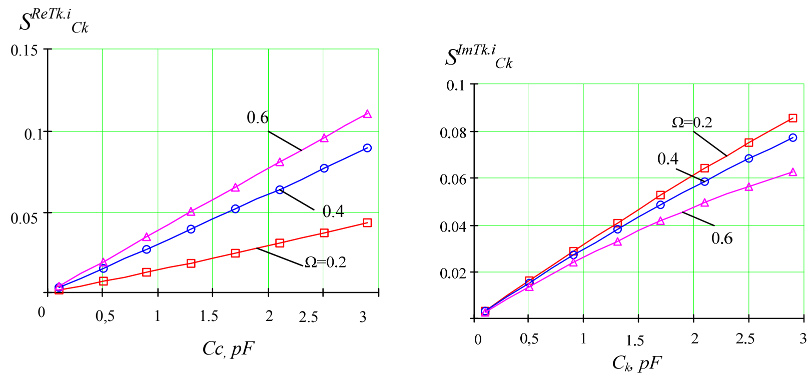
Fig. 3. Dependences of sensitivity for the inverse conversion coefficient $T_{c.i}$ in the case of ideal GIC on the basis of UT on resistance R_{b2} of base 2 (a); transistor current transfer coefficient β_0 (b) for different reduced frequencies $\Omega=f/f_T$

For the chosen conversion coefficient the quality does not greatly depend on the resistance R_{b2} variations (fig. 3a), the reduced frequency variations having practically no influence on quality. Both real and imaginary parts of the quality dependence on β_0 have descending character and are located in different quarters; real part has negative sensitivity values while the imaginary part – positive ones.

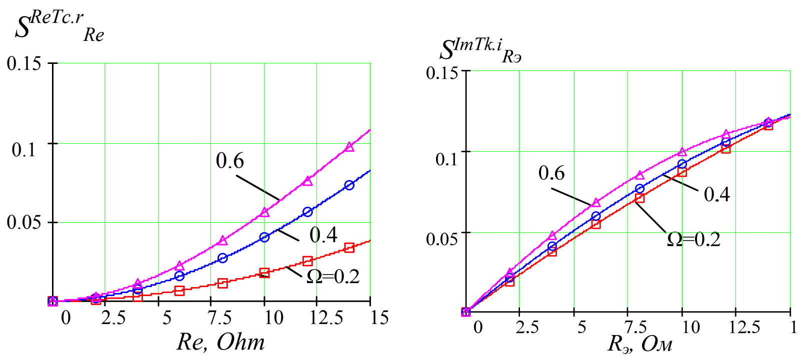
The analysis of quality dependences for the direct and inverse conversions for the ideal converter on main physical parameters of the bipolar transistor circuit is presented in fig. 4, 5. Real part of sensitivity grows considerably reducing the converter quality (fig.4a) when the base resistance r_b as well as the reduced frequency are growing. At the same time the imaginary part has the opposite character and is negative: it reduces with the growth of r_b and Ω. Growth of the collector capacitance increases sensitivity (for both real and imaginary parts), but growth of the reduced frequency leads to the real part quality reduction and to its increase for the imaginary one (fig. 4 b).



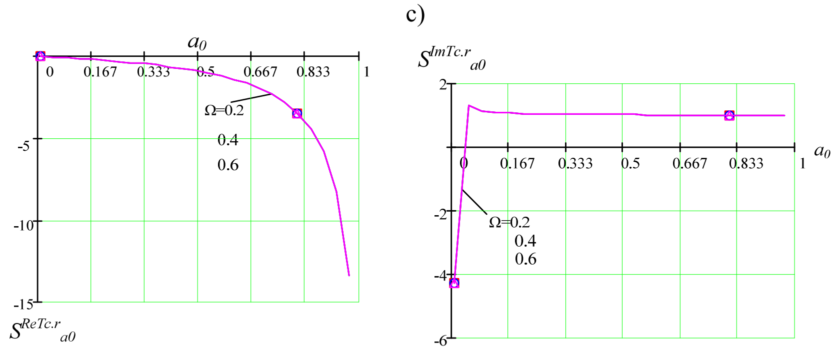
a)



b)



c)



d)

Fig. 4. Dependences of the direct conversion quality for ideal GIC on the basis of BT on the base resistance r_b (a); the collector capacitance C_c (b); the emitter resistance r_e (c); transistor current transfer coefficient a_0 (d) for reduced frequency $\Omega=f/f_T$

Increase of the emitter resistance r_e and of the reduced frequency has positive influence on the quality change (fig. 4 c). The dependences have the same numerical limits but the character of the plots is the evidence of different signs of the first derivatives. The change connected with the growth of BT current transfer coefficient reduces the sensitivity value increasing the quality (fig. 4 d); real part of the plot of these dependences is totally negative. The imaginary part is of complex character: below α_0 = 0,038 quality is negative while above this value it is positive. For the value of α_0 = 0,05 the maximal growth of $S_{\alpha 0}^{Tk.u}$ is observed while subsequent growth of the transfer coefficient as well as that of the reduced frequency have no influence on the quality change.

For the inverse transformation of conversion coefficient $T'_{c.i}$ real part of the quality dependence on the base resistance r_b (fig. 5a) is growing and lies in the region of positive values while the influence of the reduced frequency Ω is the same as for the direct conversion coefficient. The dependence in the imaginary part has descending character with negative values and its reduction is observed.

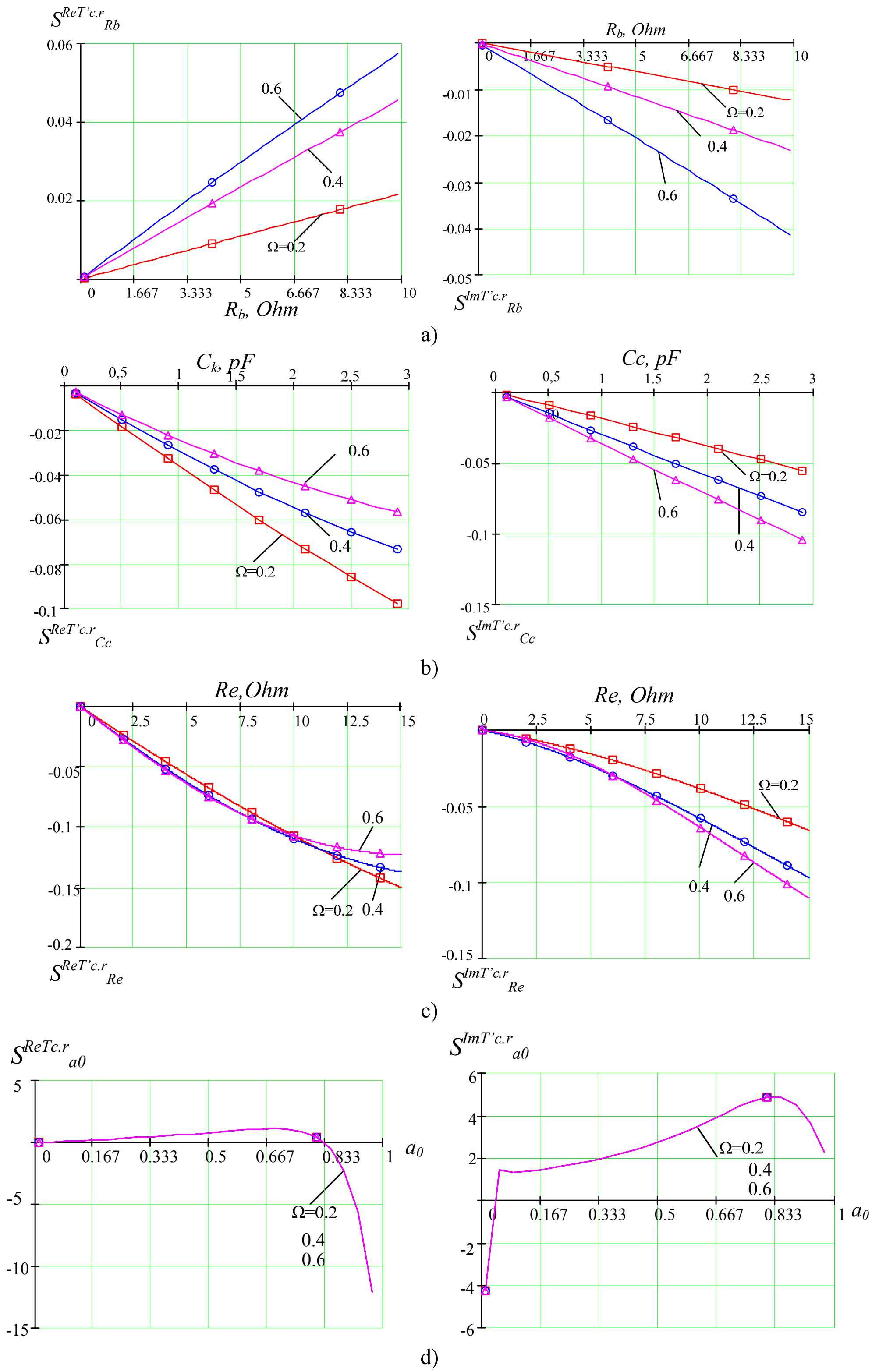
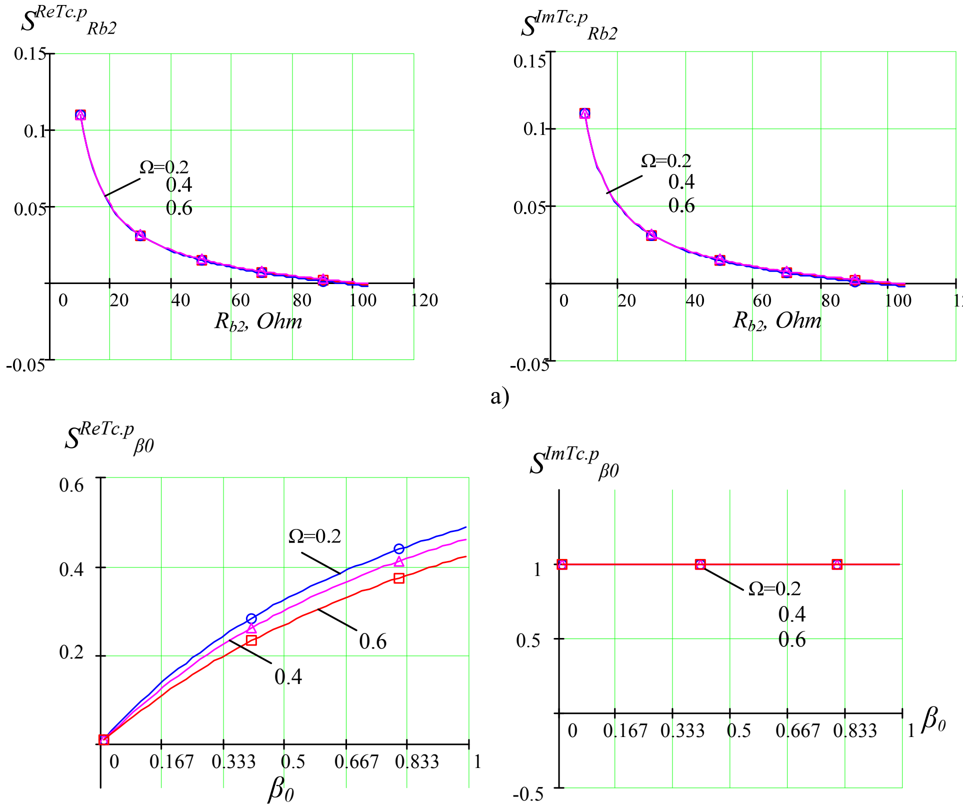


Fig. 5. Quality dependences for the inverse conversion of ideal GIC on the basis of BT on the base resistance r_b (a); the collector capacitance C_c (b); the emitter resistance r_e (c); transistor current transfer coefficient a_0 (d) for reduced frequency $\Omega=f/f_T$

For a field transistor, when direct and inverse conversion is performed, sensitivity dependences on its main physical parameters are not considerable (10^{-14} – 10^{-15}).

The next stage of the research was finding the same dependences for the real converter.

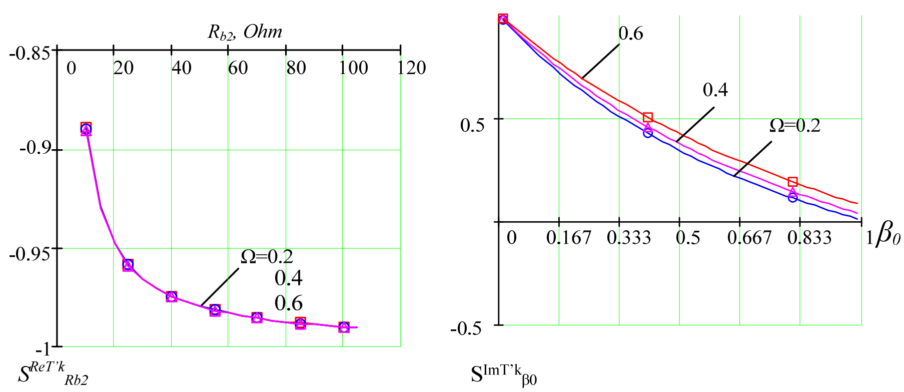
Let us consider them in the cases of direct and inverse conversion for UT. The results of numerical calculations of sensitivity $S_{\alpha i}^{Tk}$ are presented in fig. 6 and 7.



b)

Fig. 6.Sensitivity dependences for direct conversion coefficient $T_{c.r}$ for different reduced frequencies $\Omega=f/f_T$ on the resistance R_{b2} of base 2 (a); transistor current transfer coefficient β_0 (b)

Growth of resistance R_{b2} of base 2 reduces the value of the converter quality (fig. 6 a) for the real part and increases quality for the imaginary part. It has the same numerical limits and is not influenced by the reduced frequency variations. Transistor current transfer coefficient (fig. 6 b) in the case of real converter has the same influence on quality as for the ideal converter.



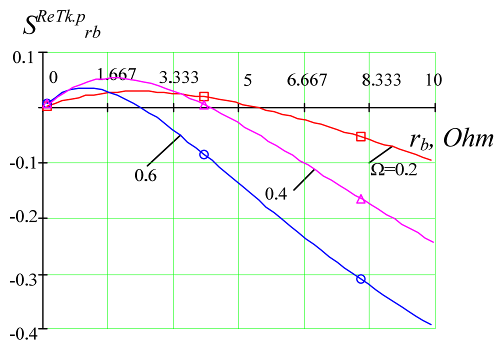
a) b)

Fig. 7. Dependences of sensitivity for the inverse conversion coefficient $T_{c.r}$‘ in the case of real GIC on the basis of UT on resistance R_{b2} of base 2(a); transistor current transfer coefficient β_0 (b) for different reduced frequencies $\Omega=f/f_T$

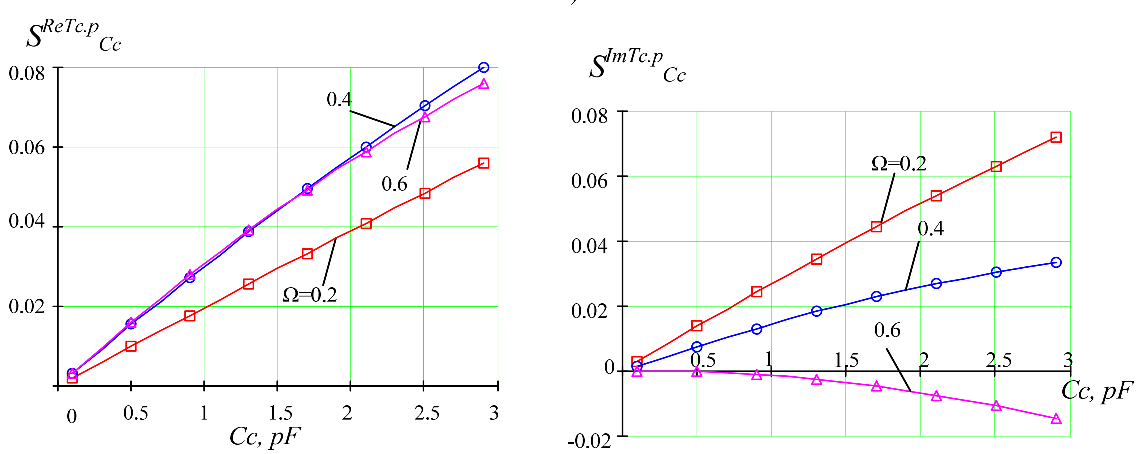
No uniformity is observed in the picture for the inverse conversion coefficient T'_c: numerical values of $S_{Rb2}^{Tk.p}$ are negative (fig.7 a) and decrease with the growth of base 2 resistance R_b.

Transistor current transfer coefficient β_0 (fig. 7 b) does not influence the size of the real part of converter quality and reduces sensitivity in its imaginary part.

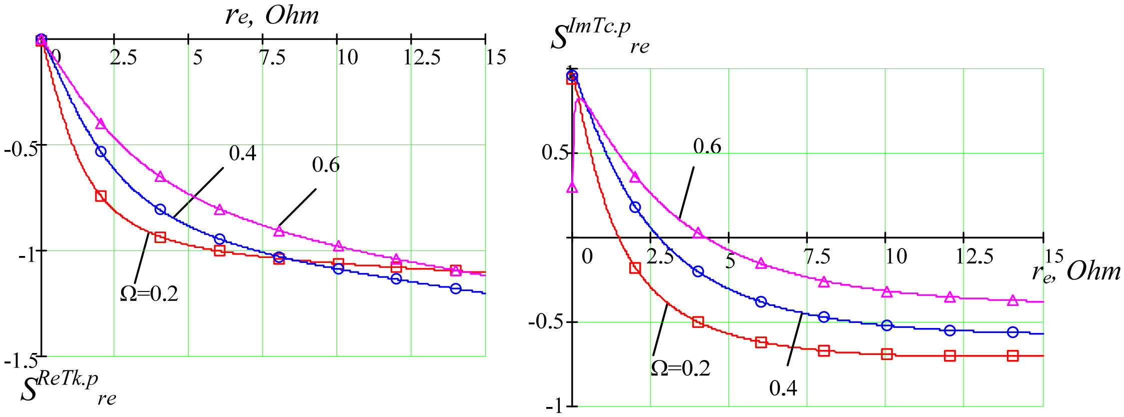
Quality dependences for direct and inverse conversion for real converter on the basis BT are presented in fig. 8 and 9. The plot gives grounds to state that r_b influence on BT transistor has an ambiguous character (fig. 8 a): in the real part the maximal growth is observed when r_b = 0,5 – 1,66 Ohm, then increase of r_b reduces sensitivity, the coefficient having negative values above the value of r_b = 3,33 – 4 Ohm. When the capacity C_c of the collector (fig. 9 b) is growing, it has negative influence on quality. When the reduced frequency increases to Ω = 0,6 reduction of S_{Cc}^{Tk} is observed in the imaginary part and it becomes negative. For all values of the emitter resistance the real part has negative numerical values (fig. 8 c) and descending character. The imaginary part is also descending, but by the value of r_e =2 – 4,5 Ohm (depending on the size of Ω) the quality has positive values and subsequently – negative ones. When α_0 increases, sensitivity (fig. 8 d) has descending character in the real part of the plot and in the imaginary part its growth is observed. Increase of the reduced frequency above Ω=0,4 has no influence on quality.



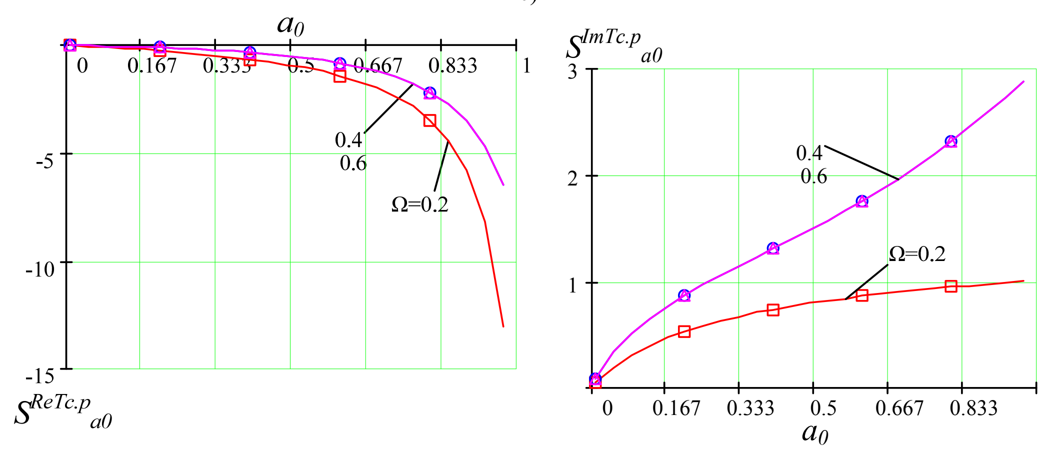
a)



b)

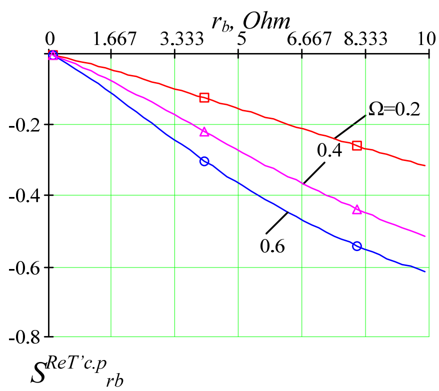


c)

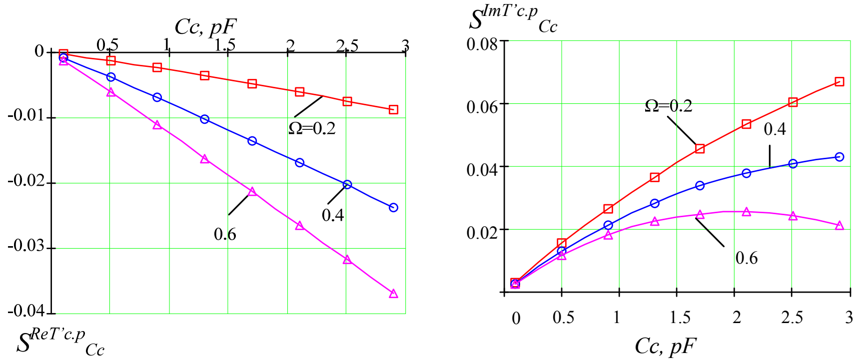


d)

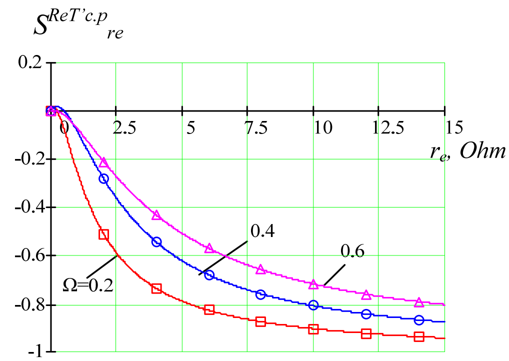
Fig. 8. Dependences of the sensitivity coefficient in the case of direct conversion for real GIC on the basis of BT on the base resistance r_b (a); collector capacitance C_c (b); emitter resistance r_e (c); transistor current transfer coefficient α_0 (d) for different reduced frequencies



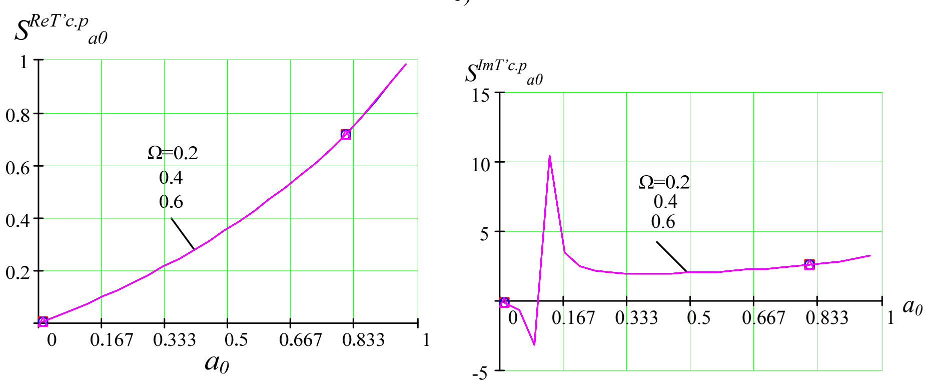
a)



b)



c)



d)

Fig. 9. Dependences of the sensitivity coefficient in the case of inverse conversion for real GIC on the basis of BT on the base resistance r_b (a); collector capacitance C_c (b); emitter resistance r_e (c); transistor current transfer coefficient α_0 (d) for different reduced frequencies

Analysis of the plots of quality dependences on r_b, C_c and r_e (fig. 9 a, b, c) shows that real part $S_{\alpha i}^{Tk}$ decreases with the growth of these parameters, its numerical values are negative and descending with the growth of reduced frequency. Growth of the transistor current transfer coefficient, as it is evident from the plot of the real part (fig. 9 d), increases the converter sensitivity considerably reducing its quality, which has negative influence on its operation that is totally independent from the reduced frequency value. In the imaginary part of the plot 2 extremums are observed – minimum ($S_{\alpha 0}^{Tk}$ = - 3,19) when α_0 = 0,09 and maximum ($S_{\alpha 0}^{Tk}$ = 10,4) when α_0 = 0,13. The increase of α_0 > 0,33 does not influence the quality. Dependences of sensitivity $S_{\alpha i}^{Tk}$ in the cases of direct and inverse conversion for real converter on the main physical parameters of FT circuit are approaching zero (10^{-15}).

Table 1 presents numerical values of the sensitivity coefficient for all cases considered above.

Table 1

Quality dependence on different parameters of the physical structure of immitance converters at frequency Ω=0,2

Direct conversion mode					
UT		BT		FT	
Ideal	Real	Ideal	Real	Ideal	Real
		$S^{Re\ Tk}_{Rb}=0.013$ $S^{Im\ Tk}_{Rb}=-0.0081$	$S^{Re\ Tk}_{Rb}=-0{,}019$ $S^{Im\ Tk}_{Rb}=-0{,}36$	$S^{Re\ Tk}_{Ri}=-2$ $S^{Im\ Tk}_{Ri}=-1$	$S^{Re\ Tk}_{Ri}=-2$ $S^{Im\ Tk}_{Ri}=-1$
$S^{Im\ Tk}_{Rb2}=1$	$S^{Re\ Tk}_{Rb2}=-0{,}0005$ $S^{Im\ Tk}_{Rb2}=-0{,}0005$	$S^{Re\ Tk}_{Ck}=0.016$ $S^{Im\ Tk}_{Ck}=0.038$	$S^{Re\ Tk}_{Ck}=0.024$ $S^{Im\ Tk}_{Ck}=0.032$	$S^{Re\ Tk}_{omegas}=-2$ $S^{Im\ Tk}_{omegasi}=-1$	$S^{Re\ Tk}_{omegas}=-2$ $S^{Im\ Tk}_{Ci}=-1$
	$S^{Im\ Tk}_{Cb1}=-2{,}294$	$S^{Re\ Tk}_{Rem}=0.0044$ $S^{Im\ Tk}_{Rem}=0.046$	$S^{Re\ Tk}_{Rem}=-0.98$ $S^{Im\ Tk}_{Rem}=-0.57$	$S^{Re\ Tk}_{s0}=-2$ $S^{Im\ Tk}_{s0}=-1$	$S^{Re\ Tk}_{s0}=-2$ $S^{Im\ Tk}_{s0}=-1$
$S^{Re\ Tk}_{\beta0}=1.93$ $S^{Im\ Tk}_{\beta0}=-0.37$		$S^{Re\ Tk}_{a0}=-18.42$ $S^{Im\ Tk}_{a0}=1{,}013$	$S^{Re\ Tk}_{a0}=-7.514$ $S^{Im\ Tk}_{a0}=2.943$		
Inverse conversion mode					
UT		BT		FT	
Ideal	REal	Ideal	Real	Ideal	Real
		$S^{Re\ Tk}_{Rb}=0.014$ $S^{Im\ Tk}_{Rb}=-0.008$	$S^{Re\ Tk}_{Rb}=-0.206$ $S^{Im\ Tk}_{Rb}=0.794$	$S^{Im\ Tk}_{Ri}=1$	$S^{Im\ Tk}_{Ri}=1$
$S^{Re\ Tk}_{Rb2}=-1$ $S^{Im\ Tk}_{Rb2}=-1$	$S^{Re\ Tk}_{Rb2}=-0{,}99$ $S^{Im\ Tk}_{Rb2}=-0{,}99$	$S^{Re\ Tk}_{Ck}=-0.043$ $S^{Im\ Tk}_{Ck}=-0.022$	$S^{Re\ Tk}_{Ck}=-0{,}003$ $S^{Im\ Tk}_{Ck}=0{,}034$	$S^{Im\ Tk}_{omegas}=1$	$S^{Im\ Tk}_{omegas}=1$
		$S^{Re\ Tk}_{Rem}=-0{,}057$ $S^{Im\ Tk}_{Rem}=-0.016$	$S^{Re\ Tk}_{Rem}=-0.79$ $S^{Im\ Tk}_{Rem}=-1.96$	$S^{Re\ Tk}_{s0}=0$ $S^{Im\ Tk}_{s0}=1$	$S^{Re\ Tk}_{s0}=0$ $S^{Im\ Tk}_{s0}=1$
		$S^{Re\ Tk}_{a0}=-17{,}732$ $S^{Im\ Tk}_{a0}=1{,}629$	$S^{Re\ Tk}_{a0}=0.983$ $S^{Im\ Tk}_{a0}=3.1$		

The lowest sensitivity and, therefore, the highest quality are observed for the ideal converter on the basis of BT connected in the common-collector circuit for both direct conversion ($S_{\alpha 0}{}^{Tk}$ = - 18,43) and inverse conversion ($S_{\alpha 0}{}^{Tk}$ = - 17,732). The lowest quality is observed for the ideal converter on the basis of UT connected in the common-base circuit for direct conversion T_c ($S_{\beta 0}{}^{Tk}$ = 1,93) and for both types of converters on the basis of FT connected in the common-drain circuit for both direct and inverse conversion for all parameters $S_{\alpha i}{}^{Tk}$ = 1.

Conclusions

For the ideal converter on the basis of UT the lowest quality ($S_{Rb2}{}^{T'k}$ = - 1) is observed for the inverse conversion in the common-base circuit. For real converter on the basis of UT the lowest quality ($S_{Rb2}{}^{Tk}$ = - 0,99) is observed for the inverse conversion coefficient. Therefore, by increasing the value of base 2 resistance parameter (R_{b2}), the quality of one-crystal converter on the basis of UT can be increased.

For the ideal converter on the basis of BT the lowest sensitivity is observed both for direct conversion ($S_{\alpha 0}{}^{Tk}$ = - 18,43) and for inverse conversion ($S_{\alpha 0}{}^{T'k}$ = - 17,732) in the common-collector circuit. For real converter on the basis of BT the highest quality is observed ($S_{\alpha 0}{}^{Tk}$ = - 0,98) in the case of direct conversion. Increasing the value of the transistor current transfer coefficient α_0, the quality of one-crystal converter on the basis of BT could be improved.

Both for the ideal and real converters on the basis of FT the lowest quality ($S_{\alpha i}{}^{Tk}$ = - 2) is observed in the case of direct conversion for all parameters in the circuit.

REFERENCES

1. Филановский Н. М. Схемы с преобразователями сопротивления / Н. М. Филановский, А. Ю. Персианов, В. К. Рыбин– Л.: Энергия, 1973, – 192 с.

2. Узагальнені перетворювачі іммітансу на основі інжекційно-пролітної транзисторної структури із загальним витоком [Електронний ресурс] / Ліщинська Л. Б., Булига Н. В., Шведюк А. Г., Філинюк М. А. //

Наукові праці Вінницького національного технічного університету. – №2: 2008, Режим доступу до журн.: http://www.nbuv.gov.ua/e-journals/VNTU/2008-2/2008-2.files/uk/08lblsts_uk.pdf

3. Радзевич В. Д. Проектирование СВЧ устройств с помощью Microwave office / В. Д. Радзевич, Ю. В. Потапов, А. А. Кукушин; под ред. В. Д. Радзевича. – М.: САЛОН- Пресс, 2003, – 496 с.

4. Філинюк М. А. Інформаційні пристрої на основі потенційно-нестійких структур Шотткі. / М. А. Філинюк, О. М. Куземко, Л. Б. Ліщинська – Вінниця, ВНТУ, 2009, – 274 с.

5. Філинюк М. А. Метрологічні основи негатроніки / М. А. Філинюк, Д. В. Гаврілов – Вінниця: УНІВЕРСУМ – Вінниця, 2006, – 188 с.

6. Сигорский В. П. Алгоритмы анализа электронных схем / В. П. Сигорский, А. И. Петренко – М.: Советское радио, 1976, – 608 с.

7. Філинюк М. А. Основи негатроніки. Том І. Теоретичні і фізичні основи негатроніки / М. А. Філинюк – Вінниця: УНІВЕРСУМ – Вінниця, 2009, – 274 с.

Ludmila Lyschinska – Cand. Sc. (Eng.), Assoc. Prof. of Vinnytsia Institute of Trade and Economics, e-mail: L_Fil1@mail.ru.

Yana Rozhkova – Student of Vinnytsia National Technical University, e-mail: rozhkova.yana@gmail.com.

Mykola Filiniuk – Dc. Sc. (Eng.), Prof., e-mail: Filinyuk@vstu.vinnica.ua.
Vinnytsia National Technical University.