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GENERALIZED CONVETERS OF IMMITTANCE ON THE BASIS OF INJECTION-TRANSIT TIME GROUNDED SOURCE TRANSISTOR STRUCTURE

Properties of injection-flight transistor structure with a general source are analysed as the generalized transformer of immittance, the tables of transformation of immittance are got

Keywords: *injection-flight transistor structure, generalized transformer of immittance*

Introduction

Injection-transit-time transistor structure (ITTT-structure) consists of semiconductor crystal usually of n type conduction with ohmic contacts on the edges. One of them performs the role of «source», another – «drain». Between the contacts p-n or m-n junction, that performs, depending on voltage polarity either the role of gate or emitter is formed [1]. Commercially available fields effect transistors (FET) and unijunction transistors possess such structure. As a rule their switching and amplifying properties find wide application . In [2] the possibility of usage of field effect transistor as the generalized converter of immittance (GCI), that is inherent for ITTT-structure operating at closed p-n transition.

Unlocking of p-n junction causes the change of properties of such GCI and extends functional possibilities of application of ITTT-structure. Proceeding from the above-mentioned, the aim of the given research is to study the properties of GCI based on ITTT-structure of included with general by a source in the mode of both direct ($U_E>0$) and reverse ($U_E<0$) mixing of emitter transition.

Development of conversion tables of immittance GTI_S

The formal mathematical models of ITTT-structures developed in [3,4] for the modes of direct and reverse bias enable to study GCI parameters on this basis. The elaboration of immittance conversion tables, needed for synthesis of information devices , and analysis of dependence of operating parameters of GCI in the range of frequencies and converted immittances is of great practical interest. In order to simplify the analysis we will proceed from the fact, that in reverse bias mode ITTT-structure operates as field-effect transistor (FET) and its parameters in $GCI_S^{(-)}$ mode are similar to parameters considered in [2]. Hence, the attention will be paid to direct bias mode($GTI_S^{(+)}$). To simplify the analysis procedure let us assume that ITTT-structure operates in the mode of high level of injection in active region.

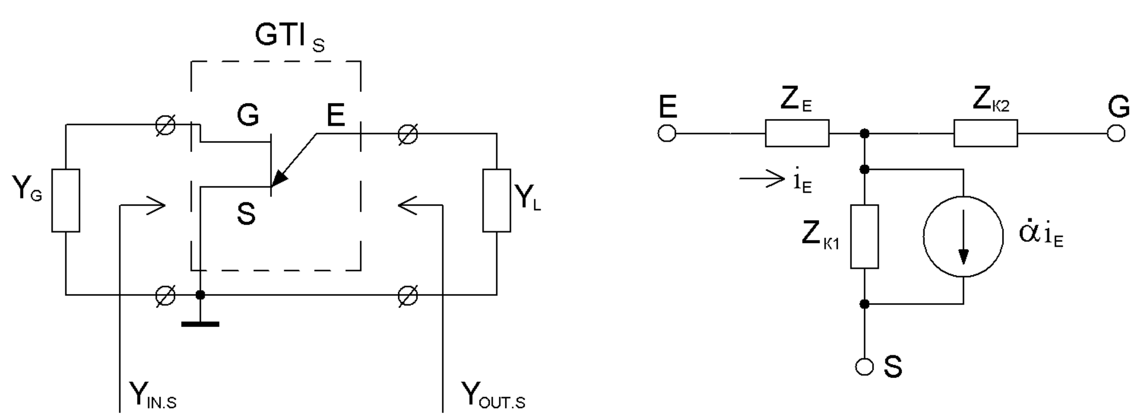


Fig. 1. GCI on the basis of ITTT-structure (a) and its physical equivalent circuit (b) in the mode of direct bias of

emitter junction

Using physical equivalent circuit of ITTT-structure (Fig. 1) connected to common source, matrix of conductivity $GTI_S^{(+)}$, on its basis we will write as

$$[Y_{11}] = \begin{bmatrix} Y_{11}^{S} & Y_{12}^{S} \\ Y_{21}^{S} & Y_{22}^{S} \end{bmatrix} = \begin{bmatrix} \dfrac{Z_{\kappa 2} + Z_{\kappa 1}}{\Delta Z} & -\dfrac{Z_{\kappa 1}}{\Delta Z} \\ -\dfrac{Z_{\kappa 1}(1-\dot{\alpha})}{\Delta Z} & \dfrac{Z_{E} + Z_{\kappa 1}(1-\dot{\alpha})}{\Delta Z} \end{bmatrix}, \tag{1}$$

where: Z_{K1} and Z_{K2} are channel impedors from the source to the emitter and from the emitter to the flow, accordingly; Z_E is the impedor of emitter junction; $\dot{\alpha}$ - current transfer ratio.

$$\Delta Z = Z_E Z_{\kappa 2} + Z_{\kappa 1}[Z_E + Z_{\kappa 2}(1-\dot{\alpha})].$$

Taking into account the above -mentioned assumptions, the determinant of this matrix equals

$$\Delta Y = \frac{Z_{\kappa 2} - Z_{\kappa 1}}{Z_{\kappa 1} Z^{2}{}_{\kappa 2}(1-\dot{\alpha})}.$$

The condition Z_{K1} ${}_i$mplemented → Z_{K2} we obtain Δ_{Y0}. If loading $GCI_S^{(+)}$ is chosen from the condition $Y_L << Y_{22}{}^S$, the examined quadripole, in case of implementation of the above-mentioned terms, will possess properties of the generalized converter of immittance with the coefficient of conversion of T_I, defined by the expresion [2]

$$T_I = \frac{Y_{11}^{S}}{Y_{22}^{S}}. \tag{2}$$

Substituting the elements of matrix (1) into (2), we find

$$T_I = \frac{Y_{IN.S}}{Y_L} = \frac{Y_{11}^{S}}{Y_{22}^{S}} = \frac{Z_{\kappa 1} + Z_{\kappa 2}}{Z_E + Z_{\kappa 1}(1-\dot{\alpha})}. \tag{3}$$

In the mode of high level of injection $Z_E \to 0$. Taking into account that $Z_{K1} \approx 1/j\cdot\omega\cdot C_{K1}$, and $Z_{K2}=R_{B2}$ and $\omega_\alpha C_{K1} R_{B2} << 1$, using single-band approximation for $\acute{\alpha} = \alpha 0 / (1+j\Omega)$, valid on frequencies of $\omega < 0,5\omega_\alpha$, where $\Omega_\alpha = f/f_\alpha$ and $\Omega^2 << 1$, the coefficient (3) of direct conversion of conductivity $GTI_S^{(+)}$ will be equal to

$$T_I = \frac{1-\alpha_0 - j\Omega_\alpha \alpha_0}{(1-\alpha_0)^2}. \tag{4}$$

Coefficient $T_C^{'}$ of reverse conversion of conductivity $GCI_S^{(+)}$ in this case equals

$$T_C^{(')} = \frac{\mathrm{Y_{IN.S}}}{\mathrm{Y_G}} = \frac{\mathrm{Y_{22}^S}}{\mathrm{Y_{11}^S}} = \frac{(1-\alpha_0)^2}{1-\alpha_0 - j\Omega_\alpha \alpha_0}\,. \qquad (5)$$

We will consider the results of direct and reverse conversion of immittance of elementary R,L,C - elements.

Mode of direct conversion of immittance

In the mode of direct conversion of immittance of $\mathrm{Y_{L\ conductivity}}$, the input $\mathrm{Y_{IN.S}}$ converted conductivity $\mathrm{GTI_S^{(+)}}$ is equal to

$$Y_{IN.S} = T_C^{S(')} \cdot Y_L\,. \qquad (6)$$

In case when $Y_L = 1/R_G$, after substitution of (4) into (6), we find

$$Y_{IN.S}(R_G) = \frac{1-\alpha_0 - j\Omega\alpha_0}{(1-\alpha_0)^2 R_L} = \frac{1}{(1-\alpha_0)R_L} - j\frac{\Omega\alpha_0}{(1-\alpha_0)^2 R_L}\,. \qquad (7)$$

The analysis (7) shows that the reactive constituent of converted conductivity is of the inductive character and is described by inductance

$$L_{IN.S}(R_L) = \frac{(1-\alpha_0)^2 R_L}{\omega\Omega\alpha_0}\,. \qquad (8)$$

Character of the active constituent of converted conductivity depends on the value of α_0.

When $\alpha_0 > 1$, the active constituent of converted conductivity is negative (10).

In the mode, when $\alpha_0 < 1$, the active constituent of converted conductivity is positive

$$\mathrm{Re}\,Y_{IN.S}(R_L) = \frac{1}{(1-\alpha_0)R_L} = \frac{1}{R_{IN.S}^{(-)}} < 0,$$

where $R_{IN.S}^{(-)}(R_L) = -(\alpha_0 - 1)R_L$.

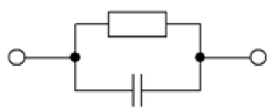
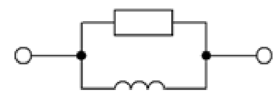
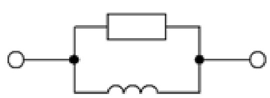
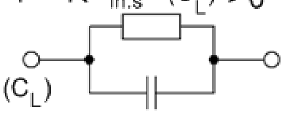
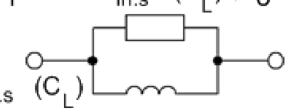
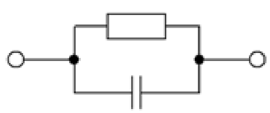
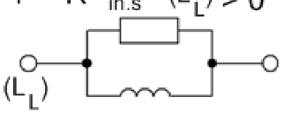
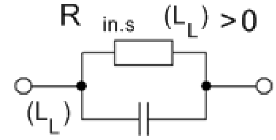
Thus, the result of direct conversion of active resistance R_L by means of $\mathrm{GCI_S^{(+)}}$ can be presented in Table 1.

The analysis of the results obtained shows that in the considered mode by means $\mathrm{GCI_S^{(+)}}$ conversion of active resistance into inductance can be provided. Thus, when $\alpha_0 > 1$, active constituent of converted conductivity is negative, that extends functional possibilities of such $\mathrm{GCI_S^{(+)}}$, but imposes the problem of evaluation of stability of information facilities constructed on their basis.

Correctness of the results obtained indirectly confirms the analysis of nonlinear input VAC of ITTT-structure at direct bias of emitter junction, which is similar to input VAC of injunction transistor (UT) and is S-shaped. In accordance with the theorem of connection of VAC shape with the character of reactivity, [5] it must be inductive, that coincides with the results obtained.

Table 1

Table of direct transformation of GTI$_s$ immittance

Transformed immittance $W_{in.s}$ for $GTI_s^{(-)}$	Transformed immittance W_L	Transformed immittance $W_{in.s}$ for $GTI_s^{(-)}$
$R_{in.s}(R_L) > 0$  $C_{in.s}(R_L)$	R_L 	$R_{in.s}(R_L) > 0$ if $\alpha_0 < 1$ $R_{in.s}(R_L) < 0$ if $\alpha_0 > 1$  $L_{in.s}(R_L)$
$R_{in.s}(C_L) > 0$  $L_{in.s}(C_L)$	C_L 	if $\alpha < 1$ $R_{in.s}(C_L) > 0$  $C_{in.s}(C_L)$ — if $\alpha_0 > 1$ $R_{in.s}(C_L) > 0$  $L_{in.s}(C_L)$
$R_{in.s}(L_L) < 0$  $C_{in.s}(L_L)$	L_L 	if $\alpha < 1$ $R_{in.s}(L_L) > 0$  $L_{in.s}(L_L)$ — if $\alpha_0 > 1$ $R_{in.s}(L_L) > 0$  $C_{in.s}(L_L)$

In case of direct conversion of capacity conduction $Y_L = j\omega C_L$, using (5) and (6), we find

$$Y_{IN.S}(C_G) = \frac{(1-\alpha_0 - j\Omega\alpha_0)\,j\omega C_L}{(1-\alpha_0)^2} = \frac{\Omega\alpha_0\omega C_L}{(1-\alpha_0)^2} + \frac{j\omega C_L}{(1-\alpha_0)}. \tag{9}$$

The analysis (9) shows that in the examined range of frequencies the active constituent of converted conduction is positive

$$\mathrm{Re}\,Y_{IN.S}(C_G) = \frac{\Omega\alpha_0\omega C_L}{(1-\alpha_0)^2} = \frac{1}{R_{IN.S}(C_L)}.$$

It follows

$$R_{IN.S}(C_L)=\frac{(1-\alpha_0)^2}{\Omega\alpha_0\omega C_L}.$$

The character of reactive constituent of converted conduction depends on the value α_0.

When $\alpha_0 > 1$, the reactive constituent of converted conduction is of inductive character

$$\operatorname{Im}Y_{IN.S}(C_L)=\frac{-\omega C_l}{(\alpha_0-1)}=\frac{1}{\omega L_{IN.S}(C_L)},$$

with inductance

$$L_{IN.S}(C_L)=\frac{\alpha_0-1}{\omega^2 C_L}.$$

In the mode, when $\alpha_0 < 1$, the reactive constituent of converted conduction is of capacitance character

$$\operatorname{Im}Y_{IN.S}(C_G)=\frac{\omega C_L}{(1-\alpha_0)}=\omega C_{IN.S},$$

where $C_{IN.S}=\frac{C_L}{1-\alpha_0}$.

Thus, result of direct conversion of reactive conduction of the capacity C_L by means of $GCI_S^{(+)}$ can be presented in Table 1.

From practical point of view it should be noted that in case of direct conversion of capacity immittance, the converted immittance in the whole range of frequencies has positive real component $R_{IN.S}(C_L) > 0$, and imaginary component ,if $\alpha_0 > 1$, is of inductive character, and in the mode, when $\alpha_0 < 1$ it is of capacitance character .

In case of direct conversion of inductive conduction $Y_L=\frac{1}{j\omega L_L}$, using (5) and (6), we find

$$Y_{IN.S}(L_L)=\frac{1-\alpha_0-j\Omega\alpha_0}{(1-\alpha_0)^2 j\omega L_L}=\frac{-\alpha_0}{\omega_\alpha L_L}-j\frac{1}{(1-\alpha_0)\omega L_L}. \tag{10}$$

The analysis (10) shows that unlike the above- considered case of direct conversion by means of $GCI_S^{(+)}$ of capacity conduction, at direct conversion of inductive conduction the active constituent of converted conduction in the range of frequencies is negative

$$\operatorname{Re}Y_{IN.S}(L_L)=\frac{1}{R_{IN.S}(L_L)}<0\text{, where}$$

$$R_{IN.S}(L_L) = -\frac{\omega_\alpha L_L}{\alpha_0}$$

The character of reactive constituent of converted conduction depends on the value α_0.

In the mode, when α_0 > 1, the reactive constituent of converted conduction is of capacitance character

$$\operatorname{Im} Y_{IN.S}(L_L) = \frac{1}{(1-\alpha_0)\omega L_L} = \omega C_{IN.S}(L_L),$$

where $C_{IN.S}(L_l) = \dfrac{1}{(\alpha_0 - 1)\omega^2 L_L}$.

In the mode, when α_0 < 1, the reactive constituent of converted conduction is of inductive character

$$\operatorname{Im} Y_{IN.S}(L_l) = -\frac{1}{(1-\alpha_0)\omega L_L} = -\frac{1}{\omega L_{IN.S}(L_L)},$$

where $L_{IN.S}(L_L) = (1-\alpha_0)\omega^2 L_L$.

Thus, the result of direct conversion of L_L with the help $GCI_S^{(+)}$ can be presented in Table 1.

From practical point of view we should pay attention to the fact that at direct conversion of inductive immittance, the converted immittance in the examined range of frequencies has a negative real constituent $R_{IN.S}(L_L)$ < 0, that extends functional possibilities of $GCI_S^{(+)}$ in this mode. Imaginary component at α_0 > 1 is of capacitance character, and in the mode, when α_0 < 1 has inductive character.

Mode conversion of immittance

In the mode of reverse conversion of conductivity Y_G output $Y_{OUT.S}$ converted conductivity of $GCI_S^{(+)}$ equals

$$Y_{OUT.S} = T_I^{(')} \cdot Y_G. \tag{11}$$

After substitution of (5) into (11), we find

$$Y_{OUT.S}(Y_G) = \frac{(1-\alpha_0)^2 Y_G}{1-\alpha_0 - j\Omega\alpha_0} = \frac{1}{Z_{OUT.S}},$$

where

$$Z_{OUT.S} = \frac{1-\alpha_0 - j\Omega\alpha_0}{(1-\alpha_0)^2} Z_G; \tag{12}$$

$$Z_G = \frac{1}{Y_G}.$$

In case when $Z_G = R_G$, from (12), we find

$$Z_{OUT.S}(R_G) = \frac{1-\alpha_0 - j\Omega\alpha_0}{(1-\alpha_0)^2} R_G = \frac{R_G}{1-\alpha_0} - j\frac{\Omega\alpha_0 R_G}{(1-\alpha_0)^2}. \quad (13)$$

The analysis (13) shows that reactive constituent of converted resistance in the examined range is of capacitance character and is described by capacitance

$$C_{OUT.S}(R_G) = \frac{(1-\alpha_0)^2}{\omega\Omega\alpha_0 R_G}. \quad (14)$$

Character of active constituent of converted resistance depends on the value α_0.

When $\alpha_0 > 1$, the active constituent of converted resistance is negative

$$\operatorname{Re} Y_{OUT.S}(R_G) = R^{(-)}_{OUT.S}(R_G) = -\frac{R_G}{\alpha_0 - 1} < 0.$$

In the mode, when $\alpha_0 < 1$, the active constituent of converted resistance is positive

$$\operatorname{Re} Y_{OUT.S}(R_G) = R^{(+)}_{OUT.S}(R_G) = \frac{R_G}{1-\alpha_0}.$$

Thus, result of reverse transformation of active resistance R_G with the help $GCI_S^{(+)}$ can be presented in Table 2.

The analysis of the results obtained shows that in the considered mode with the help of $GCI_S^{(+)}$ the transformation of active resistance into capacitive reactance can be provided. In the mode, when $\alpha_0 > 1$ the active constituent of transformed resistance will be negative.

Correctness of the results obtained confirms the analysis of nonlinear output VAC of ITTT-structure which at direct bias of emitter junction is similar to output VAC of UT, which has N-shaped form. And in accordance with a theorem of connection of VAC type with the character of negatron reactivity [5], for the negatron of N-type, the character of reactivity must be capacitance, that coincides with the results obtained.

In case of reverse transformation of capacitive reactance $Z_G = 1/j\omega C_G$, using (12) we find

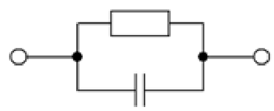
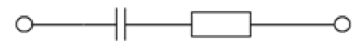
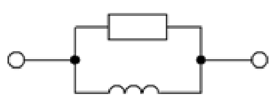
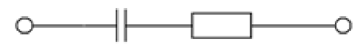
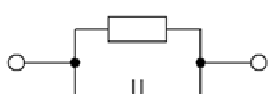
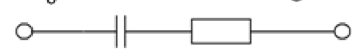
$$Z_{OUT.S}(C_G) = \frac{1-\alpha_0 - j\Omega\alpha_0}{(1-\alpha_0)^2\, j\omega C_G}. \quad (15)$$

The analysis (15) shows that in the examined range of frequencies the active constituent of converted resistance is negative

$$\mathrm{Re}\, Z_{OUT.S}(C_G) = R_{OUT.S}(C_G) = -\frac{\Omega\alpha_0}{\omega C_G}.$$

Table 2

Table of reverse transformation of GTI_s immittance

Transformed immittance $W_{out.s}$ for $GTI_s^{(-)}$	Transformed immittance W_G	Transformed immittance $W_{out.s}$ for $GTI_s^{(+)}$
$R_{out.s}(R_G) > 0$  $C_{out.s}(R_G)$	R_G 	$R_{out.s}(R_G) > 0$ if $\alpha_0 < 1$ $R_{out.s}(R_G) < 0$ if $\alpha_0 > 1$  $C_{out.s}(R_G)$
$R_{out.s}(C_G) > 0$  $L_{out.s}(C_G)$	C_G 	if $\alpha < 1$ $R_{out.s}(C_G) < 0$  $C_{out.s}(C_G)$ if $\alpha_0 > 1$ $R_{out.s}(C_G) < 0$  $L_{out.s}(C_G)$
$R_{out.s}(L_G) < 0$  $C_{out.s}(L_G)$	L_G 	if $\alpha < 1$ $R_{out.s}(L_G) > 0$  $L_{out.s}(L_G)$ if $\alpha_0 > 1$ $R_{out.s}(L_G) > 0$  $C_{out.s}(L_G)$

Character of reactive constituent of converted resistance

$$\mathrm{Im}\, Z_{OUT.S}(C_G) = \frac{1}{(1-\alpha_0)\, j\omega C_G} \tag{16}$$

depends on the value of α_0.

In the mode, when $\alpha_0 < 1$, reactive constituent $\mathrm{Im}\, Z_{OUT.S}(C_G) < 0$, i.e. is of capacitive character, capacitance value being

$$C_{OUT.S}(C_G) = C_G(1-\alpha_0).$$

Thus, the result of reverse transformation of reactance of the capacity C_G by means of $GCI_S^{(+)}$

can be presented in Table 2.

From practical point of view the attention should be paid to the fact that at reverse transformation of capacity resistance, converted resistance in examined range of frequencies has a negative real constituent $\operatorname{Re} Z_{\text{OUT.S}}(C_G) = R_{\text{OUT.S}}(C_G) < 0$, that extends functional possibilities of $\text{GTI}_\text{S}^{(+)}$ in this mode. Imaginary component of converted resistance at $\alpha_0 > 1$ has inductive character, and at $\alpha_0 < 1$ has capacitance character and corresponds to properties of classic generalized converter of immittance.

In case of reverse transformation of inductive resistance $Z_\text{G} = j\omega L_\text{G}$, using (12) we find

$$Z_{OUT.S}(L_\text{G}) = \frac{(1-\alpha_0 - j\Omega\alpha_0)\, j\omega L_\text{G}}{(1-\alpha_0)^2}. \tag{17}$$

The analysis (17) shows that in the examined range of frequencies the active component of converted resistance is positive

$$\operatorname{Re} Z_{OUT.S}(L_G) = R_{OUT.S}(L_G) = \frac{L_\text{G}\omega\Omega\alpha_0}{(1-\alpha_0)^2}.$$

Character of reactive component of converted resistance

$$\operatorname{Im} Z_{OUT.S}(L_\text{G}) = \frac{\omega L_\text{G}}{1 - \alpha_0} \tag{18}$$

depends on the value of α_0.

In the mode, when $\alpha_0 > 1$, reactive component $\operatorname{Im} Z_{\text{OUT.S}}(L_G) < 0$, i.e. has capacitance character, capacitance value being

$$C_{OUT.S}(L_\text{G}) = \frac{\alpha_0 - 1}{\omega^2 L_\text{G}}.$$

In the mode, when $\alpha_0 < 1$, reactive componentt $\operatorname{Im} Z_{\text{OUT.S}}(L_G) > 0$, i.e. has inductive character, value of inductance being

$$L_{OUT.S}(L_\text{G}) = \frac{L_\text{G}}{(1 - \alpha_0)}.$$

Thus, the result of reverse transformation of inductance reactance of L_G with the help of $\text{GCI}_\text{S}^{(+)}$ can be presented in Table 2.

From the practical point of view the attention should be paid to the fact that at reverse transformation of inductive immittance, converted resistance in the examined range of frequencies has a positive real component $R_{\text{OUT.S}}(L_G)$, and imaginary component of transformed resistance at $\alpha_0 > 1$ has capacitance character, and at $\alpha_0 < 1$ has inductive character.

Comparative analysis of transformation properties of GCI$_S$ in the modes of direct and reverse bias of emitter junction of ITTT-structure .

Taking into account that in case reverse bias of emitter junction of ITTT-structure it corresponds by its properties to FET, generalized transformer GTI$_S^{(-)}$ on the base of ITTT-structure will possess similar transformation properties the generalized results of which are presented in Tables. 1, 2 [2].

In the same Tables the results of previous analysis of GTI$_S^{(+)}$ transformation properties are presented

The comparative analysis of Tables 1 and 2 shows that in case of reverse bias of emitter junction the ITTT-structure connected in the circuit with general source (GTI$_S^{(-)}$), it possesses the properties of immittance inverter. Negative real immittance will be realized only in cases of transformation of immittance inductance L.

At direct bias of emitter junction of ITTT-structure connected in circuit with general source (GTI$_S^{(+)}$), in the mode of direct transformation of immittance W_L, when the transformed immittance is active $(W_L = R_L)$, the input immittance W_{IN} is inductive, that allows to use such mode for creation of transistors equivalents of inductance. It should be noted, that at low frequencies, where $\frac{\alpha_0}{1+\Omega^2} > 1$, the active component of the transformed immittance $R_{IN.S}(R_L)$ is negative, and at high-frequencies, where $\frac{\alpha_0}{1+\Omega^2} < 1$ it is positive. Limiting frequency of sign change of $R_{IN.S}(R_L)$ will be equal

$$f_B = f_0\sqrt{\alpha_0 - 1}. \tag{19}$$

The same frequency determines properties of GCI$_S^{(+)}$ at transformation of reactive immittances.

At low frequencies $f < f_{bor}$ at transformation of both capacitive (C_L), and inductive (L_L) immittances GCI$_S^{(+)}$ possesses properties of immittance inverter. At high-frequencies $f > f_{bor}$ – properties of immittance converter. The negative value of active component of the transformed immittance is observed both at low and at high-frequencies, but only in the case of transformation of inductive immittance.

In case of reverse transformation of immittance (Table 2) in the mode of the reverse bias of emitter junction, GCI$_S^{(-)}$ possesses similar properties, as well as in the mode of direct transformation of immittance.

At direct bias of emitter junction, when the transformed immittance is active $(W_L = R_L)$, output immittance W_{OUT} is capacitive with negative active component at low frequencies ($f < f_{bor}$).

At reverse transformation of both capacitive (C_L), and inductive (L_L) immittance, CCI$_S^{(+)}$ possesses properties of immittance inverter , and at high-frequencies ($f > f_{bor}$) – properties of immittance converter. The negative value of active component of converted immittance is observed both at high-frequencies and at low frequencies, but only in case of transformation of inductive immittance.

Research of GTI$_S$

The results obtained provide the functional synthesis of information devices by means of using the conversion Tables of different types of immittance parameters. However, the obtained formulas for the coefficients of immittance transformation are approximate and can not be used in engineering calculations.In order to obtain more exact calculations, we will transform expressions for input W$_{IN}$ and output W$_{OUT}$ immittances of quadripole, expressed by parameters of its immittance W-matrix [6]. We find as a result:

1. For the mode of direct transformation of immittance of W_L:

$$\operatorname{Re} W_{IN} = \frac{\operatorname{Re}(\Delta + W_{11}W_L)\operatorname{Re}(W_{22}+W_L) + \operatorname{Im}(\Delta + W_{11}W_L)\operatorname{Im}(W_{22}+W_L)}{\operatorname{Re}^2(W_{22}+W_L) + \operatorname{Im}^2(W_{22}+W_L)}; \tag{20}$$

$$\operatorname{Im} W_{IN} = \frac{\operatorname{Im}(\Delta + W_{11}W_L)\operatorname{Re}(W_{22}+W_L) - \operatorname{Re}(\Delta + W_{11}W_L)\operatorname{Im}(W_{22}+W_L)}{\operatorname{Re}^2(W_{22}+W_L) + \operatorname{Im}^2(W_{22}+W_L)}. \tag{21}$$

2. For the mode of reverse transformation of immittance of W_G:

$$\operatorname{Re} W_{OUT} = \frac{\operatorname{Re}(\Delta + W_{22}W_G)\operatorname{Re}(W_{11}+W_G) + \operatorname{Im}(\Delta + W_{22}W_G)\operatorname{Im}(W_{11}+W_G)}{\operatorname{Re}^2(W_{11}+W_G) + \operatorname{Im}^2(W_{11}+W_G)}; \tag{22}$$

$$\operatorname{Im} W_{OUT} = \frac{\operatorname{Im}(\Delta + W_{22}W_G)\operatorname{Re}(W_{11}+W_G) - \operatorname{Re}(\Delta + W_{22}W_G)\operatorname{Im}(W_{11}+W_G)}{\operatorname{Re}^2(W_{11}+W_G) + \operatorname{Im}^2(W_{11}+W_G)}. \tag{23}$$

The obtained formulas are valid for the calculation of any variant of transformation of immittance by ITTT-structure if lowsignal values of its immittance W- parameters are used. Taking into account that in the mode of the reverse bias of emitterjunction such calculations and verifications of their adequacy are performed in [2], we will carry out the research for the mode of direct bias of emitter junction of ITTT-structure.

As the real ITTT-structure we use UT of KT-117A type, having the following parameters [7]: f_α = 300 Mhz, $R_{K2} = 10^3$ Ohm, $C_{K1} = 10^{-10}$ F, I_E = 10 mA.. Value of α_0, depending on emitter current changes within the limits of 0,5-4 ut.

We will perform analytical estimation of dependence of converted immittance on the frequency and values of parameters of the examined ITTT-structure.

In case of direct transformation of immittance $Y_L = 1/R_L$ using $GTI_S^{(+)}$, generalized results are shown in Fig. 2. Comparing them with the data of Table 1 we see, that to frequency, where $\operatorname{Re}Y_{IN.S} < 0$ and $\operatorname{Im}Y_{IN.S} < 0$, the obtained dependences completely correspond to the conversion Table. Expansion of frequency range is possibly due to reduction of active resistance R_{K2} of the passive region of the channel, capacitance C_{K1} of active region of the channel and increase of low frequency value of current transfer ratio α_0. The character of influence on the transformed immittance of the $Y_{IN.S}$ parameters of ITTT-structure are carried out by means of numerical experiment using of the program of AWR Design Environment and are presented in Fig. 2.

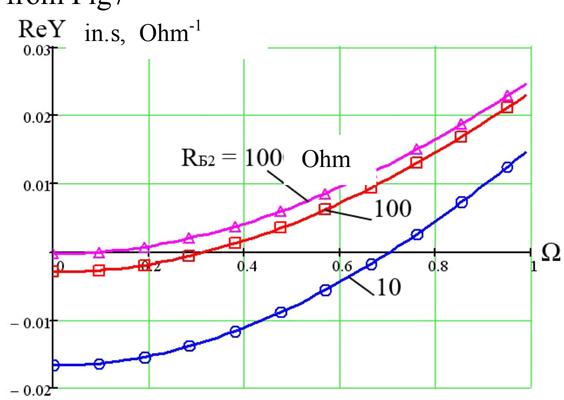
In case of direct transformation of immittance with the help of $GCI_S^{(+)}$ $Y_H = j\omega C_H$, the results of calculations are presented in Fig. 3. Comparing them the data of the Table 1 we see, that $\operatorname{Re}Y_{IN.S} > 0$ and $\operatorname{Im}Y_{IN.S} < 0$ in examined range, up to frequency $\Omega = 1$, when $\alpha_0 > 1$, what is characteristic for the mode of direct bias of emitter junction of ITTT-structure. In this mode $GCI_S^{(+)}$ operates, as immittance inverter. If to provide $\alpha_0 < 1$, for instance, by reduction of direct bias of emitter junction, then $\operatorname{Im}Y_{IN.S}(C_L) > 0$. But in both modes of $\operatorname{Re}Y_{IN.S}(C_L) > 0$, that limits functional possibilities of such GTI. It is expedient to use the possibilities of electric junction from the mode of converter in the mode of inverter of immittance in combination with other types of GCI, having ReY < 0.

In case of direct transformation of inductive immittance $Y_H = \frac{1}{j\omega L_H}$ with the help of $GCI_S^{(+)}$, the results of calculations are presented in Fig.4. Comparing them with the data of the Table 1 we see, that in such mode the substantial influencing is rendered by the parameters of ITTT-structure. For the high-quality coincidence with the data of the Table 1, when at $\alpha_0 > 1$ $ReY_{IN.S}(L_L) < 0$ and $ImY_{IN.S}(L_L) > 0$, it is necessary to decrease C_{K1} and to increase R_{K2}. At $\alpha_0 > 2$ the character of converted conductivity does not change.

The results of reverse transformation of active $Y_G = \frac{1}{R_G}$, capacitive $Y_G = j\omega C_G$ and inductive $Y_G = \frac{1}{j\omega L_G}$ conductivities using $GCI_S^{(+)}$ is presented in Fig. 5-7. Comparing them with the data of the Table 2 we see, that in the mode of transformation of active conductivity (Fig. 5), they exactly coincide in all frequency range for $ImY_{OUT.S}(R_G)$, and for $ReY_{OUT.S}(R_G)$ this coincidence is observed to frequency $\Omega = 0.2$, where $ReY_{OUT.S}(R_G) < 0$. increase of R_{K2} and C_{K1}, and decrease of α_0 narrows the frequency range.

In case of transformation of capacitive conductivity $Y_G = j\omega C_G$ (Fig. 6) the coincidence with the results of conversion Table is observed at $\alpha_0 \geq 3$ pt., $C_{K1} \geq 100$pF and $R_{K2} < 100$ Ohm. In this case especially sharply the change of these parameters influences the character of susceptance of $ImY_{OUT.S}(C_G)$, in this connection the use of results of Table 2 for the case $Y_G = j\omega C_G$ should be to limit to frequency $\Omega \leq 0.2$.

If it is necessary to carry out transformation of inductive conductivity $Y_G = \frac{1}{j\omega L_G}$, as it is seen from Fig7



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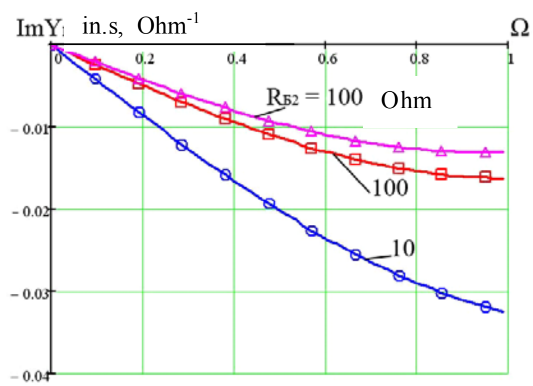

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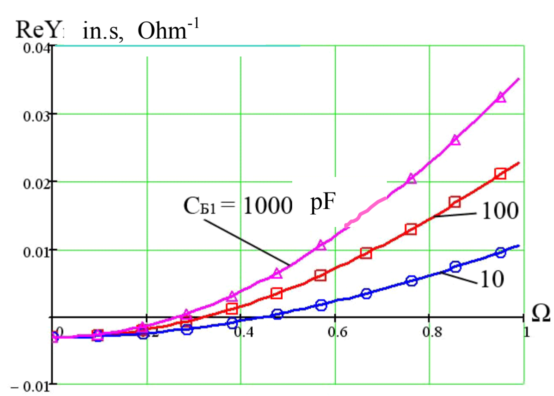

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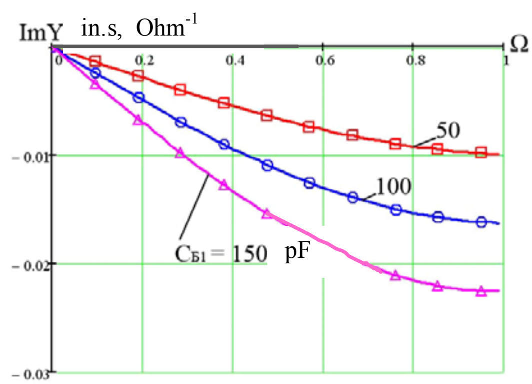

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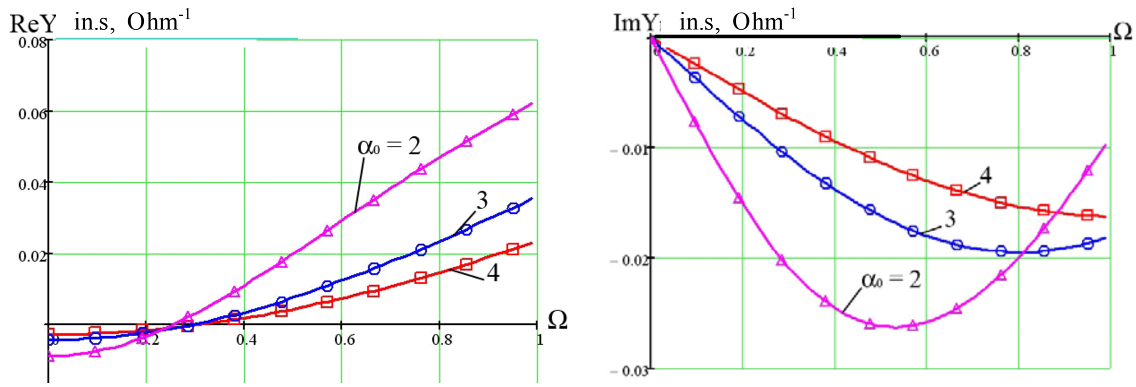
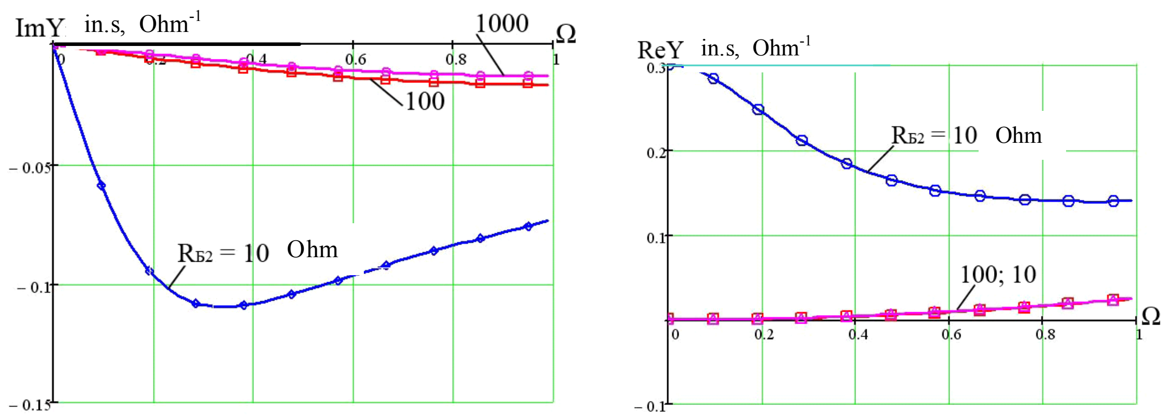


e) f)

Fig. 2 Frequency dependences of input conductivity GTI$_S^{(+)}$ at different values of parameters of ITTT-structure in the mode of direct transformation of active conductivity, where R_L = 10 Ohm



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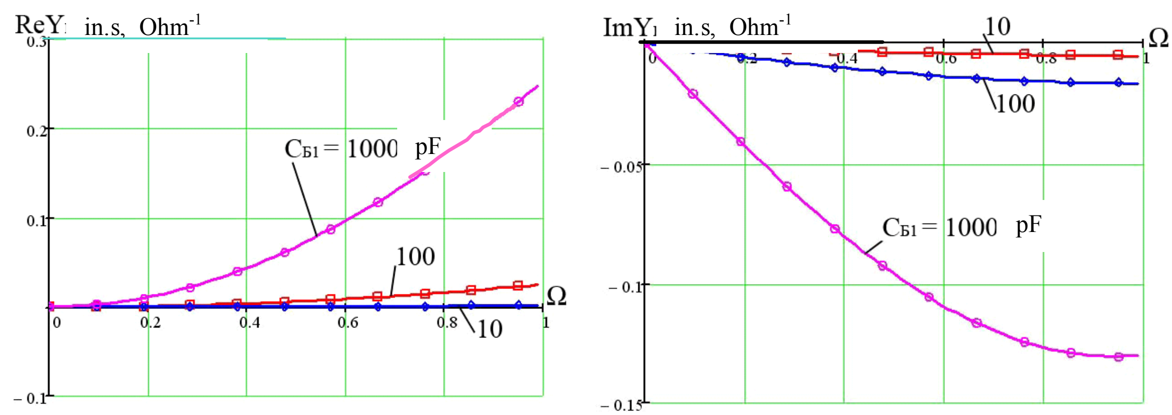

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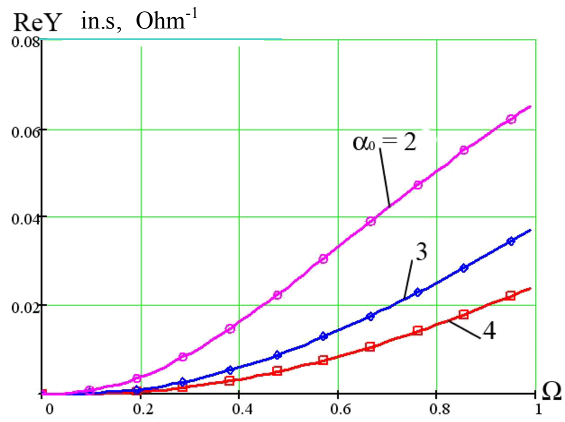

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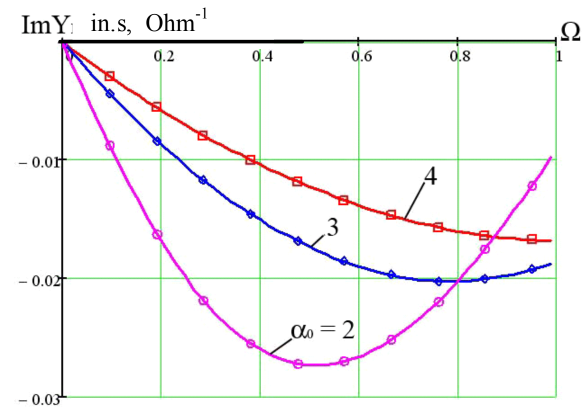

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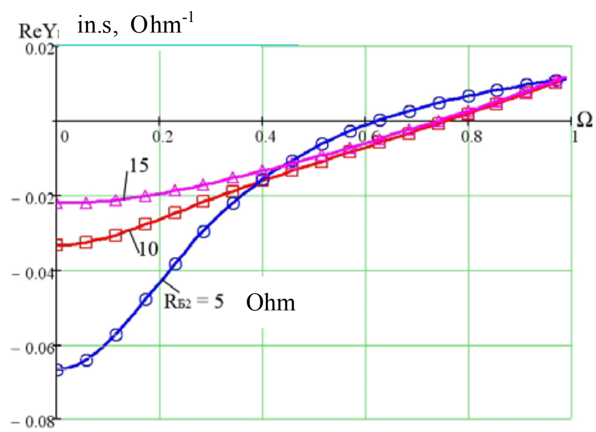
Fig. 3 Frequency dependences of input conductivity of $GTI_S^{(+)}$ at different values of parameters of ITTT-structure in the mode of direct transformation of capacitive conductivity, where C_L = 50 pF



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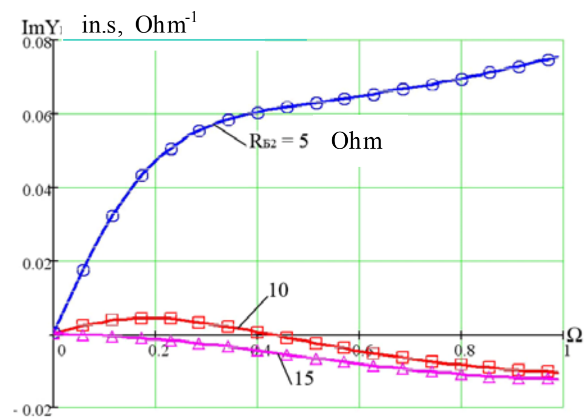

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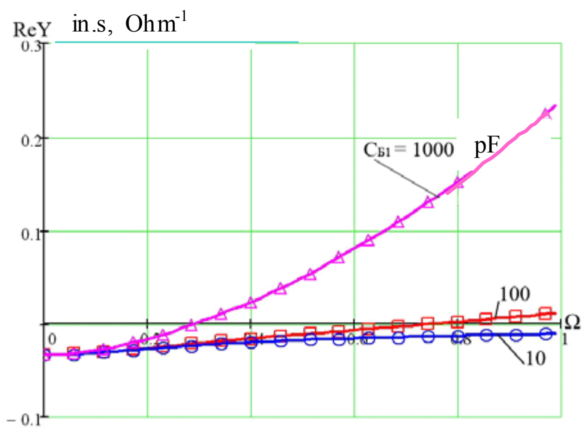

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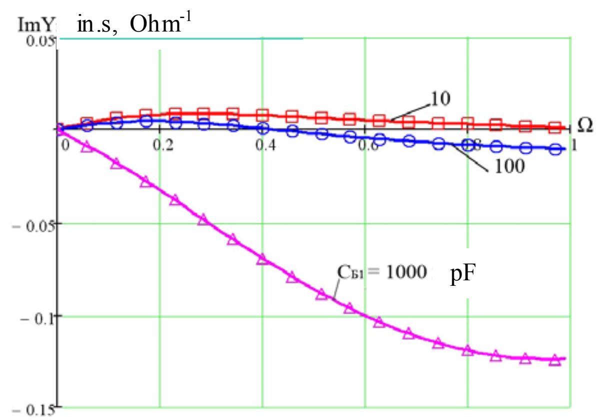

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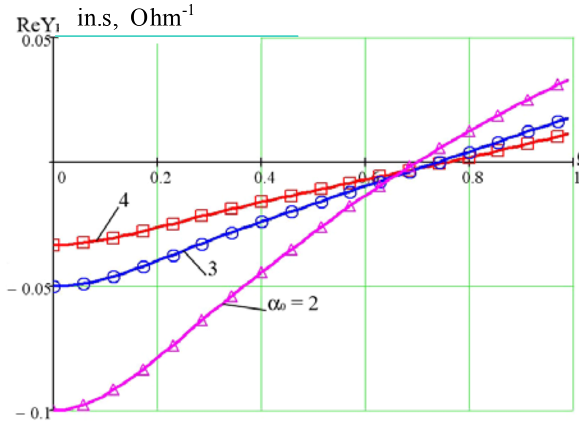

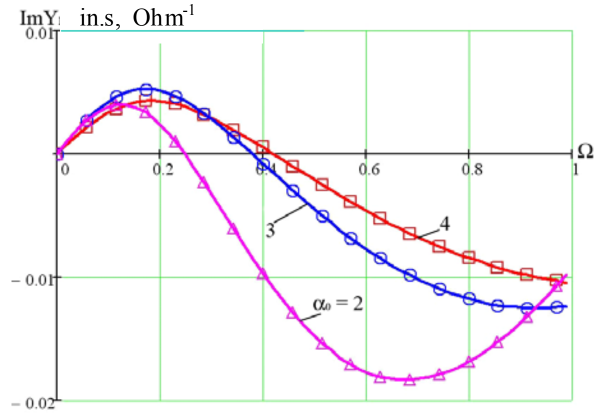

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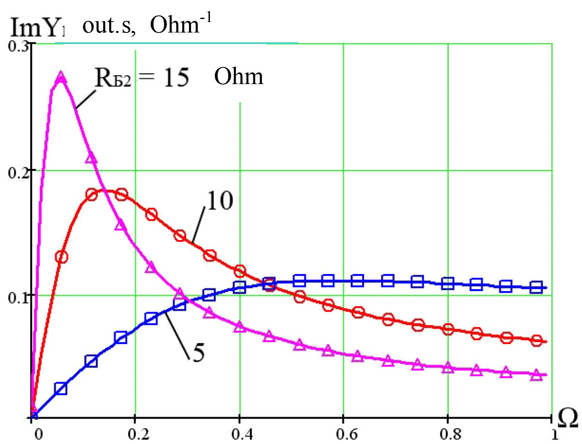
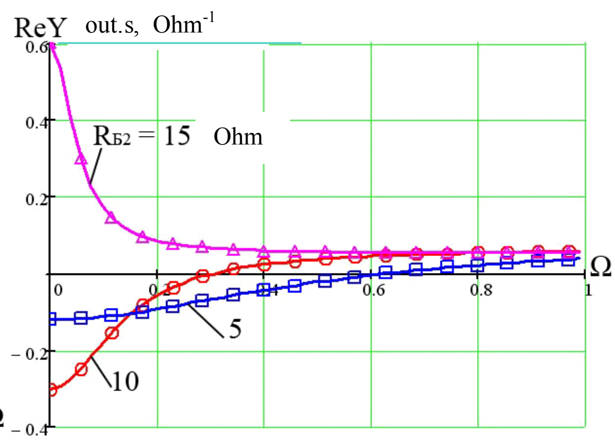
Fig. 4 Frequency dependences of input conductivity of $GTI_S^{(+)}$ at different values of parameters of ITTT-structure in the mode of direct transformation of inductive conductivity, where L_L = 50 nHn





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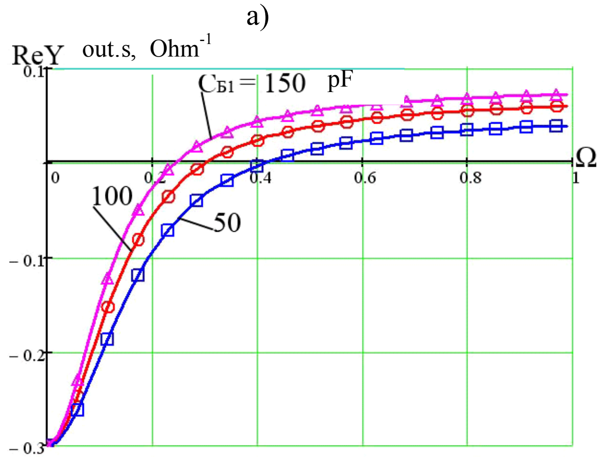

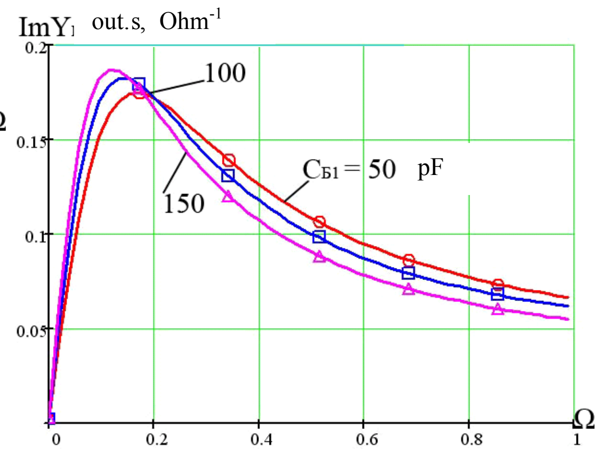

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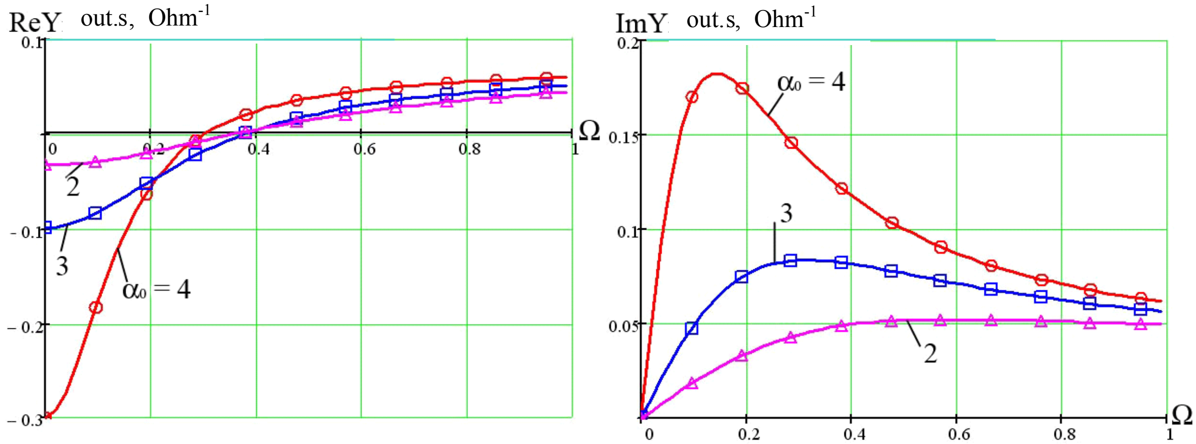

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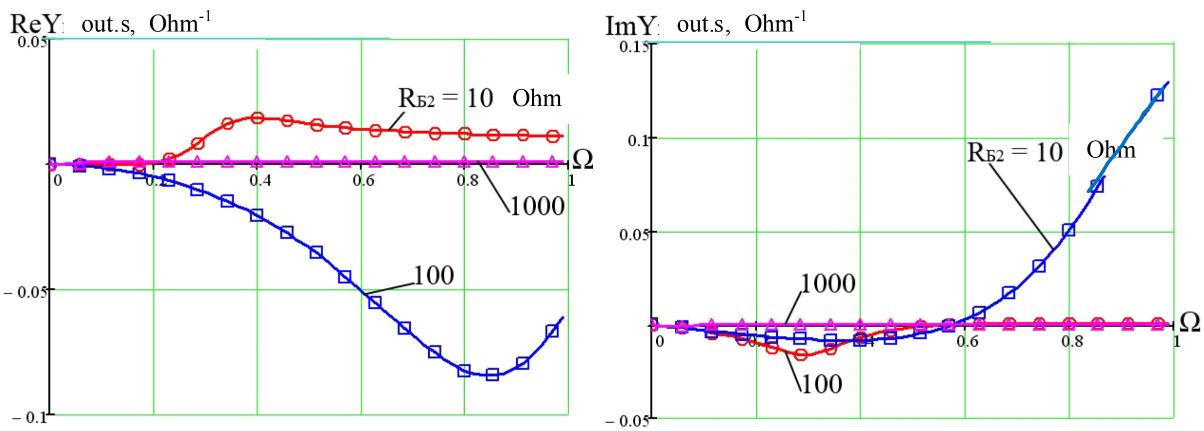
Fig. 5 Frequency dependences of input conductivity of $GTI_S^{(+)}$ at different values of parameters of ITTT-structure in the mode of reverse transformation of active conductivity, where R_G = 40 Ohm



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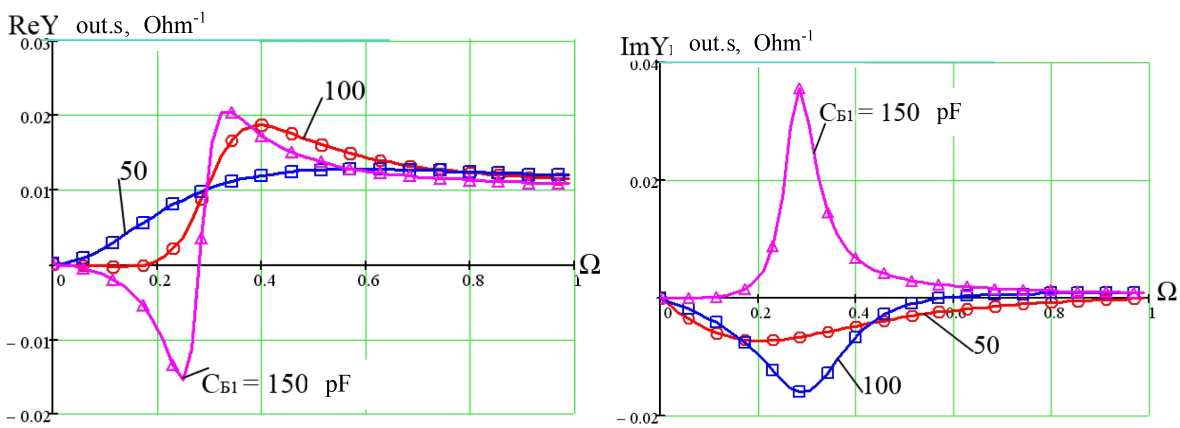

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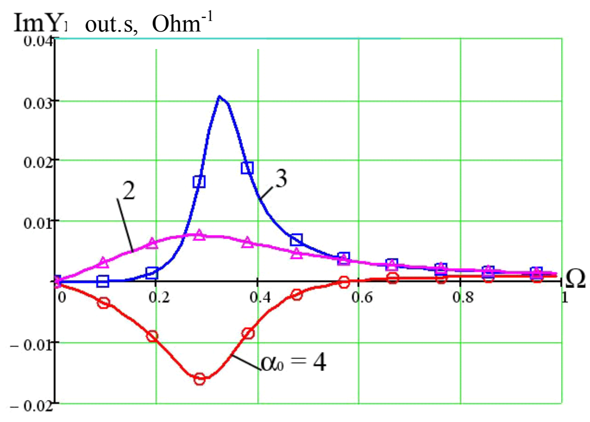

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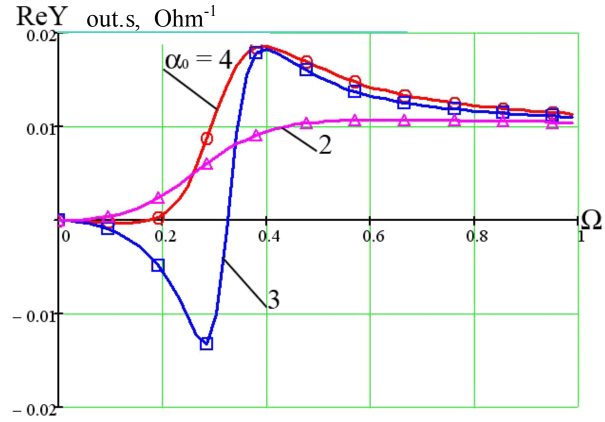

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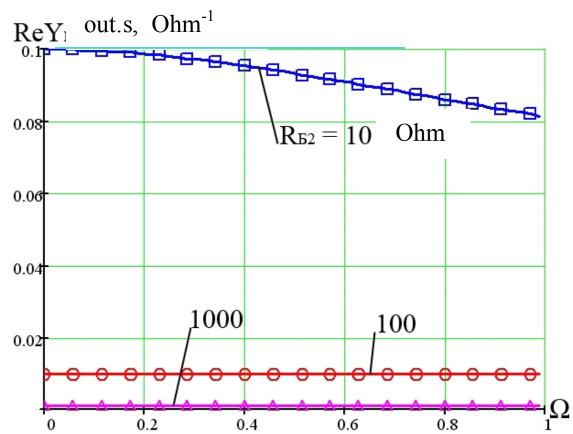
Fig. 6 Frequency dependences of output conductivity $GTI_S^{(+)}$ at different values of parameters of ITTT-structure in the mode of reverse transformation of capacitive conductivity, where C_G = 50 pF



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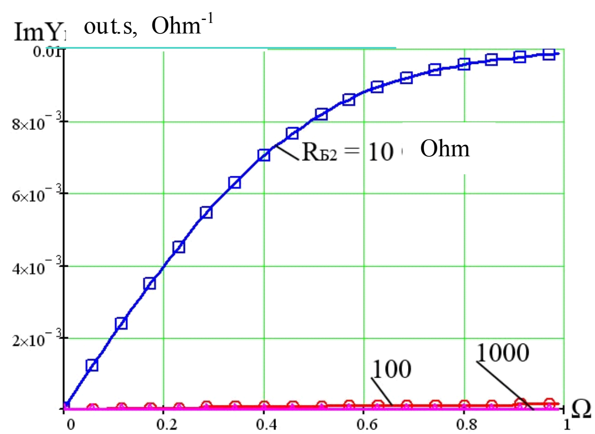

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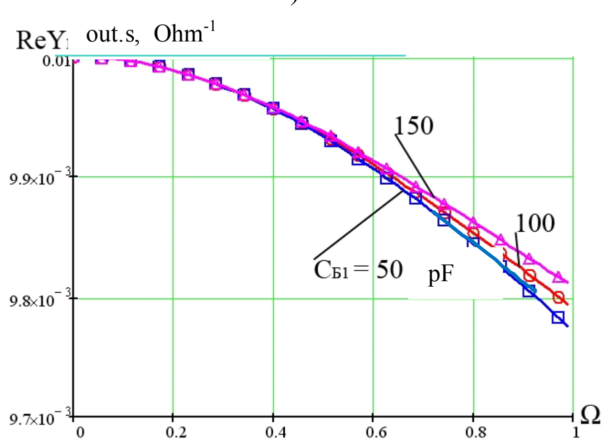

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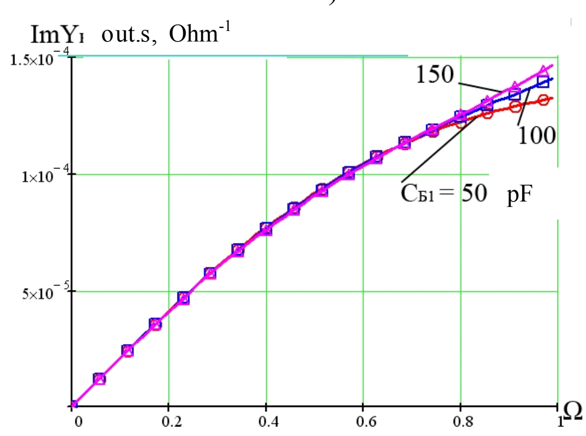

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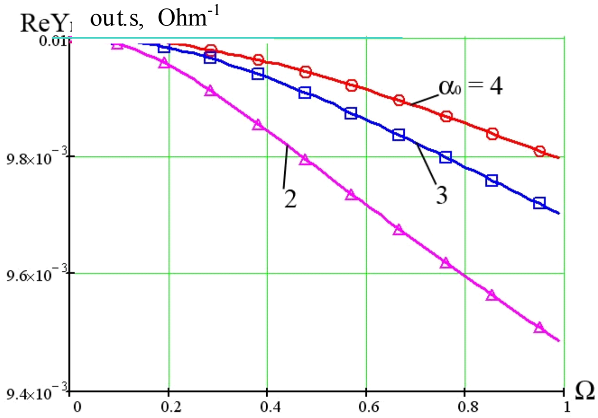

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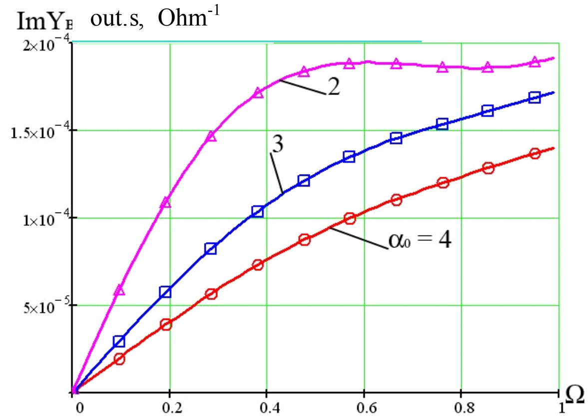

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Fig. 7 Frequency dependences of output conductivity of $GTI_S^{(+)}$ at different values of parameters of ITTT-structure in the mode of reverse transformation of inductive conductivity, where L_G = 50 nHn

it is possible to use the whole examined range of frequencies, but since $ReY_{OUT.S}(L_G) > 0$, this mode of transformation has the limited practical application.

For experimental verification of the results obtained the method of measuring described in [8] was used, applying the phase voltmeter of ФК2-12 type. The results of measurements, presented in Fig. 2-7, showed that in the examined range of frequencies (0,1÷1)GHz in all the modes of transformation divergence of results of calculations and model experiment does not exceed 12%. More substantial divergences, observed at high-frequencies, are explained by the influence of parasite reactance of ITTT-structure which were not taken into account in its mathematical model.

Conclusions

Injection-transit transistors structures possess properties of GTI in the modes of both reverse and direct bias of emitter junction. Changes of potential sign of emitter junction causes the change of both quality and quantitative characteristics of such GTI, including the change of function of transformation from inversion to conversion, and vice versa.

At reverse bias of emitter junction the ITTT-structure connected by circuit with general source ($GTI_S^{(-)}$), possesses properties of immittance inverter. Negative material immittance will be realized only in cases of transformation of immittance of inductance immittance L.

At direct bias of emitter junction of ITTT-structure connected in circuit with general source ($GTI_S^{(+)}$), in the mode of direct transformation of W_L immittance when the transformed immittance is active ($W_L = R_L$), the input immittance of W_{IN} is inductive, that allows to use such mode for creation of transistors equivalents of inductance.

At low frequencies $f < f_{гр}$ in case of transformation of both capacitive (C_L), and inductive (L_L) immittances $GTI_S^{(+)}$ possesses properties of immittance inverter. At high-frequencies $f > f_{гр}$ – properties of immittance converter. The negative value of active component of the transformed immittance is observed both at low and at high-frequencies, but only in case of transformation of inductive immittance.

In case of reverse transformation of immittance in the mode of the reverse bias of emitter junction, $GTI_S^{(-)}$ possesses similar properties, as well as in the mode of direct transformation of immittance.

At reverse bias of emitter juncion, when the transformed immittance is active ($W_G = R_G$), output immittance $W_{OUT.S}$ is capacitive with negative active component at low frequencies (f-f).

At reverse transformation of both capacitive (C_G), and inductive (C_G) immittances, $GTI_S^{(+)}$

possesses properties of immittance inverter, and at high-frequencies ($f > f_{гр}$) – properties of immittance converter. The negative value of active component of converted immittance is observed both at high and at low frequencies, but only in case of transformation of inductive immittance.

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