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EVALUATION OF OPERATION PARAMETERS OF SINGLE-TRANSISTOR CURRENT CONVERGER

The paper substantiates the system of basic operation parameters of current conveyers. Analytical dependences between operation and formal parameters of current conveyer are determined, that enables to determine basic operation and formal parameters of single transistor current conveyer by the values of four Y – parameters of the transistor. The study of basic operation parameters of single – transistor current conveyers on bipolar and field – effect transistor is carried out, this enables to determine the advantages and disadvantages of the considered current conveyers.

Key words: *current conveyer, Y – parameters of the transistor, criterial evaluation of efficiency.*

Introduction

Nowadays circuit engineering of information devices, based on current conveyers is rapidly developing [1]. Current conveyer is the basic element for construction of electronic circuits, it was suggested by Sedra A. S. and Smith K. C. [2]. In 1970 they proposed the improved variant of current conveyer of the second generation [3], this conveyer turned out to be more efficient unit for construction of electronic circuits Current conveyer is a basic unit for construction of all the circuits, realized on operation amplifiers (constant multipliers, integrators, differentiators, adders, converters and inverters of resistances, active filters, etc.) [4]. In 90's of the last century the interest to current conveyers renewed, since there appeared the necessity in higher frequency and efficient circuits. Current approach provides certain advantages as compared with operation with voltages, namely: greater operation speed and frequency range, as the circuits can operate on the frequencies up to f_T transistors; there is no need to provide great values of gain factors, as for current conveyers current transmission coefficient equals unit; have higher accuracy and are rather simple, because there is no need to use precision resistor for transformation of currents into voltages and circuits may be constructed only on transistors; have less power consumption as in this case the circuit are less sensitive to non-linear distortions, that emerge during operation with small voltages.

The desire to obtain the parameters of current conveyer close to ideal led to the construction of multitransistors current conveyers Comparative analysis of their efficiency showed that such multitransistors circuits by certain parameters (energy consumption, frequency operation range) are worse than single – transistor circuits [5].

That is why, evaluation of operation parameters of single transistor current conveyers and making the most optimal decisions, regarding the construction of single-transistor current conveyers is the urgent problem.

Aim and tasks of the research

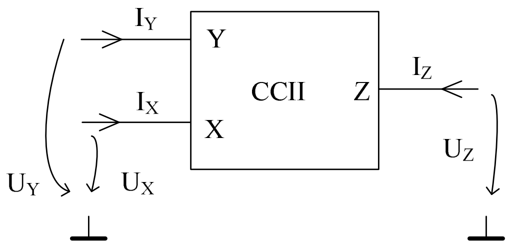
The aim of the research is analytical evaluation of main operation parameters of single-transistor current conveyers in order to perform their comparative analysis and find the most efficiency circuit engineering solutions.

To reach this aim the following problems are to be solved:

1. Substantiate main operation parameters of current conveyers;
2. Find analytical dependence between operation and formal parameters of current conveyor;
3. Study of operation parameters of single – transistor current conveyors in frequency range and search of the most efficient solutions.

Substantiation of main parameters of current conveyors

At initial stage the problem of substantiation of main operation parameters of current conveyors of the second generation (CCII) (Fig. 1) is solved, in ideal case it is described by the system of equations (1), shown in Fig. 1 [6]:



a)

$$\begin{cases} I_Y = 0 \\ U_X = U_Y \\ I_Z = \pm I_X \end{cases} \quad (1)$$

b)

Fig. 1. Designation CCII (a) and system of equations (b); I_X, I_Y, I_Z -currents of electrodes and values of voltages U_X, U_Y, U_Z between terminals and common bus in current conveyor of the second generation

Proceeding from this system, we will define the following main parameters of CCII:

– current transmission coefficient: $K_I = \frac{I_Z}{I_X}$ (for ideal CCII $K_I = 1$);

– voltage transmission coefficient: $K_U = \frac{U_X}{U_Y}$ (for ideal CCII $K_U = 1$);

– conductance of input Y: $Y_Y = \frac{I_Y}{U_Y}$ (for ideal CCII $Y_Y = 0$);

– resistance of input X: $Z_X = \frac{U_X}{I_X}$ (for ideal CCII $Z_X = 0$);

– conductance of output Z: $Y_Z = \frac{I_Z}{U_Z}$ (for ideal CCII $Y_Z = 0$).

Limiting frequency of current transmission coefficient f_{K_I}. This is the frequency at which modulus of current transmission coefficient K_I decreases $\sqrt{2}$ as compared with low – frequency value of K_{I0}.

Limiting frequency of voltage transmission coefficient f_{K_U}. This is the frequency at which modulus of voltage transmission coefficient K_U decreases $\sqrt{2}$, as compared with law – frequency value of K_{U0}.

Analytical dependence between operating and formal parameters of current conveyor

System of equations (1) characterizes an ideal current conveyor. Real current conveyor is characterized by the following system of equations:

$$\begin{cases} I_Y = a_{11}U_Y + a_{12}I_X + a_{13}U_Z \\ U_X = a_{21}U_Y + a_{22}I_X + a_{23}U_Z \\ I_Z = a_{31}U_Y + a_{32}I_X + a_{33}U_Z \end{cases}, \quad (2)$$

where a_{ij} – elements of square matrix, *i*=1..3, *j*=1..3.

As a result of the analysis of equations system (2) we find analytical dependences between the elements a_{ij} and operating parameters of current conveyor:

$$\dot{K}_I = \frac{I_Z}{I_X} = a_{32}(U_Y = 0, U_Z = 0), \quad \dot{K}_U = \frac{U_X}{U_Y} = a_{21}(I_X = 0, U_Z = 0),$$

$$Y_Y = \frac{I_Y}{U_Y} = a_{11}(I_X = 0, U_Z = 0), \quad Z_X = \frac{U_X}{I_X} = a_{22}(U_Y = 0, U_Z = 0), \qquad (3)$$

$$Y_Z = \frac{I_X}{U_Z} = a_{33}(U_Y = 0, I_X = 0).$$

Thus, to determine operating parameters of CCII, it is necessary to measure complex a_{ij}-parameters. They may be either dimensionless or have dimensionality of the conductance or resistance. For their measurements it is necessary to provide short-circuit modes and no-load mode in various combinations, that represents rather complex engineering problem at high and super – high frequencies. That is why, it is suggested to describe current conveyor by Y_{ij}- parameters, for their measurement it is necessary to provide only short-circuit mode [7]. For this purpose, current conveyor is considered as an independent three – terminal device, that is described by the system of equations

$$\begin{cases} I_Y = Y_{11}U_Y + Y_{12}U_X + Y_{13}U_Z \\ I_X = Y_{21}U_Y + Y_{22}U_X + Y_{23}U_Z \\ I_Z = Y_{31}U_Y + Y_{32}U_X + Y_{33}U_Z \end{cases} \qquad (4)$$

Having solved simultaneously the systems of equations (2) and (3), we find analytical dependences between the systems a_{ij}- and Y_{ij}- parameters:

$$a_{11} = Y_{11} - \frac{Y_{12}Y_{21}}{Y_{22}}, \quad a_{12} = Y_{12}/Y_{22}, \quad a_{13} = Y_{13} - \frac{Y_{12}Y_{23}}{Y_{22}},$$

$$a_{21} = -\frac{Y_{21}}{Y_{22}}, \quad a_{22} = 1/Y_{22}, \quad a_{23} = -\frac{Y_{23}}{Y_{22}}, \qquad (5)$$

$$a_{31} = Y_{31} - \frac{Y_{32}Y_{21}}{Y_{22}}, \quad a_{32} = Y_{32}/Y_{22}, \quad a_{33} = Y_{33} - \frac{Y_{32}Y_{23}}{Y_{22}}.$$

Thus, having calculated or measured Y_{ij}- parameters of current conveyor, we find its a_{ij} and operating parameters (3).

The process of a_{ij}- parameters search could be simplified. Y_{ij}- parameters, that make part of (4), are the parameters of indefinite matrix for which the equation [8] is valid:

$$\sum_{i=1}^{m} y_{ij} = 0 (j = 1, 2..m); \quad \sum_{j=1}^{m} y_{ij} = 0 (i = 1, 2..m). \qquad (6)$$

Using Y- parameters of four-terminal device, created by means of grounding of one of the electrodes of current conveyor and condition (6), we find other Y-parameters of current conveyor and calculate on their base its a_{ij}-parameters (5) and operating parameters (3) (Table. 1).

Table 1

Y- and operating parameters f current conveyor

№ п/п	Conductance matrix	Y- parameters of the matrix	Operating parameters of current conveyor
With grounded Z-electrode	$\left[Y_Z\right]=$ $=\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}=$ $=\begin{bmatrix} Y_{11}^Z & Y_{12}^Z \\ Y_{21}^Z & Y_{22}^Z \end{bmatrix}$	$Y_{13}=-(Y_{11}+Y_{12})=-(Y_{11}^Z+Y_{12}^Z)$ $Y_{23}=-(Y_{21}+Y_{22})=-(Y_{21}^Z+Y_{22}^Z)$ $Y_{31}=-(Y_{11}+Y_{21})=-(Y_{11}^Z+Y_{21}^Z)$ $Y_{32}=-(Y_{12}+Y_{22})=-(Y_{12}^Z+Y_{22}^Z)$ $Y_{33}=-(Y_{13}+Y_{23})=Y_{11}^Z+Y_{12}^Z+$ $+Y_{21}^Z+Y_{22}^Z$	$\dot{K}_I=\frac{-(Y_{12}^Z+Y_{22}^Z)}{Y_{22}^Z}$ $\dot{K}_U=-\frac{Y_{21}^Z}{Y_{22}^Z}$ $Y_Y=Y_{11}^Z-\frac{Y_{21}^Z Y_{12}^Z}{Y_{22}^Z}$ $Z_X=1/Y_{22}^Z$ $Y_Z=Y_{11}^Z+Y_{12}^Z+Y_{21}^Z+Y_{22}^Z-$ $-\frac{(Y_{12}^Z+Y_{22}^Z)(Y_{21}^Z+Y_{12}^Z)}{Y_{22}^Z}$
With grounded X-electrode	$\left[Y_Z\right]=$ $=\begin{bmatrix} Y_{11} & Y_{13} \\ Y_{31} & Y_{33} \end{bmatrix}=$ $=\begin{bmatrix} Y_{11}^X & Y_{12}^X \\ Y_{21}^X & Y_{22}^X \end{bmatrix}$	$Y_{12}=-(Y_{11}+Y_{13})=-(Y_{11}^X+Y_{12}^X)$ $Y_{32}=-(Y_{31}+Y_{33})=-(Y_{21}^X+Y_{22}^X)$ $Y_{23}=-(Y_{13}+Y_{33})=-(Y_{12}^X+Y_{22}^X)$ $Y_{21}=-(Y_{11}+Y_{31})=-(Y_{11}^X+Y_{21}^X)$ $Y_{22}=-(Y_{12}+Y_{32})=Y_{11}^X+Y_{12}^X+$ $+Y_{21}^X+Y_{22}^X$	$\dot{K}_I=\frac{Y_{21}^X+Y_{22}^X}{Y_{11}^X+Y_{12}^X+Y_{21}^X+Y_{22}^X}$ $\dot{K}_U=\frac{Y_{11}^X+Y_{21}^X}{Y_{11}^X+Y_{22}^X+Y_{21}^X+Y_{12}^X}$ $Y_Y=Y_{11}^X-$ $-\frac{(Y_{11}^X+Y_{12}^X)(Y_{11}^X+Y_{21}^X)}{Y_{12}^X+Y_{22}^X+Y_{11}^X+Y_{21}^X}$ $Z_X=1/(Y_{22}^X+Y_{12}^X+Y_{21}^X+Y_{11}^X)$ $Y_Z=Y_{22}^X-$ $-\frac{(Y_{21}^X+Y_{22}^X)(Y_{12}^X+Y_{22}^X)}{Y_{11}^X+Y_{22}^X+Y_{21}^X+Y_{21}^X}$

With grounded X-electrode	$[Y_Z]=$ $=\begin{bmatrix} Y_{22} & Y_{23} \\ Y_{32} & Y_{33} \end{bmatrix}=$ $=\begin{bmatrix} Y_{11}^X & Y_{12}^X \\ Y_{21}^X & Y_{22}^X \end{bmatrix}$	$Y_{12}=-(Y_{22}+Y_{32})=-(Y_{11}^Y+Y_{21}^Y)$ $Y_{13}=-(Y_{23}+Y_{33})=-(Y_{12}^Y+Y_{22}^Y)$ $Y_{21}=-(Y_{22}+Y_{23})=-(Y_{11}^Y+Y_{12}^Y)$ $Y_{31}=-(Y_{32}+Y_{33})=-(Y_{21}^Y+Y_{22}^Y)$ $Y_{11}=-(Y_{21}+Y_{31})=Y_{11}^Y+Y_{12}^Y+$ $+Y_{21}^X+Y_{22}^X$	$\dot{K}_I=\frac{Y_{21}^Y}{Y_{11}^Y}$ $\dot{K}_U=\frac{Y_{21}^Y+Y_{22}^Y}{Y_{11}^Y}$ $Y_Y=Y_{11}^Y+Y_{12}^Y+Y_{21}^Y+Y_{22}^Y-$ $-\frac{(Y_{11}^Y+Y_{21}^Y)(Y_{11}^Y+Y_{12}^Y)}{Y_{11}^Y}$ $Z_X=1/Y_{11}^Y$ $Y_Z=Y_{22}^Y-\frac{Y_{21}^Y Y_{12}^Y}{Y_{11}^Y}$

Investigation of operating parameters of single-transistor current conveyors

Bipolar and field – effect transistors may be used as the simplest current conveyors (Fig. 2) [6].

For bipolar transistor (Fig. 2, a) $U_X=\frac{U_Y}{\left(1+\left(1/g_m R_X\right)\right)}$, where g_m – slope of bipolar transistor, R_X – resistance, connected to the output X. As $g_m R_X>>1$, then $U_X\approx U_Y$. $I_Z=-\beta/(\beta+1)I_X$, as $\beta>>1$, then $I_Z\approx -I_X$ [6]. Thus, taking into account (1), bipolar transistor can be considered as the simplest current conveyor with the inversion of CCII current direction.

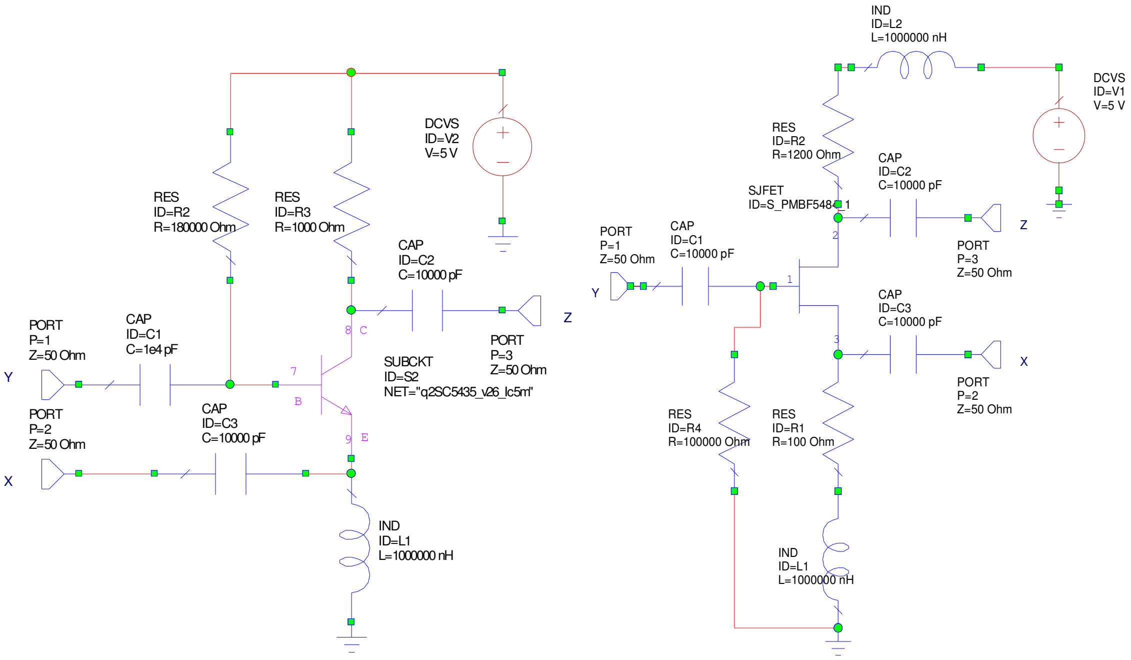
a) b)

Fig. 2. Single – transistor current conveyors CCII⁻ on bipolar (a) and field effect (b) transistors

Similar to field – effect – transistor (Fig. 2, b) $U_X=\frac{U_Y}{\left(1+\left(1/g_m R_X\right)\right)}$, where g_m – slope of field – effect transistor. As $g_m R_X>>1$, then $U_X\approx U_Y$. $I_Z\approx -I_X$. Thus, taking into account (1) field – effect transistor can be considered as the simplest current conveyor CCII with inversion of current direction.

To perform comparative evaluation of operating parameters of these current conveyors we will carry out computer modeling and calculation of their basic parameters.

Schemes, used for computer modeling of single – transistor current conveyors operation on bipolar and field – effect transistors, are shown in Fig. 3. Modeling is performed in the program AWK Microwave Office 10. In the scheme (Fig. 3, a) bipolar transistor 2SC5435 is used in the mode: $I_E=2{,}4$ mA, $U_{CE}=2{,}6$ V, limiting frequency $f_T\approx 7$ GHz. In the scheme (Fig. 3,b) field – effect transistor PMBF5484, $I_D=2$ mA, $U_{GS}=-0{,}2$, $f_T\approx 220$ MHz.



а) б)

Fig. 3. Schemes of simple – transistor current conveyors on bipolar (a) and field – effect (b) transistors

To determine the complete system of formal *a*- and operating parameters of CCII it is necessary to determine only the values of any four Y – parameters of indefinite matrix of current conveyor.

Figs 4 and 5 contain graphs of frequency dependence of Y_{11}, Y_{12}, Y_{21}, Y_{22} parameters on current conveyor on bipolar and field – effect transistors in frequency range from 0,001 f_T to f_T.

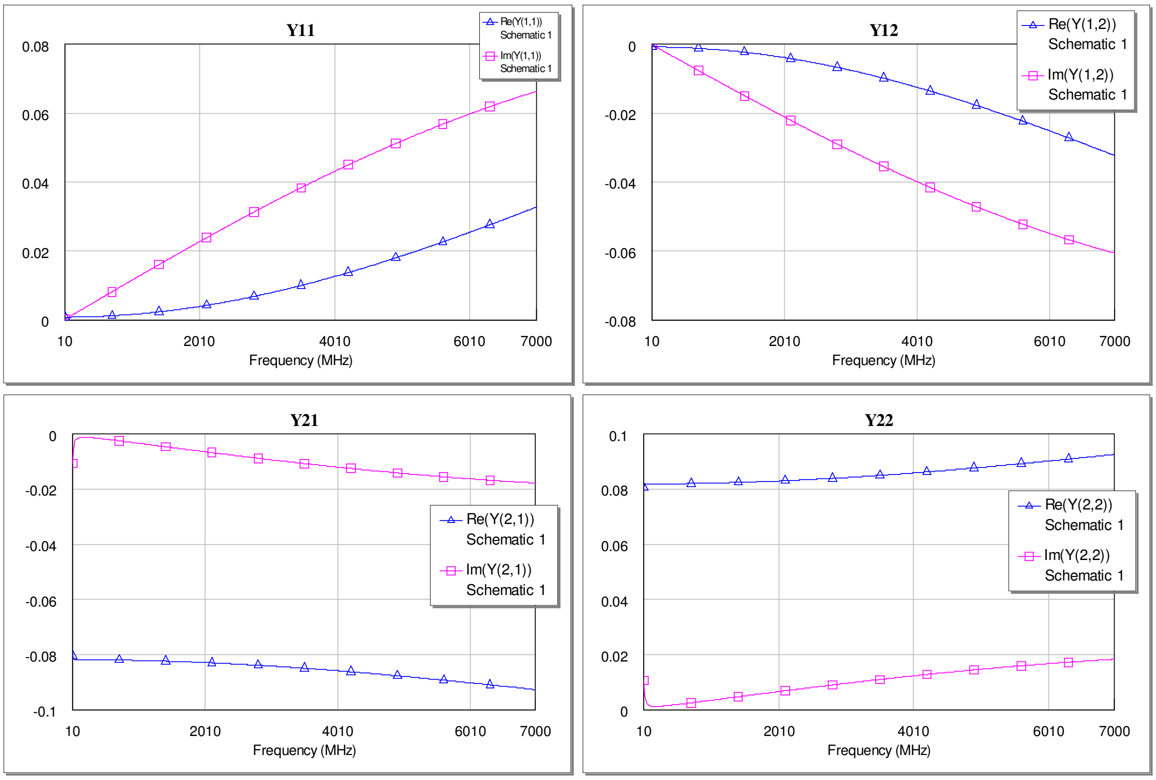


Fig. 4. Frequency dependences Y_{11}, Y_{12}, Y_{21}, Y_{22} – parameters of CCII on bipolar transistor

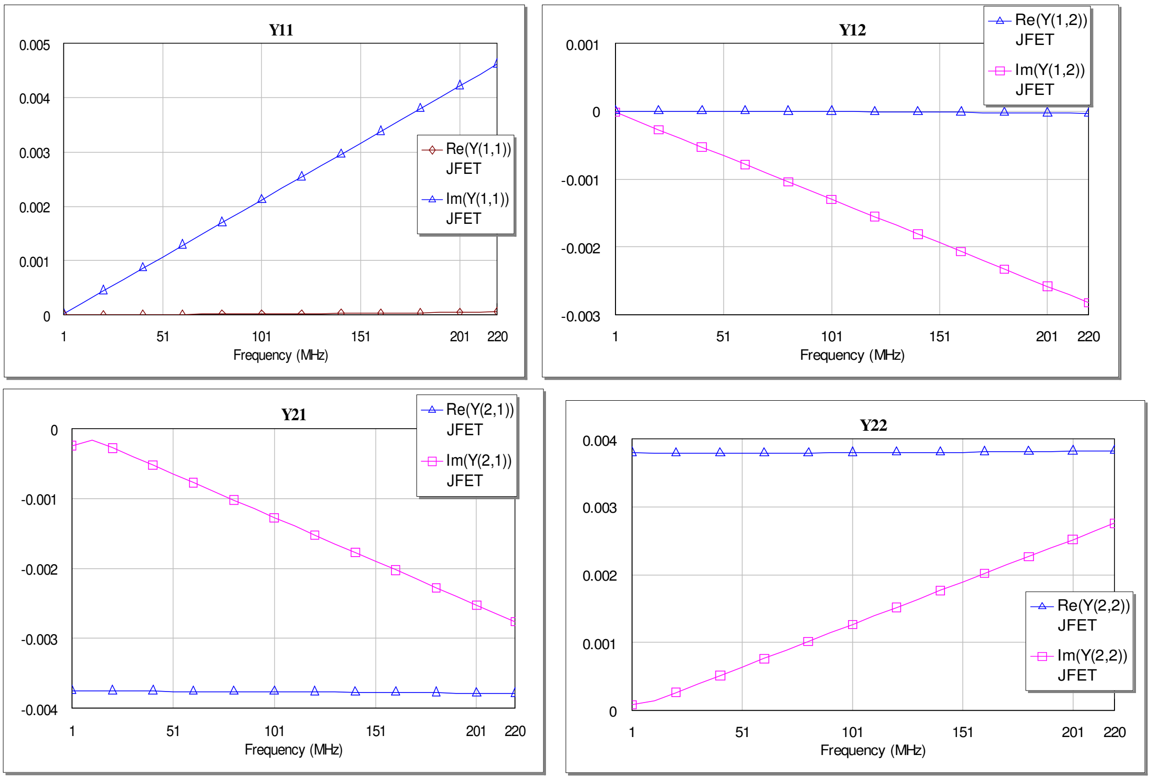
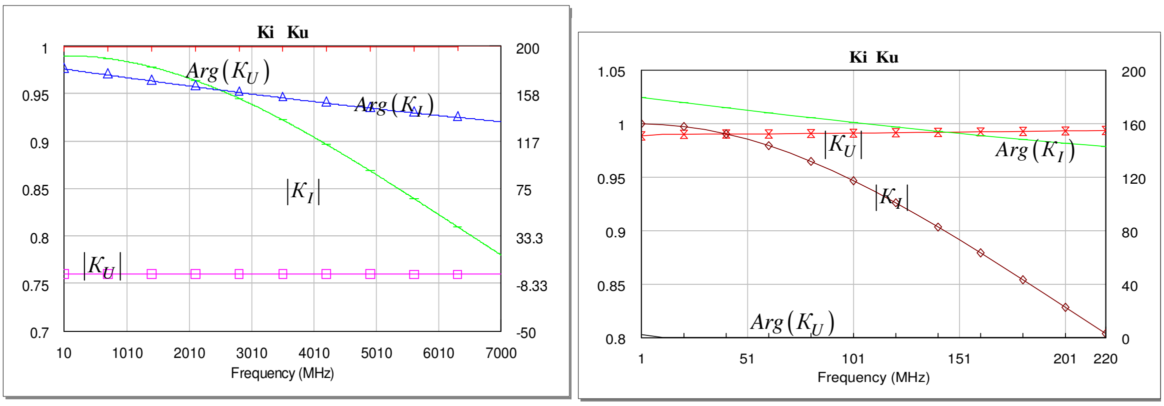


Fig. 5. Frequency dependences Y_{11}, Y_{12}, Y_{21}, Y_{22} – parameters of CCII on field – effect transistor

Using the values of CCII Y – parameters frequency dependences of current and voltage transmission coefficients of current conveyor on bipolar and field – effect transistors (Fig. 6) are calculated.



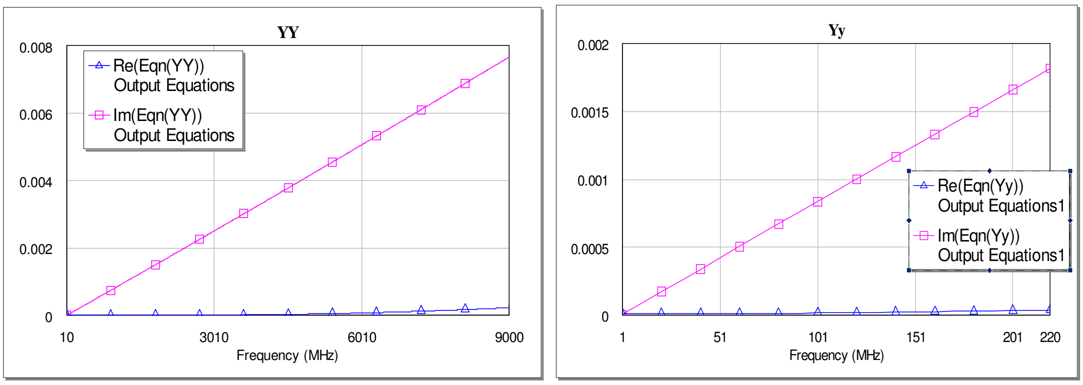
a) b)

Fig. 6. Frequency dependences of phase and modulus of current K_I and voltage K_U (a) transmission coefficients of current conveyor on bipolar (b) and field-effect transistors

It should be noted, that the given values of transmission coefficients are defined for short-circuit modes on the terminals Y and Z, and idle mode on X. In load mode, for instance 50 Ohm, values of the coefficients decrease.

If stray interelectrode capacitances of the transistors $C_{BC} = 0,25\,\text{pF}$, $C_{EC} = 0,25\,\text{pF}$, and inductances of transistor outputs $L_C = 0,6\,\text{nHn}$, $L_{Б} = 0,45\,\text{nHn}$ are taken into account, active component of the transistor inductance becomes negative at high frequencies, that leads to the increase of current and voltage transmission coefficients at these frequencies.

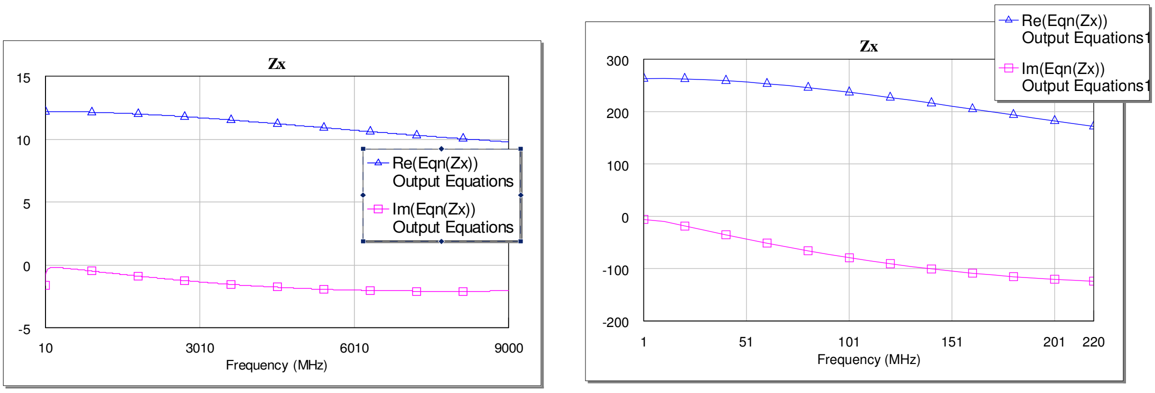
Fig. 7, 8 and 9 show frequency dependences of input conductance Y_Y, input resistance Z_X and output conductance Y_Z.



a) b)

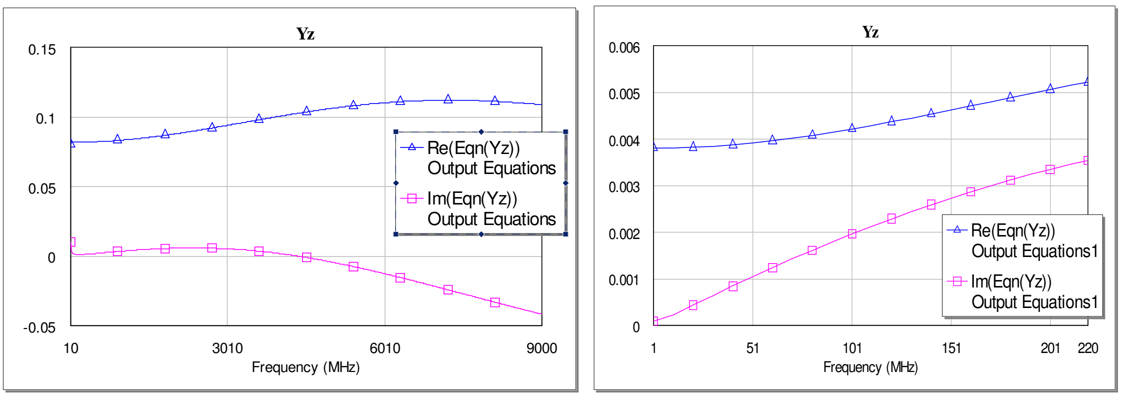
Fig. 7. Active and reactive component of input conductance Y_Y of current conveyor on bipolar (a) and field effect (b) transistors

According to the results of computer modeling bipolar and field – effect transistor are single – transistor current conveyor at the frequencies up to f_T. Availability of inductances and capacitances of the outputs leads to the emergence of negative active resistance, that but allows to increase the values of transmission coefficients to more than unit.



a) b)

Fig. 8. Active and reactive component of input resistance Z_X of current conveyor on bipolar (a) and field- effect transistors (b)



a) b)

Fig. 9. Active and reactive component of output conductance Y_Z of current conveyor on bipolar (a) and field- effect transistors (b)

Let us perform comparative analysis of single – transistor current conveyors on bipolar and field – effect transistors. Table 2 contains operating parameters of the given current conveyors on the frequency 0.5 f_T Both current conveyors can operate on frequencies up to f_T transistors, however current transmission coefficient is greater (by 5…10%) in field – effect transistor and voltage transmission coefficient is greater in bipolar transistor, due to greater slope g_m of transistors. Also current conveyor, based on field – effect transistor has considerably greater (21 times) input resistance Z_X, that leads to greater impact of load resistance on voltage transmission coefficient.

Table 2

Operating parameters of current conveyors, based on bipolar and field-effect transistors

Parameter	Bipolar current conveyor	Field- effect current conveyor	Ideal current conveyor
K_I	0,92	0,94	1
K_U	0,999	0,99	1
Y_Y	0,003 S	0,009 S	0 S
E_{Y_Y}	0,87	0,69	1
Y_Z	0,098 S	0,0048 S	0 S
E_{Y_Z}	0,169	0,806	1
Z_X	11,6 Ohm	247 Ohm	0 Ohm
E_{Z_X}	0,812	0,168	1
E	0,643	0,614	1

Efficiency criteria by the conductances Y_Y, Y_Z and resistance Z_X are calculated by the formulas $E_Y = \frac{0,01}{0,01+Y}$, $E_Z = \frac{100}{100+Z}$, proceeding from the assumption that conductance 0,02S and resistance 50 Ohm correspond to efficiency 0,5. Integral efficiency criterion is calculated by the formula $E = \sqrt[n]{\prod_{i=1}^{n} E_i}$ [5].

Proceeding from the results obtained, current conveyor on bipolar transistor by the integral efficiency criterion is a little better (*E*=0,643) than current conveyor on field – effect transistor (*E*=0,614), this is explained by greater value of voltage transmission coefficient K_U and smaller value of input resistance Z_X.

Conclusions

1. System of main operating parameters of current conveyors, that contains: current transmission coefficient K_I, voltage transmission coefficient K_U, input conductance Y Y_Y, input resistance X Z_X, output conductance Z Y_Z, limiting frequency of current transmission coefficient f_{K_I}, is substantiated, this enabled to determine the criteria for carrying out the comparative analysis of single – transistor f_{K_U}, current conveyors on bipolar and field – effect transistors.

2. Analytical dependences between operating and formal parameters of current conveyor are determined, this enables to define basic operating and formal parameters of single – transistor current conveyor by the values of four Y – parameters of the transistor.

3. Studies of main operating parameters of single-transistor current conveyors on bipolar and field – effect transistors are carried out, this enables to define the advantages and drawbacks o the given current conveyors. Both current conveyors operate on the frequencies up to f_T transistor frequency, however current conveyor on the bipolar transistor by the integral criterion of the

efficiency is better (*E*=0,643) than current conveyor on the base of field – effect transistor (*E*=0,614), it is explained by greater value of voltage transmission coefficient K_U and less input resistance Z_X .

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