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CAPACITIVE ACTIVE ELEMENT ON THE FIELD-TRANSISTOR STRUCTURE WITH NEGATIVE RESISTANCE

The results of studying the capacitive active element on a field-transistor structure with negative resistance are presented. Analytical dependences of the impedance on the supply and control voltages are obtained. Volt-ampere, frequency and volt-farad dependencies of the equivalent capacity of the active element on a field-transistor structure with negative resistance are investigated.

***Key-words**: field-transistor structure, negative resistance, radio-measuring device, equivalent capacitance, impedance.*

Actuality

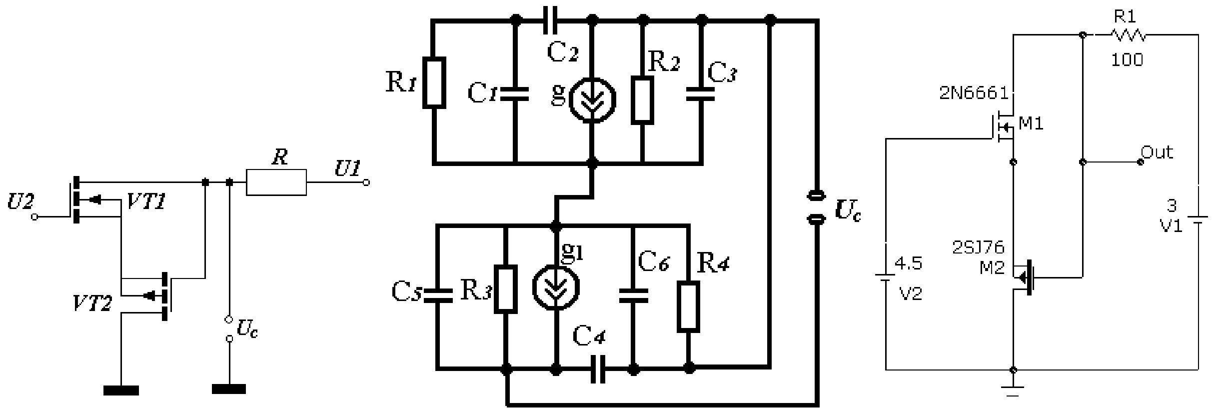
The development of modern radio-measuring devices is known to be performed with the application of the latest element base, which enables essential simplification of their classic circuits. Besides, simultaneous extension of their functional capabilities is now possible due to the application of original circuit solutions [1]. Electrical control of the parameters of the functional units in radio-engineering and radio-measuring equipment is implemented, as a rule, with the help of varicaps. However, these devices have relatively low re-adjustment coefficient (from 1 to 50), low values of equivalent capacitance (from 1 to 500 pF), high control voltage values (from 5 to 25 V) and low Q-factor (from 10 to 50) [2, 3]. The above drawbacks are eliminated in the developed capacitive active element based on a field-transistor structure with negative resistance [4, 5]. In order to use such electrically-controlled capacitance equivalents, it is important to know physical processes on which their operation is based.

Therefore, the goal of this paper is investigation of the capacitive active element on the field-transistor structure with negative resistance (CAE on FTSNR). To reach the goal, it is necessary to solve the following problems: to derive the impedance equation for CAE on FTSNR; to perform modeling of the volt-ampere characteristic of CAE on FTSNR, real and imaginary parts of CAE on FTSNR in the frequency range depending on the changes of supply and control voltages; to obtain the plots of the frequency characteristics of the equivalent capacitance; to investigate the influence of destabilizing factors on the above parameters of CAE on FTSNR.

Investigation of CAE on FTSNR

Internal positive relationship in the field-transistor structure (fig. 1a), which leads to the appearance of a negative resistance, makes it possible to obtain an electrically operated capacitance equivalent with the value that can be changed by the control and supply voltages [5]. At the terminals of drain-drain transistors VT1, VT2 the impedance is observed that is the sum of a real component having negative value and an imaginary component of the capacitive nature (effect).

The presented CAE on FTSNR consists of two complementary field transistors VT1, VT2; two sources: U1 – supply, U2 – control. Its equivalent AC circuit (fig. 1b) includes the equivalent circuits of the first and second transistors respectively: R1, R4 – gate-source resistance, R2, R3 – drain-source resistance, C1, C6 – gate-source capacitance, C2, C4 – gate-drain capacitance, C3, C5 – drain-source capacitance, g, g1 – voltage sources controlled by the voltages at the gates of transistors VT1, VT2 respectively. An equivalent capacitance appears at the terminals Uc and its value can be changed by the control and supply voltages.



a) b) c)

Fig.1. Circuits of CAE on FTSNR: electrical (a), AC equivalent (b), in MicroCAP environment(c)

To derive analytical dependences of the real and imaginary components of the impedance on the supply and control voltages, the package of Applied Mathematical Research – Maple – is used as well as its specialized application Syrup for symbolic calculation of electrical circuits. Analytical relationship of CAE on FTSNR is obtained.

$$\dot{Z}=\frac{-(U_1(-jB_1+jB_2+((C_1+C_3+C_5+C_6)R_1R_2R_3R_4+(B_6R_1R_2R_3+(B_8+(C_2+C_3+C_4+C_6)R_1R_2)R_4)R_5)\omega))}{B_4-jB_7R_3+R_1(-j(1+g1R_3)R_4U_1+R_2(jB_3+B_5-j(U_1+g1R_3U_1-gR_4U_2))+R_3R_4(B_6U_1-(C_1+C_2)U_2)\omega)},$$

where

$$B_1=R_1R_2R_3+R_1R_2R_4+R_1R_3R_4+R_2R_3R_4+(R_1+R_3+gR_1R_3)(R_2+R_4)R_5,$$

$$B_2=(C_3(C_4+C_5)+C_5C_6+C_1(C_2+C_3+C_4+C_6)+C_4(C_5+C_6)+C_2(C_3+C_5+C_6))R_1R_2R_3R_4R_5\omega^2,$$

$$B_3=R_3R_4(C_1(C_2+C_3+C_4+C_6)U_1+(C_3(C_4+C_5)+C_5C_6+C_4(C_5+C_6))U_1+C_2(C_3+C_5+C_6)(U_1-U_2)-$$

$$-C_1(C_2+C_3+C_6)U_2)\omega^2,\ B_4=R_2R_3R_4((C_2+C_3+C_4+C_6)U_1-(C_2+C_3+C_6)U_2)\omega,$$

$$B_5=(((C_1+C_2+C_4+C_5)R_3+(C_2+C_3+C_4+C_6+(C_3+C_6)g1R_3)R_4)U_1-$$

$$-((C_1+C_2)R_3+(C_2+(C_1+C_5)gR_3)R_4)U_2)\omega,\ B_6=C_1+C_2+C_4+C_5,\ B_7=(R_2+R_4)U_1-$$

$$-(R_2+R_4+gR_2R_4)U_2,\ B_8=(B_6R_1+(C_2+C_3+C_4+C_6+(C_3+C_6)g1R_1)R_2)R_3.$$

Decomposition of the impedance of CAE on FTSNR into real and imaginary components is conducted with the application of a specialized mathematical package WolframMathematica [5]. The obtained equations are cumbersome and their solution is possible using advanced computer technology with the application of specialized mathematical program packages. Their detailed study and solution is given in monograph [5].

Electrical circuit of CAE on FTSNR in MicroCAP environment is presented in fig. 1c. Simulation modeling is performed using computer modeling program MicroCAP for electrical circuits. Volt-ampere characteristic of CAE on FTSNR for the supply voltage V1 and different control voltages (2…9 V) is presented in fig. 2. With the growth of control voltage the length of descending portion of the obtained relationship increases and there appears negative differential resistance of the field transistor structure. Under control voltage of 3V negative resistance is observed in the voltage range of 0,5 – 1,5V. When control voltage is 6V negative resistance is observed in the voltage range of 2 – 4,5V. Having visual representation of the volt-ampere characteristic, it is easy to choose the required range of control and supply voltages in order to maintain the operating point in the region where the capacitance equivalent exists (in the descending portion of the volt-ampere characteristic).

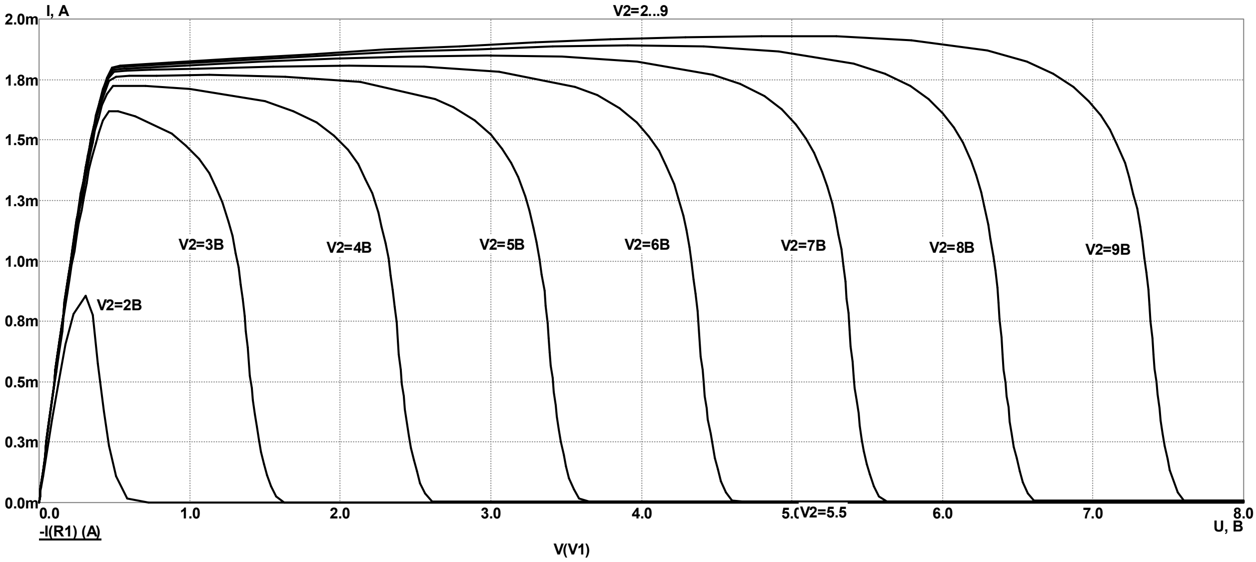


Fig. 2. The family of volt-ampere characteristics of CAE on FTSNR for different control voltages 2 – 8 V

Frequency dependence of the real and imaginary components of the impedance of CAE on FTSNR for different control voltages (4,75; 5; 5,25; 5,5V) is presented in fig. 3. The control voltage provides the possibility of changing absolute values of the real and imaginary components as well as frequency location of the qualitative (characteristic) points of these dependencies (fig. 3). In particular, for the real component of the impedance of CAE on FTSNR the negative resistance value changes from 1 kOhm to 6 kOhm, which is observed in the frequency range from 38 MHz to 100 MHz respectively for voltages 4,75 V and 5,5 V. The imaginary component of the impedance of CAE on FTSNR with capacitive character has the form of the upturned bell, the extremum of which increases its absolute value as the voltage grows and is shifted to the low-frequency region (832 kHz…8,3 MHz).

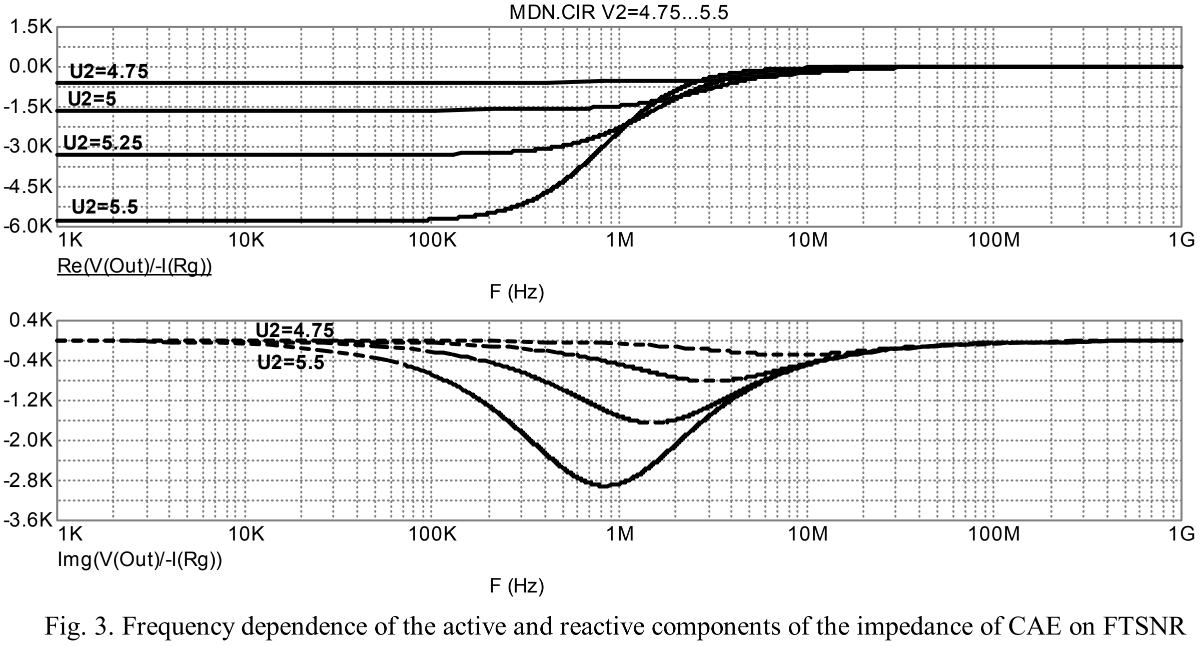


Fig. 3. Frequency dependence of the active and reactive components of the impedance of CAE on FTSNR

Frequency dependence of the equivalent capacitance of the investigated CAE on FTSNR for the control voltage of 4,5 V is presented in fig. 4. On the obtained dependence two characteristic regions are observed. The first is the region where significant changes of the equivalent capacitance of CAE on FTSNR is observed – from 1090 pF to 43 pF. In the second region the equivalent capacitance remains practically unchanged in the wide frequency range from 500 kHz to 1GHz, varying from 43 pF to 32 pF.

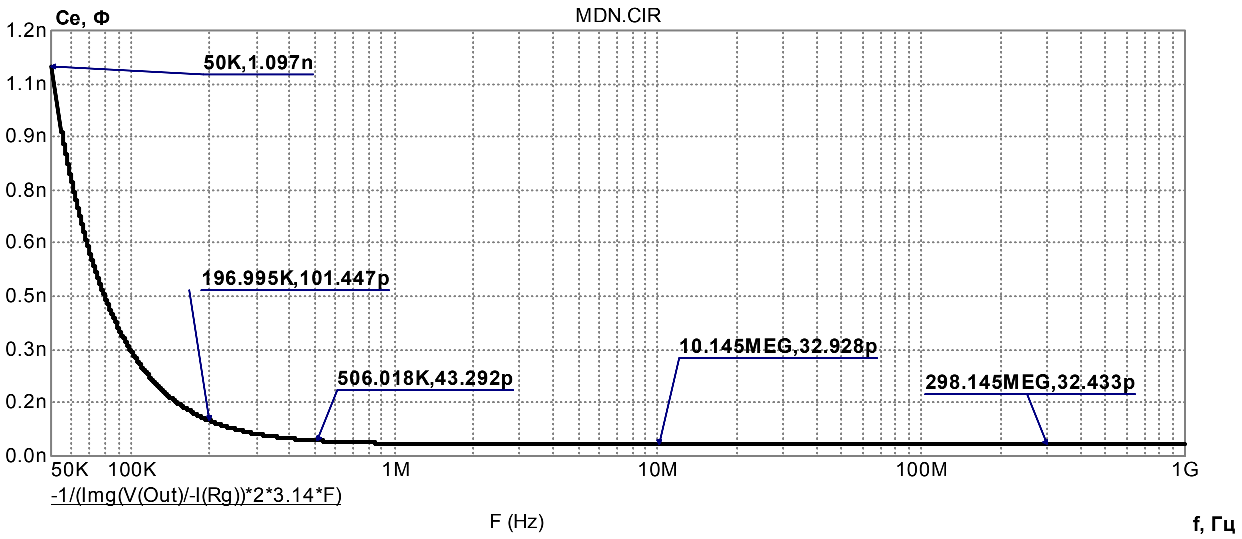


Fig. 4. Frequency dependence of the equivalent capacitance of CAE on FTSNR

The relationship curve for the variations of the equivalent capacitance of CAE on FTSNR versus supply voltage (0...4V) for different control voltages (3…5V) is presented in fig. 5 (volt-farad characteristic). The maximal capacitance overlap coefficient is 139 (10,506 nF / 75,504 pF) for the supply voltage of 3,31 V (supply voltage 5 V, experimental frequency 500 kHz).

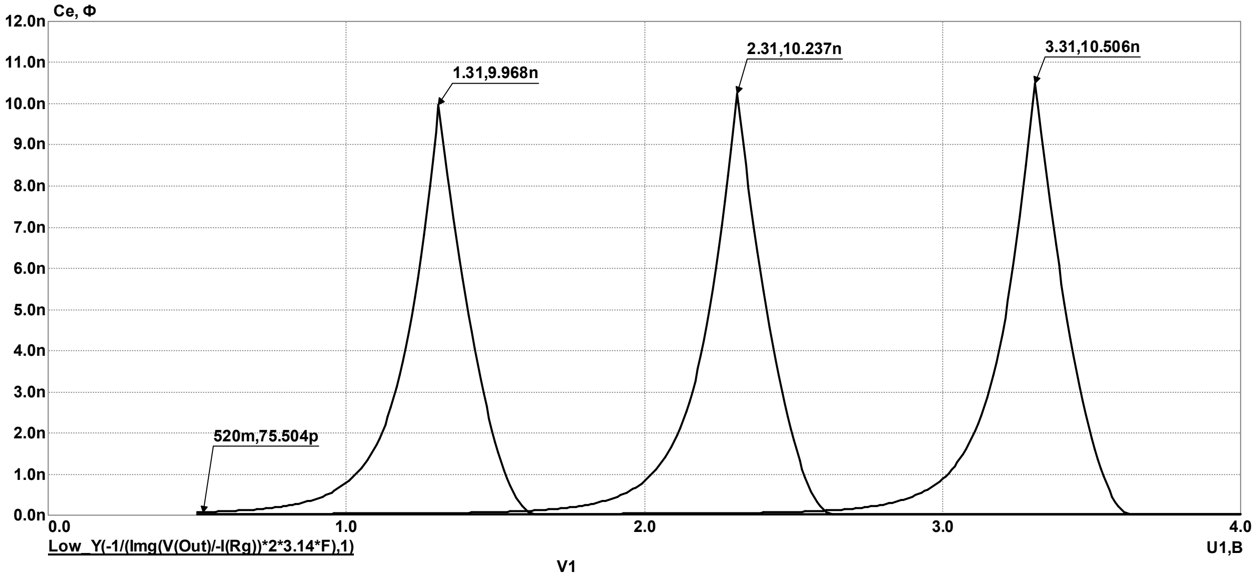


Fig. 5. Dependence of the equivalent capacity value of CAE on FTSNR on the control voltage (supply voltage is 3…5 V)

Influence of the destabilizing factor (environmental temperature variations) on the frequency dependence for the changes of the equivalent capacitance of CAE on FTSNR is presented in fig. 6. With the growth of environmental temperature, the absolute value of equivalent capacitance of CAE on FTSNR decreases. Temperature coefficient of the capacitance of the developed CAE on FTSNR is in the range of 2 – 3*10^{-4} (1 / ^{o}C), i. e. as that of modern varicaps.

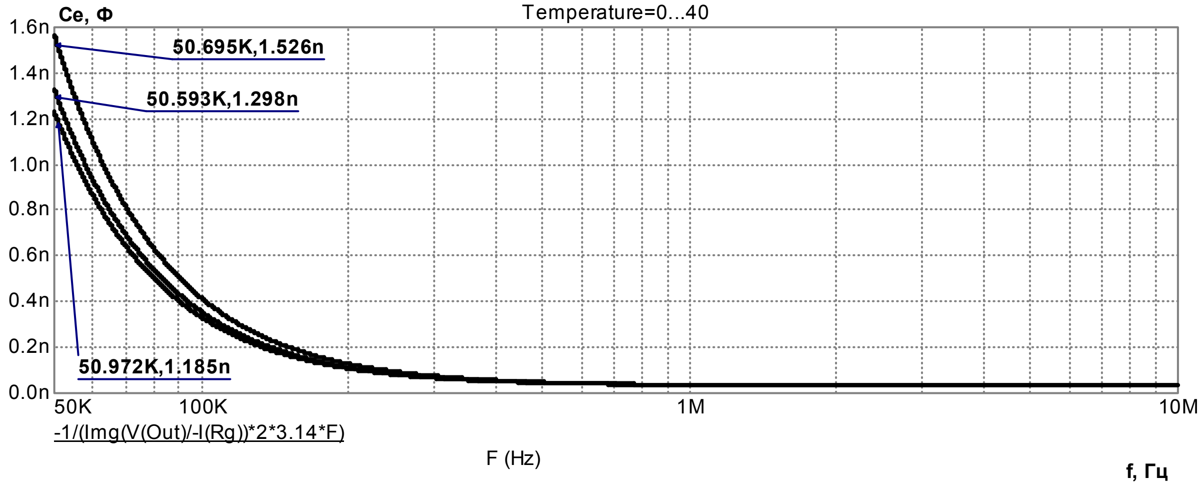


Fig. 6. Frequency dependence of the equivalent capacitance of CAE based on FTSNR in the varying environmental temperature conditions

The results of simulation of CAE on FTSNR are presented in the table.

Table

Results of simulation modeling of CAE on FTSNR

Parameter	The value of negative resistance (kOhm)	Variation range of the equivalent capacitance (nF)	Frequency range (MHz)	Operating voltage range (V)	Readjustment coefficient (units)
Value	1 – 6	0,075 – 10,5	0,001 – 31	0,5 – 8	139

With the application of capacitive effect of CAE on FTSNR one- and two-tier electric filters are designed and investigated. Simulation of their main characteristics and parameters (cut-off frequencies, passbands, the slope of fading outside the passbands) depending on the influence of the control and supply voltages was conducted. CAE on FTSNR in the developed low-pass filter (fig. 7) is formed by the transistor structure VT1, VT2 (2N6804 и 2N6661), the impedance of which is created by the sum of the real and imaginary components having negative resistance and capacitive character respectively. The value of impedance components can be changed by the control and supply voltages, which influences the operating parameters and characteristics of the low-pass filters on FTSNR on the whole.

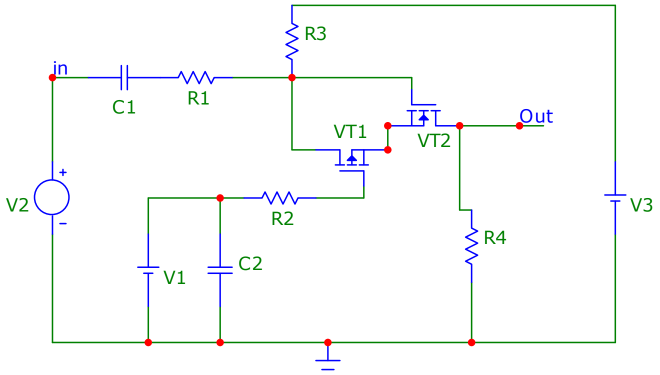


Fig. 7. Electrical circuit of the one-tier low-pass filter on FTSNR

The obtained results of simulation of the amplitude frequency and phase characteristics of the developed low-pass filter for different control voltages (2…5 V) confirm the possibility to control the cut-off frequency (with the growth of control voltage the cut-off frequency value increases) in the range of 0,5 … 5 MHz with maximal fading outside the bandwidth of up to 20 dB / octave.

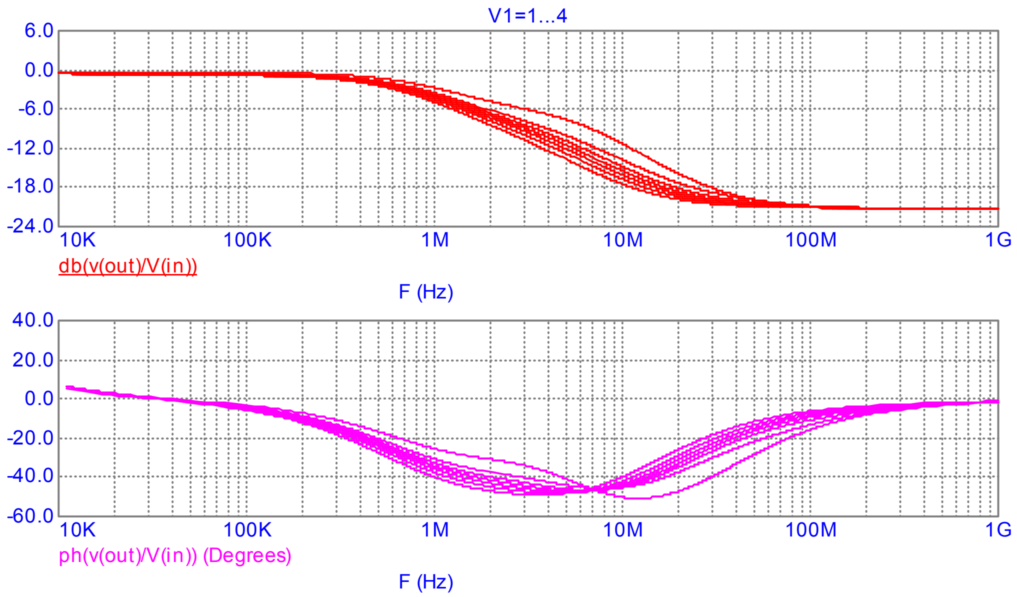


Fig. 8. Frequency and phase characteristics of a one-tier low-pass filter on FTSNR for different control voltages (1 – 4V)

In order to improve operating characteristics of the investigated low-pass filter on FTSNR it is feasible to increase the number of active units and to analyze the operating parameters of the two-tier low-pass filter on FTSNR with the electric circuit containing two filtering units presented in fig, 7. The results of simulation of frequency characteristics for two-tier low-pass filter on FTSNR are presented in fig. 9. .

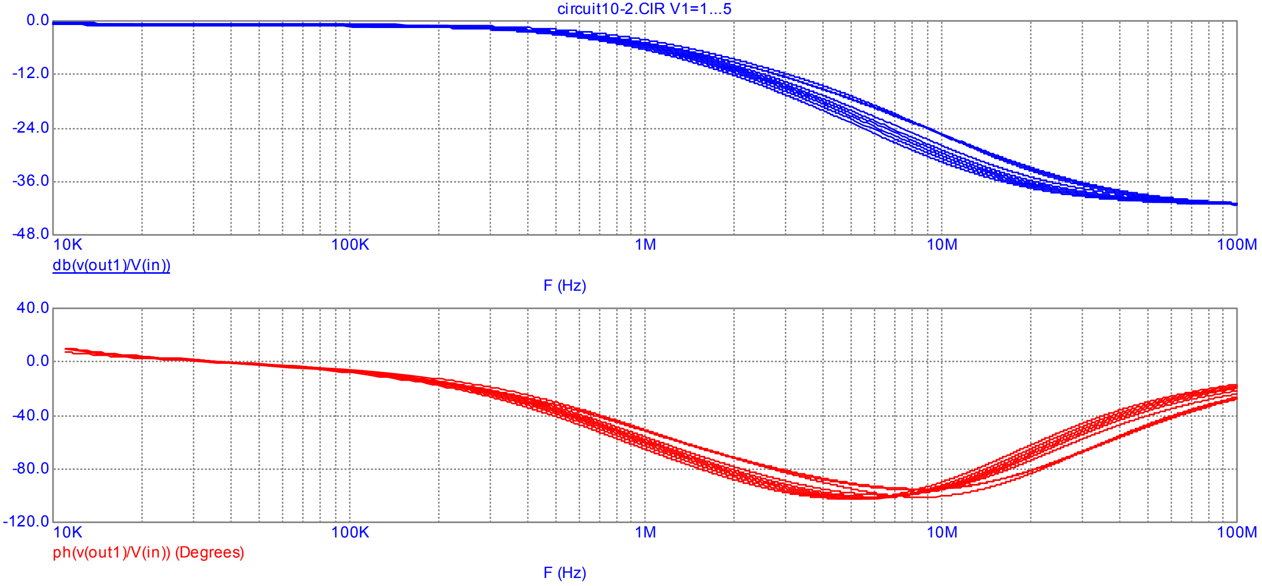


Fig. 9. Amplitude frequency and phase frequency characteristics of the two-tier low-pass filter on FTSNR for different control voltages (1 – 5 V)

The obtained amplitude frequency characteristic confirms the possibility to control the cut-off frequency (with increasing control voltage the cut-off frequency values are growing) in the range of 700 KHz – 2 MHz with control voltage varying from 1 to 5V and doubling attenuation outside the passband (maximum 40 dB).

Conclusions

The paper investigates the capacitive active element on the field-transistor structure with negative resistance where the equivalent capacitance value could be electrically controlled with readjustment coefficient up to 139 units for control voltage of 3,31V (supply voltage of 5V and experimental frequency of 500 KHz). The negative component of the impedance of CAE on FTSNR varies in the range of 1 – 6 kOhm, absolute change of its equivalent capacitance corresponds to 0,075 – 10,5 nF and operating frequency range is in the range of 0,001 – 31 MHz. Investigation of one- and two-tier low-pass filters with the application of CAE on FTSNR has confirmed the electrical controllability of the passband (the cut-off frequency) , the possibility of a cut-off frequency control in the range of 0,5…5 MHz (700 kHz … 2 MHz), as well as to determine that maximal attenuation outside the passband is up to 20 dB / octave (40 dB / octave) for one- and two-tier low-pass filters with CAE on FTSNR. Application of the developed CAE on FTSNR will make it possible to simplify classical circuits of radio-measuring and radio-engineering equipment with simultaneous improvement of their electrical controllability providing the possibility of their integral implementation.

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