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ACTIVE COMPONENT OF RADIOMEASURING DEVICES ON BIPOLAR TRANSISTOR STRUCTURE WITH NEGATIVE RESISTANCE

There had been suggested the research and computer simulation of active component in radiomeasuring devices on bipolar transistor structure with negative resistance. There had been received the dependences of full resistance and its real and imaginary parts on supply voltage and control, using the equivalent circuit, frequency dependence of equivalent capacity of active, components on bipolar transistor structure with negative resistance.

Key words: *bipolar transistor structure, negative resistance, radiomeasuring device, equivalent capacity, real component of full resistance, imaginary part of full resistance.*

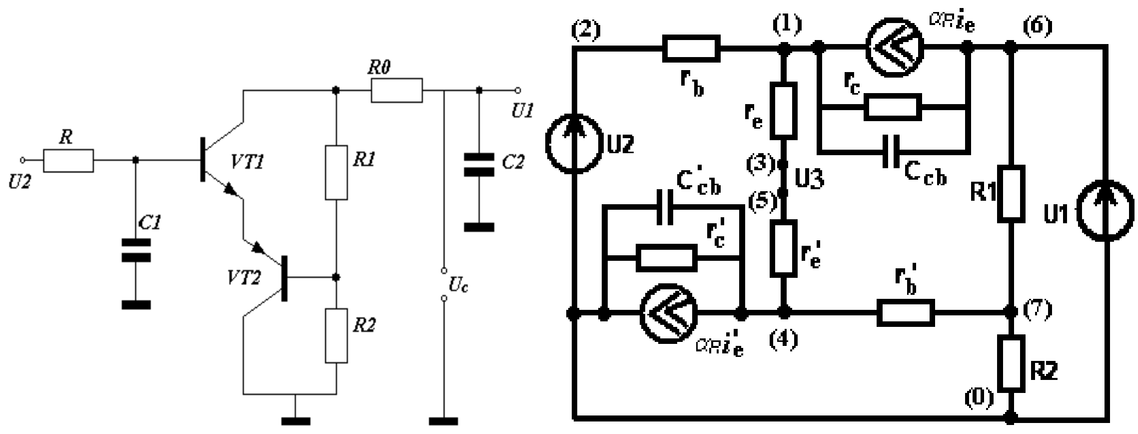
Topicality

It is known that the development of modern radiomeasuring devices goes on using the latest element base, which allows to simplify classical circuits of radiomeasuring devices (RMP). Use of original circuit engineering solutions allows to widen functional peculiarities of such RMD [1]. Electrical control over parameters of functional nodes of RMD is mainly performed by voltage variable capacitors. However, these devices have relatively small coefficient of retargeting (from 1 to 50), value of equivalent capacity (from 1 to 500 pF) and good quality (from 10 to 100) [2, 3]. Electrically controlled capacity equivalents on bipolar transistor structure with negative resistance (BTSNR) do not suffer from such drawback due to use of four p-n-barriers [4, 5]. Using such elements requires the knowledge of physics of their processes and the knowledge of simulation of their electric characteristics.

Therefore the object of this paper is to research the active component of radiomeasuring devices on bipolar transistor structure with negative resistance. The solution of the above aim requires the solution of the following tasks: 1) to receive dependences of full resistance of active component of RMD and its active and reactive constituents on BTSNR on voltage supply and controlling taking into account physical processes which occur; 2) to simulate the dependences of current-voltage characteristics, equivalent capacity, real and imaginary part of the full resistance in frequency range and on voltage supply change and controlling over active component of RMD on BTSNR; 3) to simulate an influence of destabilizing factors of the above parameters of active component of RMD on BTSNR.

Development and research of active component of RMD on BTSNR

Using inner positive connection in bipolar transistor structure (fig. 1a), which results in appearance of negative resistance, it is possible to receive the electrically controlled equivalent of capacity, the value of which it is possible to change by supply and control voltages [5]. Visual presentation of such possibility is observed in CVC of active component of BTSNR. On the outputs collector-collector in transistors VT1, VT2 the full resistance is composed of a real component with negative value and imaginary component with capacitive effect.



a) b)

Fig. 1. Electric circuit (a) and equivalent circuit (b) of active component of RMD on BTSNR

The presented active element of RMD on BTSNR is composed of two complementary bipolar transistor VT1, VT2; two power supplies U1 – power supply, U2 – control; filter strips of voltage supply RC1, R0C2; potential divider R1, R2, which determines the location of the operating point current-voltage characteristics of this equivalent of capacity relating to voltage supply. To derive the dependence of real and imaginary components of full resistance on voltage supply and control, we compose the equivalent circuit for active component for RMD on BTSNR, using the model of Ebers-Mole for bipolar transistors (fig. 1b).

Using the package of applied mathematical research Maple and its specialized application Syrup for symbol calculations of electric circuits, we conduct calculations of the full resistance of active element for BMP on BTSNR. The description of equivalent circuit (fig. 1b) of active component for BMD on BTSNR in symbols

```
> bb4 :=
"
V1 6 0
R8 4 7
R7 4 0
R6 7 0
R5 6 7
R4 1 6
R3 5 4
R2 1 3
R1 2 1
C1 6 1
C2 4 0
V2 2 0
V3 3 5 0
F 1 6 V3 a1
F1 0 4 V3 a2
.end";
syrup(bb4, ac, 'curr');
```

We simplify and transform the received symbol result of the full resistance, using specialized mathematical package WolframMathematica,

$$Z = \frac{iR_2(B_1 + B_2R_3 + B_2R_4) - R_1(-iB_7 + B_{12}B_4C_2R_5\omega + R_2(iB_{10} - i(1 + a1)(R_7 + R_8) + B_{15}\omega) - iB_4(1 + a1 + iB_{12} + C_1\omega))}{-iB_{14} + R_1(B_{16} + (C_1R_2(B_{11} + B_4 + B_5 + B_{13}R_3) + C_2R_5(B_9 + B_8(R_6 + R_8)))\omega + iB_9C_1C_2R_2R_5\omega^2}$$

,

where $B_1 = (1 + a2)R_5(R_7R_8 + R_6(R_7 + R_8))$, $B_{16} = -i(B_{11} + B_5 + B_{13}B_8 + B_{13}R_3 + R_6R_7 + R_6R_8 + R_7R_8$,
$B_2 = R_7R_8 + R_6(R_7 + R_8) + R_5(R_7 + R_8 + iC_2(R_7R_8 + R_6(R_7 + R_8))\omega)$, $B_3 = R_3(R_5 + R_6 + R_7)R_8$,
$B_4 = R_7R_8 + R_6(R_7 + R_8)$, $B_5 = R_4(R_5 + R_6 + R_8)$, $B_6 = (R_5 + R_6)R_7$, $B_{13} = R_5 + R_6 + R_8$,
$B_7 = B_1 + B_3 + B_6R_3 + B_6R_4 + R_4(R_5 + R_6 + R_7)R_8$, $B_8 = (1 + a1)R_2$,
$B_9 = R_6(R_3 + R_4 + R_7) + (R_3 + R_4 + R_6 + R_7)R_8$, $B_{10} = B_4C_1C_2(R_3 + R_4)\omega^2$, $B_{11} = R_5(R_6 + a2R_6 + R_7)$,
$B_{14} = B_1 + B_2R_3 + B_2R_4 + R_2(-B_{10}R_5 + R_3R_5 + R_4R_5 + R_3R_6 + R_4R_6 + R_5R_6 + a2R_5R_6 + R_3R_8 +$
$+R_4R_8 + R_5R_8 + a1R_5R_8 + a2R_5R_8 + i(B_7C_1 + B_{12}C_2R_5(R_6 + R_8))\omega)$,
$B_{15} = (1 + a1)B_4C_2 + C_1(B_{12} + R_6 + a2R_6)R_7 + C_1(B_{12} + (1 + a2)(R_6 + R_7))R_8$, $B_{12} = R_3 + R_4$.

Using specialized mathematical package WolframMathematica, we factorize and simplify the received expression of full resistance of active component of BMD on BTSNR on real and imaginary parts. The real part of active component of BMD on BTSNR

$$\mathrm{Re}[Z] = \frac{-(D + D_1)R_2}{D + 2D_1 + R_2^2(2D_5R_3R_5 + R_3^2(C_1D_2 + D_4 + (R_6 + R_8)^2 + 2R_5(R_6 + R_8 + C_1^2D_3(R_7 + R_8)^2\omega^2)))},$$

де $D_4 = R_5^2(1 + (2C_1C_2R_8^2 + C_1^2(R_7 + R_8)^2 + C_2^2(C_1^2D_2 + (R_6 + R_8)^2))\omega^2)$,
$D = (R_3(R_5 + R_6)R_7 + R_3(R_5 + R_6 + R_7)R_8 + (1 + a2)R_5(R_7R_8 + (R_6(R_7 + R_8)))^2 + C_2^2R_3^2R_5^2(R_7R_8 +$
$+(R_6(R_7 + R_8))^2\omega^2$,
$D_1 = R_2((1 + a2)R_5^2((1 + a2)R_6 + (1 + a1 + a2)R_8)(R_7R_8 + (R_6(R_7 + R_8)) + R_3R_5((2(1 + a2)R_6 + 2(1 + a)R_3 \cdot$
$\cdot(R_7R_8 + (R_6(R_7 + R_8)) + R_5(2(1 + a2)R_6(R_7 + R_8) + R_8((2 + a1 + 2a2)R_7 + +(1 + a1 + a2)R_8))) +$
$+R_3^2((R_5 + R_6 + R_8)((R_5 + R_6)R_7 + (R_5 + R_6 + R_7)R_8) + C_2^2R_5^2(R_6 + R_8)(R_7R_8 + (R_6(R_7 + R_8))\omega^2))$,
$D_2 = (R_7R_8 + (R_6(R_7 + R_8))^2\omega^2$, $D_3 = (R_7R_8 + (R_6(R_7 + R_8))\omega^2$,
$D_5 = ((1 + a2)C_1^2D_2 + (R_6 + R_8)((1 + a2)R_6 + (1 + a1 + a2)R_8) + R_5(R_6 + a2R_6 + R_8 + a1R_8 + a2R_8 +$
$+C_1D_3(-a1C_2R_8 + (1 + a2)C_1(R_7 + R_8))))$,
$D_6 = 2(1 + a2)R_6R_8(1 + a1 + a2 + (1 + a2)C_1^2R_7(R_7 + R_8)\omega^2)$.

The imaginary part of full resistance of active element of BMD on BTSNR

$$\mathrm{Im}[Z] = \frac{R_2^2(C_1F_2 + C_2R_3R_5^2R_8(-a1F_3 + R_3R_8))\omega}{F_2 + F_7R_2^2 + 2R_2(F_8 + (1 + a2)F_1F_3R_5^2 + R_3R_5(F_3(2(1 + a2)R_6 + (2 + a1 + 2a2)R_8) + R_5F_9))},$$

де $F = (R_3(R_5 + R_6)R_7 + R_3(R_5 + R_6 + R_7)R_8 + (1 + a2)R_5(R_7R_8 + R_6(R_7 + R_8)))^2$,
$F_1 = (1 + a2)R_6 + (1 + a1 + a2)R_8$, $F_2 = F + C_2^2R_3^2R_5^2(R_7R_8 + R_6(R_7 + R_8))^2\omega^2$,
$F_3 = R_7R_8 + R_6(R_7 + R_8)$, $F_4 = R_5^2(1 + \omega^2(2C_1C_2R_8^2 + C_1^2(R_7 + R_8)^2 + C_2^2((R_6 + R_8)^2 + C_1^2F_3^2\omega^2)))$,
$F_5 = R_6 + a2R_6 + R_8 + a1R_8 + a2R_8 + C_1F_3(-a1C_2R_8 + (1 + a2)C_1(R_7 + R_8))\omega^2$,
$F_6 = R_8^2((1 + a1 + a2)^2 + (1 + a2)^2C_1^2R_7^2\omega^2) + 2(1 + a2)R_6R_8(1 + a1 + a2 + (1 + a2)C_1^2R_7(R_7 + R_8)\omega^2) +$
$+(1 + a2)^2R_6^2(1 + C_1^2(R_7 + R_8)^2\omega^2)$,
$F_7 = (F_6R_5^2 + 2R_3R_5(F_5R_5 + F_1(R_6 + R_8) + (1 + a2)C_1^2F_3^2\omega^2) + R_3^2(F_4 + (R_6 + R_8)^2 + C_1^2F_3^2\omega^2 +$
$+2R_5(R_6 + R_8 + C_1^2F_3(R_7 + R_8)))$,
$F_8 = R_3^2((R_5 + R_6 + R_8)((R_5 + R_6)R_7 + (R_5 + R_6 + R_7)R_8) + C_2^2F_3R_5^2(R_6 + R_8)\omega^2)$,
$F_9 = R_8((2 + a1 + 2a2)R_7 + (1 + a1 + a2)R_8) + 2(1 + a2)R_6(R_7 + R_8)$.

Let us simulate the researched active component of BMD on BTSNR by program of computer simulation of electric circuits MicroCAP [6]. The electric circuit of the researched active component in the environment MicroCAP is presented in fig. 2.

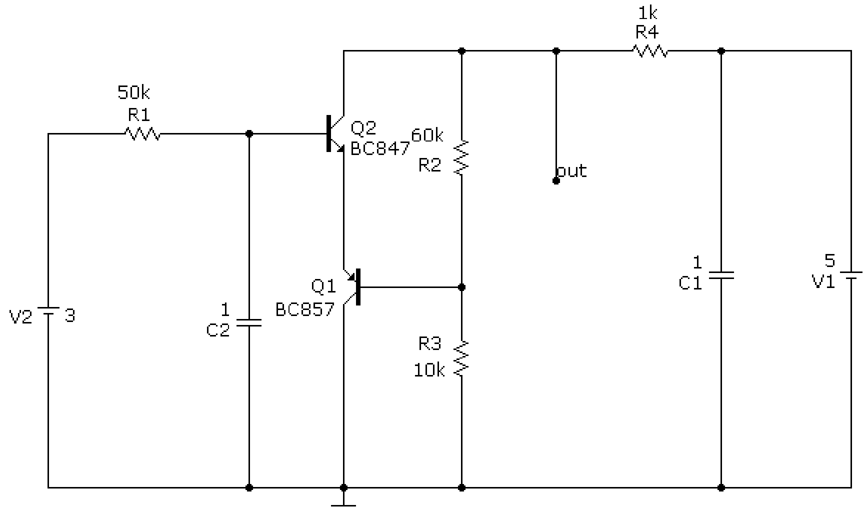


Fig. 2. Electric circuit of active component of BMD on BTSNR in the environment of MicroCAP

Current-voltage characteristics of active component of BMD on BTSNR relative to voltage supply source V1 under different control voltages (1,5...3,5 V) is presented in fig. 3. Increasing voltage of control, we observe the increase of maximal current CVC, accordingly, the length of descending section increases, on which there appears the negative differential resistance of bipolar transistor structure. With control voltage of 1,5 V, the negative resistance is observed within the range of voltages 1 – 2,8 V. With control voltage of 3,5 V, the negative resistance is observed within the range of voltages 1 – 20 V. Pitch of CVC is almost the same under different control voltages, that is, the value of negative resistance is also constant and approximately equals 2 kOhm. Visual presentation of CVC allows to choose the necessary range of control and supply voltages with an aim to retain the operating point on the section with equivalent capacity (on the descending section of CVC).

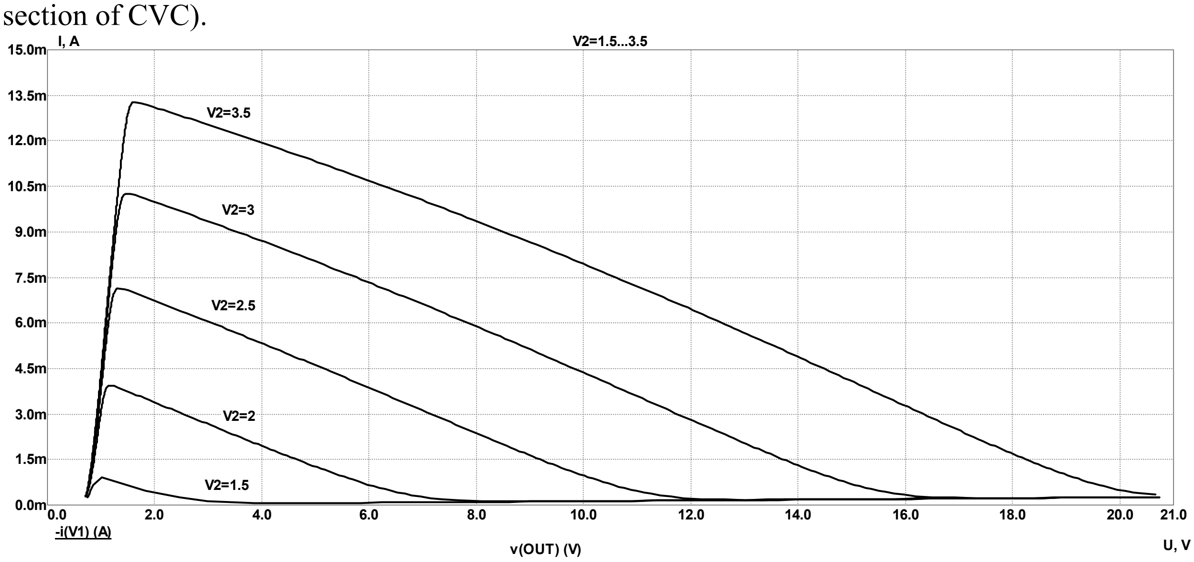


Fig. 3. Current-voltage characteristics of the researched equivalent of capacity on bipolar transistor structure with negative resistance

Frequency dependence of real and imaginary components of full resistance of active component of BMD on BTSNR is presented in fig. 4. The graph shows that the operating frequency range of existing of capacity equivalent for the set conditions of analysis corresponds to frequencies from 1 kHz to 455 kHz. The negative component of full resistance is constant in frequency range (1 kHz...20 kHz) and makes up approximately 2 kOhm. Transition region of gradual increase is within 20 kHz to 455 kHz. Reactive component of full resistance has the form of upturned bell, the valley appears on frequency 87,3 kHz.

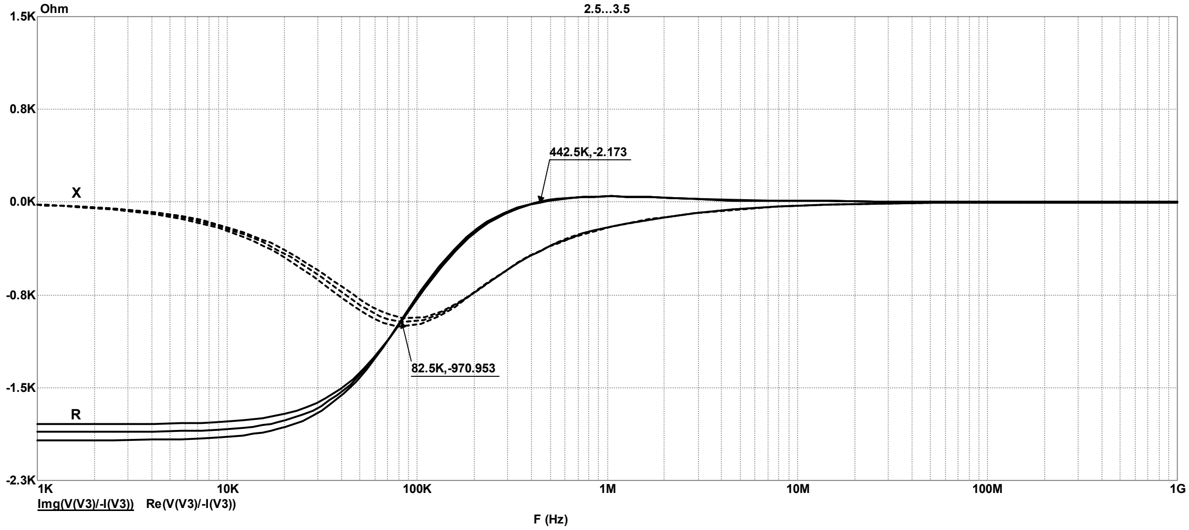


Fig. 4. Frequency dependence of active and reactive components of full resistance of active component BMD on BTSNR

Dependence of equivalent capacity change of the researched active component BMD on BTSNR on frequency with different controlling voltages (2...4 V) is presented in fig. 5. The obtained equivalent capacity is almost not changing in the wide frequency range (50 kHz…1 MHz) and varies within (1.2…0.85 nF).

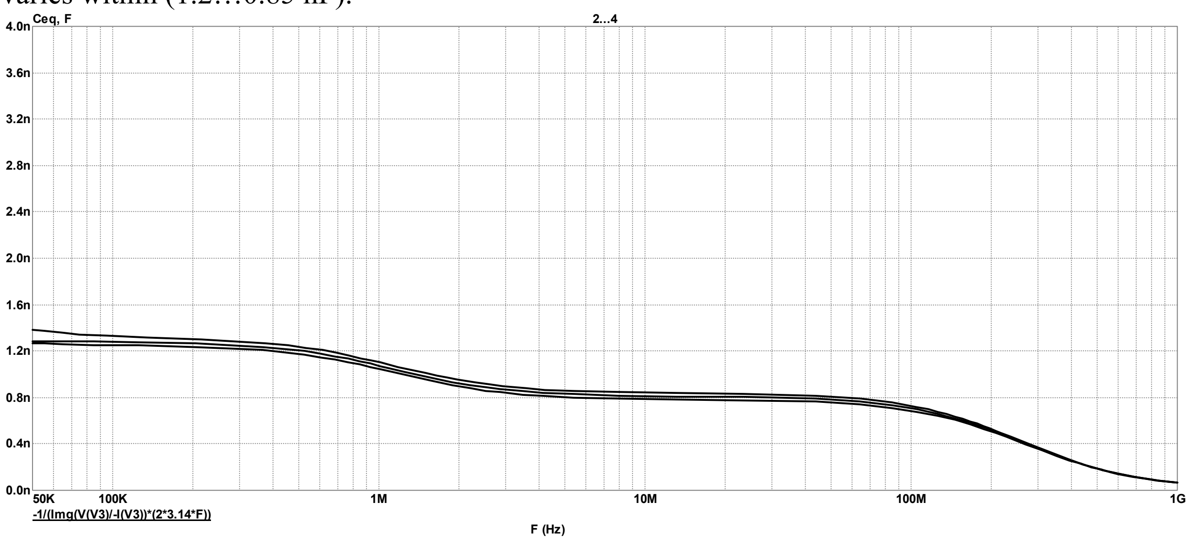


Fig. 5. Dependence of equivalent capacity change of active component BMD on BTSNR on frequency

The change of equivalent capacity on voltage supply (2,5...6 V) under different controlling voltages (3…5 V) is presented in fig. 6. Maximal factor of capacity overlapping makes up 30 with control voltage of 3 V, experimental frequency 100 kHz.

The influence of destabilizing factor (change of environment temperature) on CVC and frequency dependence of changing equivalent capacity of active element of BMD on BTSNR is presented in fig. 7 and 8.

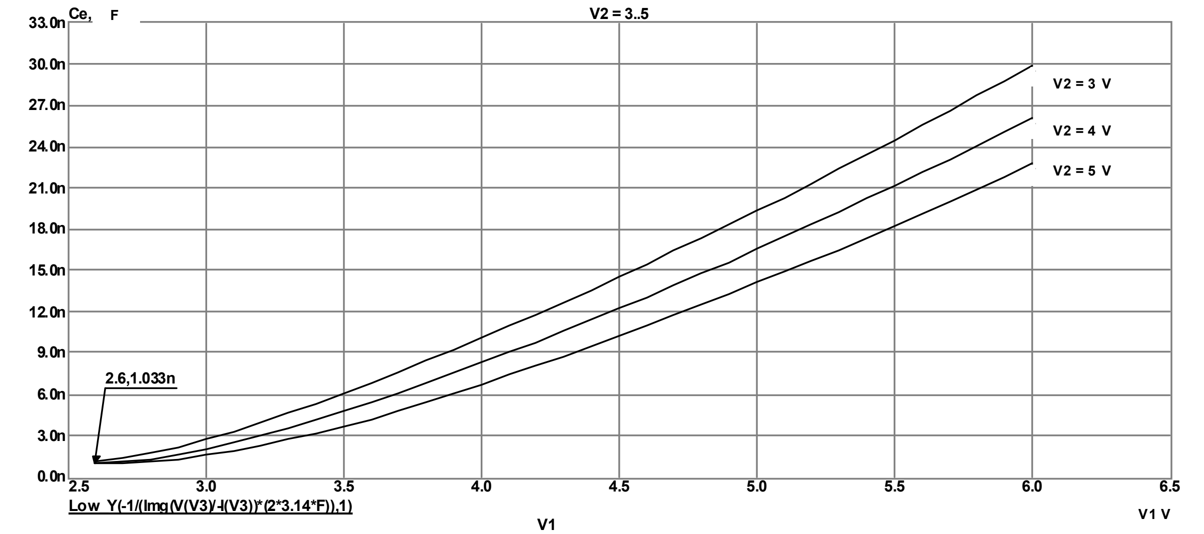


Fig. 6. Dependence of equivalent capacity change of active component BMD on BTSNR on voltage supply with different controlling voltage 3…5 V

As it is seen from the figure, the increase of temperature increases the maximum current by 0,34 mA for T=50 ^oC and 75 ^oC accordingly.

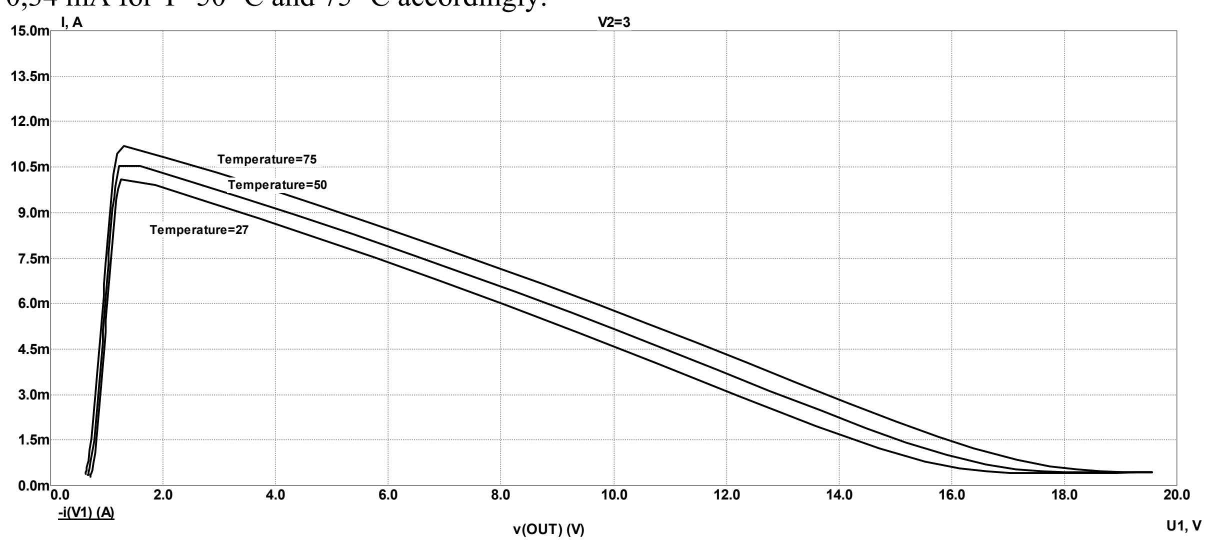


Fig. 7. CVC of active component of BMD on BTSNR under different operating temperatures with controlling voltage of 3 V

Equivalent capacity of active component of BMD on BTSNR changes 0,6 nF and by 1 nF for T=50 ^oC and 75 ^oC accordingly on frequency 50 kHz. This influence of temperature on character of frequency dependence under different temperatures of environment is observed within the frequency range (50...250 kHz). Results of imitating simulation of active component of BMD on BTSNR is shown in table.

Table

The obtained results of imitating simulation of active component of BMD on BTSNR

Parameter	Value of negative resistance	Range of equivalent capacity	Frequency range	Range of operating voltage	Factor of retargeting
Value	kOhm	nF	kHz	V	units
	2	1 – 30	1 – 455	1.8 – 6	30

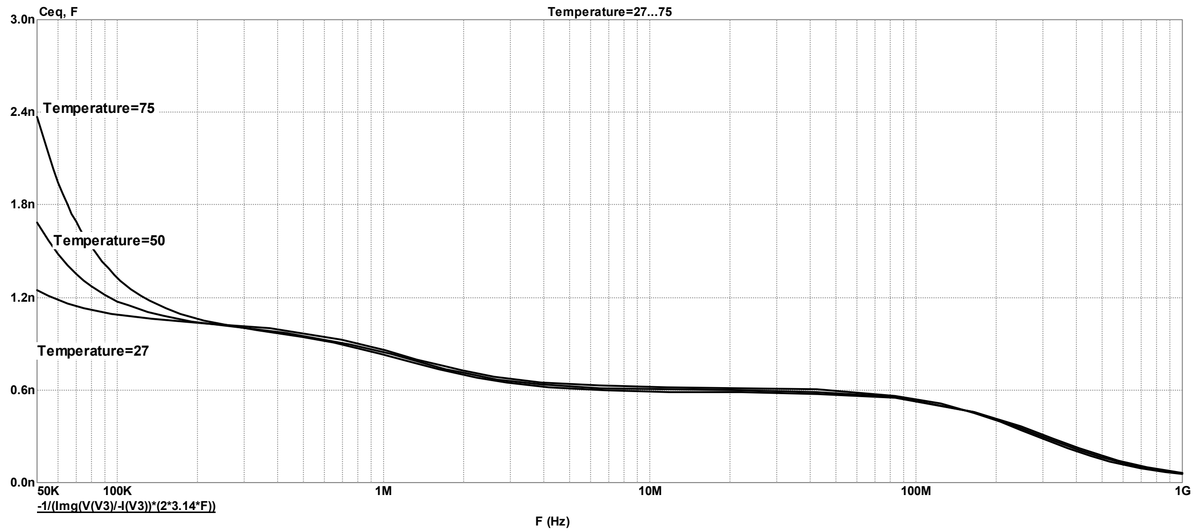


Fig. 8. Dependence of change of equivalent capacity of active component of BMD on BTSNR on frequency with 27, 50, 75 ºC

Conclusions

There had been researched active component of BMD on BTSNR with the possibility of electric control over its negative capacity with retargeting 30. There had been received the analytical dependences of active and reactive constituents of complete resistance of component of BMD on BTSNR. With the help of computer simulation there had been simulated the family of current-voltage-characteristics, frequency dependence of real and imaginary part of complete resistance, equivalent capacity of BTSNR and influence of destabilizing factor on these parameters of the researches of active component of BMD.

The use of the developed active component of BMD on BTSNR will allow to simplify the classical circuits of BMD, improve the controllability of BMD and perform them in the integral kind.

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