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THE RESEARCH OF RADIO-FREQUENCY SWITCHES BASED ON INDUCTIVE TRANSISTOR NEGATRONS

Mathematical models of the radio-frequency switch on the basis of transistors inductive negatron with use of matrixes of transfer are constructed, active resistance of the switch on frequency of a signal is certain at absence of a signal of management and dependence of dynamic resistance on necessary reduction of factor of transfer is received. Expression for on estimation of the relation of power of a signal of management to power of a target signal in a mode is received.

Keywords: *the radio-frequency representation of the information, radio-frequency management, radio impulse logic elements, transistor negatrons, transistor analogues reactivity.*

Introduction

Control elements for amplitude VHF microwave oscillation – frequency switches, are widely used in pulse-frequency logical elements (PFLE) construction. Today different kinds of microwave switches are used in various radiotechnical devices and in measuring equipment, but they do not fit for PFLE construction. It is caused by videopulse controlling in the radiotechnical devices. Such controlling method of switches in radiopulse logical elements requires an extra transformations of radiopulses to videopulses. As a result, the pulse circuits appear in element, causing additional delay and the circuit becomes more complicated [1]. Furthermore, the basic performances of radiotechnical switches are also not suitable for using in logical elements. Radiotechnical switches are to ensure the minimal output power drop and little loss in pass mode [2]. Because of this, the pass band of switch's resonant system in "locked" mode is much less than in "pass" mode. In radiocontrolled switches that are used in logical elements, the maximum power drop is not required, it's necessary to provide with equal bands in both "locked" and "opened" modes with defined the drop of power and with minimal level of controlling power. Thus in order to control the amplitude in logical elements, the special switches are required.

Problem statement

Papers [3, 4] suggest the radiofrequency switches based on dynamic negatrons that use changing of active and reactive impedance components. Analysis of these papers indicates that such devises are specified by a number of advantages and at the same time they are not sufficiently researched. There are no researches allowing to estimate influence of technological-manufacturing divergence of parameters of components for output parameters, their optimization is not done, the synthesis methods are not designed. To solve these problems it's necessary to build the mathematical models of such elements – which is the objective this paper.

Basic part

Mathematical models of such elements represent the dependence of their parameters: gain, power drop from component parameters of the electrical circuit in both "opened" and "locked" modes, voltages and supply currents and also these parameters versus control voltage response, etc.

For processes' analysis occurring inside of the switch, the quasi-linear technique will be used and the following simplifications will be introduced: frequencies of resonant systems will match with the frequency of control signal; oscillating systems are narrow-band enough and hence harmonic components' influence might be neglected; filters used in the switching circuit have high quality-factor and their influence on switch's performance is not considered.

The development of the mathematical model for the switch will be started with the mean transistor negatron resistance versus control and signal response definition.

Transistor voltage will be equal to:

$$U_T = U_c \cos \omega_c t + U_k \cos \omega_k t\,, \tag{1}$$

where U_c, U_k – voltage amplitudes of signals ω_c and ω_k.

During the approximation of the dynamic input transistor response by 3-rd power polynomial we obtain:

$$i_T(U_T) = I_0 + \alpha(U_c \cos\omega_c t + U_k \cos\omega_k t) + \beta(U_c \cos\omega_c t + U_k \cos\omega_k t)^2 + \gamma(U_c \cos\omega_c t + U_k \cos\omega_k t)^3. \tag{2}$$

Amplitudes of constituent currents on the frequencies of signal and control can be obtained from (2) by Fourier series [5]

$$I_c = \frac{1}{\pi}\int_0^{2\pi} i_T(U_T)\cos\omega_c t d\omega_c t, \qquad I_k = \frac{1}{\pi}\int_0^{2\pi} i_T(U_T)\cos\omega_k t d\omega_k t.$$

Integrating the last expression taking into account (2), we obtain:

$$I_c = -\alpha U_c + \frac{3}{4}\gamma U_c^2 + \frac{1}{2}U_k^2 U_c, \qquad I_k = -\alpha U_k + \frac{3}{4}\gamma U_k^2 + \frac{1}{2}U_c^2 U_k. \tag{3}$$

Correspondingly, the average transistor resistances on the frequencies of signal and control are equal to:

$$R_{TC} = \frac{U_c}{I_c} = \frac{4}{-4\alpha + \gamma\left(3U_c^2 + 2U_k^2\right)}, \qquad R_{TK} = \frac{U_k}{I_k} = \frac{4}{-4\alpha + \gamma\left(3U_k^2 + 2U_c^2\right)}. \tag{4}$$

Let us establish the connection between the signal's power drop of the switch in both "opened" and "locked" modes and equations for power of signal and control. To do that, let us consider the circuit of switch shown on fig.1.

Let's analyze the pass mode with absent control power. Power gain in such switch can be calculated by determining the total transmission matrix of the element

$$T = [T_1][T_2][T_3][T_4] =$$

$$\begin{vmatrix} e^{j(\theta_1-\theta_2)}\left[\left(1+\frac{Z_1}{2}\right)\left(1-\frac{Y_1}{2}\right)+\frac{Z_1Y_1}{4}\right] & e^{j(\theta_1+\theta_2)}\left[\left(1+\frac{Z_1}{2}\right)-\frac{Z_1}{2}\left(1+\frac{Y_1}{2}\right)\right] \\ \frac{Z_1}{2}\left(1+\frac{Y_1}{2}\right)e^{j(\theta_2-\theta_1)}-\left(1-\frac{Z_1}{2}\right)\frac{Y_1}{2}e^{j(\theta_1-\theta_2)} & \frac{Z_1Y_1}{2}e^{j(\theta_2-\theta_1)}-\left(1-\frac{Z_1}{2}\right)\left(1-\frac{Y_1}{2}\right)e^{j(\theta_1-\theta_2)} \end{vmatrix},$$

where T_1, T_3 – transmission matrixes of transmission line segments; T_2 - transistor negatron transmission matrix; T_4 – transmission matrix of load conductivity; $\theta_i = \frac{4\pi l_i}{\lambda}$ - phase shift introduced by the i-th segment; l_i - segment length; Zi – normalized impedance of transistor negatron; $Y1$ – normalized admittance of load.

$$\tau = S_{21} = \frac{1}{t_{11}} = \left\{e^{j(\theta_1-\theta_2)}\left[\left(1+\frac{Z_1}{2}\right)\left(1+\frac{Y_1}{2}\right)+\frac{Z_1Y_1}{4}\right]\right\}^{-1}. \tag{5}$$

If, for simplification, we neglect the influence of length of line segments and consider assumptions above, then the expression (5) for transmission coefficient can be written as:

$$\tau = \frac{2}{(1+G_н)(R_T+1)+1}. \tag{6}$$

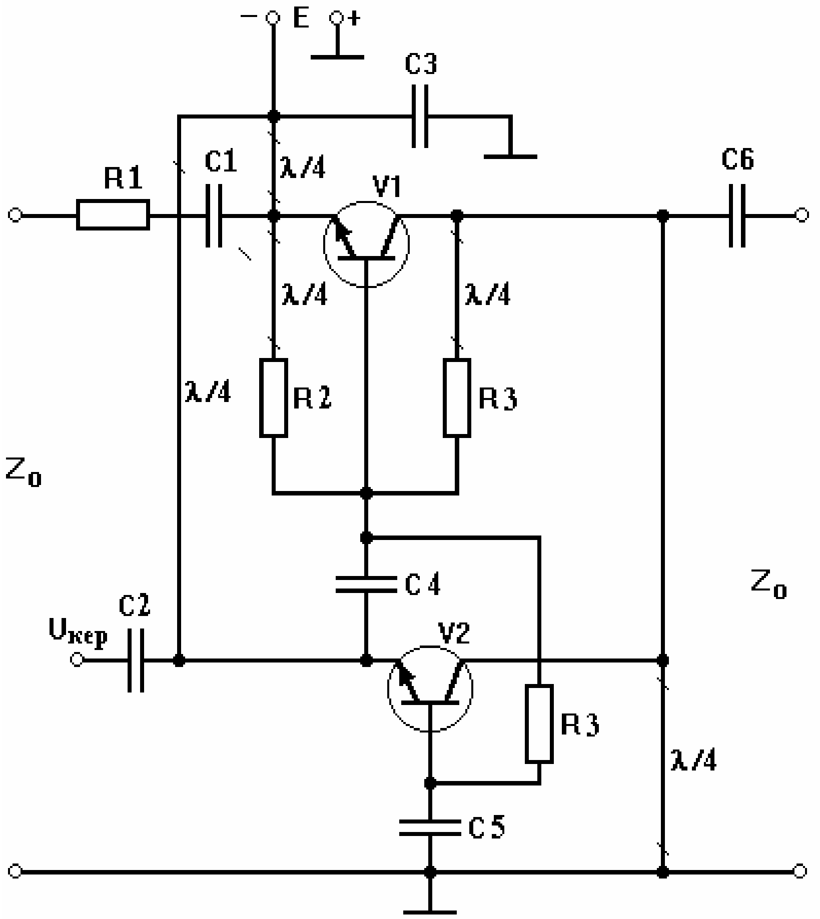

Figure 1. Radiofrequency switch

Choosing the mode of operation for the switch, it’s necessary to provide with minimal controlling power to input signal power ratio, for which it is desirable to increase output power at the assigned gain. This can be achieved by increasing the output signal power, but in this case the gain decreases due to negative resistance reduction, as it is shown in [6].

The gain decrease with the operating power level of the signal in comparison with the gain at very small signal powers is defined as:

$$\frac{K_n}{K_M} = \frac{\left(1 + G_{н,,}\right)\left(1 + R_{TM}\right) + 1}{\left(1 + G_{н,,}\right)\left(1 + R_{Tn}\right) + 1}, \tag{7}$$

where R_{TM}, $R_{TП}$ – reduced average values of the dynamic active resistance of transistor negatron with the infinitely small signal power on input and at pass mode;
G_{HC} – reduced load admittance at signal frequency;
$K_П$, K_M – signal gains in the mass mode and at negligible signal level.

It is possible to obtain the average active resistance of the transistor negatron on the signal frequency with no control signal, from (7):

$$R_{TП} = \frac{K_M}{K_П}\left(\frac{1}{1+G_{YC}} + R_{TM} + 1\right) - \frac{1}{1+G_{HC}} - 1. \tag{8}$$

Let's consider the mode of operation when the control signal is applied to the switch. In this case the average active resistance of the transistor negatron rises, and accordingly, the signal gain decreases. Since the input signal power is constant, the response of power drop on the input of the switch with varying resistance is defined as:

$$\frac{K_П}{K_з} = \frac{R_{T3} + G_{HC} + R_{T3}G_{HC} + 2}{R_{TП} + G_{HC} + R_{TП}G_{HC} + 2}, \tag{9}$$

where R_{T3} – average dynamic resistance of transistor negatron on signal frequency with the simultaneous affecting both, power and control signals; K_3 – signal gain in "locked" mode.

Substituting (8) in (9) and solving obtained expression relatively R_{T3}, we obtain the dynamic resistance of the transistor negatron versus required gain reduction

$$R_{T3} = \frac{K_M}{K_3}\left(R_{TM} + G_{HC} + 2\right) - G_{HC} - 2\,. \tag{10}$$

Let us now determine the control power, required to achieve the desirable gain reduction in "locked" mode. Voltage magnitude with the control frequency required to reduce the gain to the assigned value with the signal frequency, will be determined from (3) and (5) expressions on the assumption that R_{TM}=1

$$U_k^2 = \frac{2(1-\alpha A)}{\gamma A} - \frac{3\gamma U_{c3}^2}{2}, \tag{11}$$

where U_{c3} – signal voltage on transistor negatron in "locked" mode;

$$A = \frac{K_M}{K_3}\left(\alpha + G_{HC} + 2\right) - G_{HC} - 2\,.$$

Signal voltage on the transistor negatron, with the presence of control voltage, can be determined by the signal voltage with the absence of the control power, in case when the output voltage is constant, that is

$$U_M = U_C\left(G_{HC}R_{TC} + 1\right) + U_{C3}\left(G_{HC}R_{T3} + 1\right), \tag{12}$$

where U_m – voltage amplitude of signal source.

From (12) we determine the signal voltage in the attenuation mode:

$$U_{C3} = \frac{G_{HC}R_{TC} + 1}{G_{HC}R_{T3} + 1}U_{CП}\,. \tag{13}$$

Signal voltage on the transistor negatron with the absence of control voltage can be obtained from (4) and (8) expressions:

$$U_{c\ n}^2 = \frac{16}{3\gamma A} + \frac{4\alpha}{3\gamma}\,. \tag{14}$$

Substituting the values of the resistance $R_{TП}$, $R_{Г3}$, expressions (14), (8) and (10) in (13) we obtain an expression for the signal voltage in "locked" mode

$$U_{c3} = \frac{1 + G_{HC}B}{1 + G_{HC}A}\sqrt{\left(\frac{16}{3\gamma A} + \frac{4\alpha}{3\gamma}\right)}, \tag{15}$$

where $B = \dfrac{K_M}{K_n}\left(\alpha + G_{HC} + 2\right) - G_{HC} - 2$.

By substituting (15) into (11) we obtain the dependence of the voltage with the control frequency on parameters of transistor negatron's volt-amps diagram response and on gain in "locked" and "opened" modes.

$$U_k = \left[\frac{2(1-\alpha A)}{\gamma A} - 2\left(\frac{1 + G_{HC}B}{1 + G_{HC}A}\right)^2\left(\frac{4}{A} + \alpha\right)^{1/2}\right]. \tag{16}$$

Control power P_k to signal power $P_{CП}$ ratio can be determined on the assumption that the admittances on inputs of circuits for signal and control are equal:

$$\frac{P_k}{P_{cn}} = \frac{U_k^2}{U_{cn}^2} = \left[\frac{2(-\alpha A)}{\gamma A} - 2\left(\frac{1 - G_{HC} B}{1 + G_{HC} A} \right)^2 \left(\frac{4}{A} + \alpha \right) \right] \left(\frac{16}{3\gamma B} + \frac{4\alpha}{3\gamma} \right)^{-1} . \tag{17}$$

Substituting (13) and (15) into (4) it is obtained mean transistor resistance at control frequency versus gains in "locked" and "opened" modes:

$$R_{TK} = \frac{2}{\gamma \left\{ \left(\frac{1 - \alpha A}{\gamma A} \right) + \left(\frac{4}{B} + \alpha \right) \left[\left(\frac{1 + G_{HC} B}{1 + G_{HC} A} \right)^2 + \frac{4}{3\gamma} \right] \right\} - 2\alpha} . \tag{18}$$

Knowing the value of the average resistance with the control frequency (18), (8) and (10) respectively it's possible to determine the gain of the switch on control frequency. Thus we obtain the mathematical models of frequency switch connecting its' output parameters of transistor negatron, voltage of control and input signals.

Using expressions (11), (14), (15) and (16) signal to control voltage responses are calculated. Plots of signal reduced to voltage signal in attenuation mode versus control voltage are shown on fig 2.

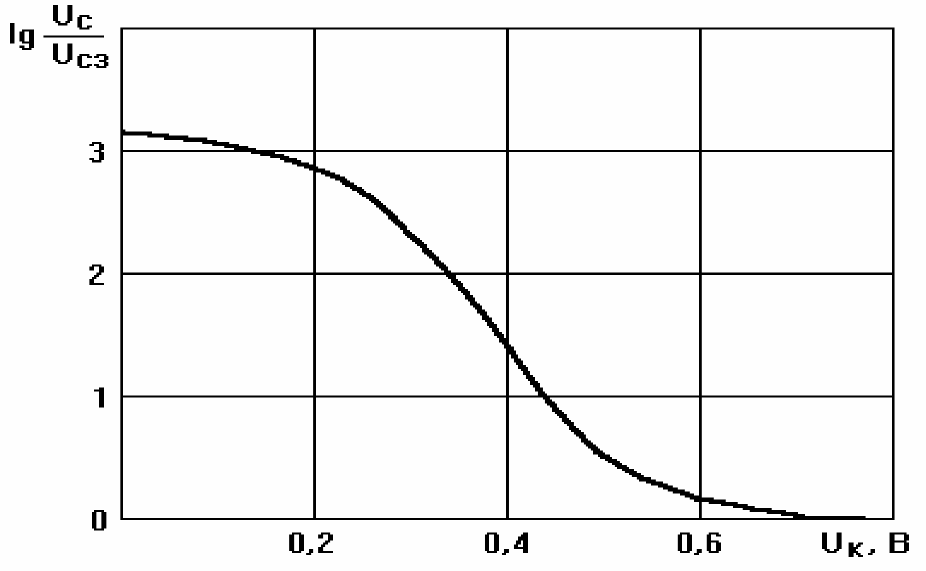

Figure 2. Voltage reduced to signal voltage in attenuation mode versus control voltage response

The obtained results indicate that with the rise of control voltage the output signal decreases and attenuation introduced by amplitude controlling device can be equal to 20 dB. For the sake of increment of attenuation different circuit engineering solutions can be used.

Conclusions

There had been built the mathematical models of frequency switches. There had been obtained the expressions to determine the gain and the average resistance of the transistor negatron on the frequencies on the assumption that the absence of control signal are obtained. For the first time there had been established the dependence of the transistor negatron dynamic resistance on the necessary gain decrement, which is important for synthesis of PFLE that use transistor negatron as the controlling element.

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