Multifrequency optoimmittance logical R-element "NOT"

Lyudmyla B. Lishchynska[*a], Elena V. Voytsekhovskaya[a], Alexander A. Lazarev[a], Roman P. Palamarchuk[a], Paweł Komada[b], Bakhyt Yeraliyeva[c]
[a]Vinnytsia National Technical University, Vinnytsia, Ukraine; [b]Lublin University of Technology, Lublin, Poland; [c]M.Kh.Dulaty Taraz Regional University, Taraz, Kazakhstan

ABSTRACT

The paper proposes the use of switches to synthesize immittance logic elements, which makes it possible to ensure the operation of logic elements at various fixed operating frequencies. This in turn allows to increase the operating frequency range of such elements. For the first time, a mathematical model of a multi-frequency immittance logic *R*-element "NOT" was developed. It allowed to determine the transient characteristics at different operating frequencies. The circuit of the multi-frequency opto-immittance logic *R*-element "NOT" was developed. The results of the study of its transient characteristics showed the possibility of using the circuit in the design of passive immittance logic elements with an extended operating frequency range.

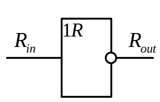
Keywords: immittance logic, optoimmittance logic element, R-element "NOT", passive logic elements, RF logic

1. INTRODUCTION

Video pulse signals are used to process and transmit information in computing technology. However, it is possible to process information at carrier frequencies without converting it into video pulse signals. Optical, radio frequency and immitance logic elements are finding more and more applications [1]. One area of research is the design of radio-frequency logic elements capable of performing logic operations at the signal carrier frequency [2]. Most technical solutions in this area are based on the use of nonlinear properties of semiconductor devices, which limits their speed and energy efficiency. A promising direction for the design of logic elements is the use of negatrons – electronic devices that in a certain mode of operation have a negative value of the main differential parameter: negative resistance, negative capacitance or negative inductance [3,4,5]. A new direction in the construction of radio-frequency logic elements is the use of the principle of fuzzy immitance, when the logic level is determined not by the quantitative value of immitance, but by its nature, such as "0" - capacitive, "1" - inductive. Such immitance logic elements can be implemented both with active [6,7] and only on passive[8-11] electronic elements. In the latter case, the noise immunity and energy efficiency of the logic element are greatly increased, as there are only energy losses at the signal frequency. From a practical point of view, in some cases it is useful to characterize the logic state with an immittance of the same nature (either capacitive (XC), inductive (XL) or active (R)). Such immittance logic elements belong to the group of "optoimmittance elements". The logic levels are defined by the limits of immittance change.

2. THE MULTI-FREQUENCY OPTOIMMITTANCE LOGIC R-ELEMENT "NOT"

In the proposed logic gate, the active immitance "R" will be used as an information parameter. The logic state of the element will be characterized by the range of this parameter values (the logic '1' corresponds to the resistance range $R_{(1)} < R_0$, and the logic '0' is the resistance range $R_{(0)} < R_0$, where R_0 is the boundary limit for the logic levels). The operation of the optoimmittance logical R-element "NOT", the electronic symbol of which is shown in Fig. 1 (left), is described by the truth table, which is shown on the right.



R_{in}		R_{out}	
1	$R_{in}^{(1)} > R_0$	0	$R_{out}^{(0)} < R_0$
0	$R_{in}^{(0)} < R_0$	1	$R_{out}^{(1)} > R_0$

Fig. 1. Electronic symbol and truth table of optoimmittance logical R-element "NOT".

*e-mail: llbnfil1@gmail.com

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The properties of the quarter-wave transmission line segment which realized the "quarter-wave transformer" (Fig. 2a), is proposed to use to implement the logical function, which is described by the truth table in Fig. 1 [7].

Fig. 2. Quarter-wave transformer implementing optoimmittance logical R -element "NOT", and its transient characteristics

Output impedance Z_{out} of such transmission line segment depends on the impedance Z_{in} that connect at its input [9]

$$Z_{out} = Z_0^2 / Z_{in} , \tag{1}$$

where $Z_0 -$ the wave impedance of the transmission line.

If $Z_{in} = Z_{out}$, then $Z_{out} = R_{out} = Z_0^2 / R_{in}$. Assuming that Z_0 has a real fixed value, the transient characteristic of such element has the form shown in Fig. 2b. The graph is shown that for $R_{in} > Z_0$, $R_{out} > Z_0$ and conversely. This corresponds to the above formulated conditions for design the optoimmittance logical R -element "NOT".

The disadvantage of this logical element is that the circuit can only operate at one frequency. Therefore, it is proposed to create a multifrequency optoimmittance logical R -element "NOT", which can operate at different frequencies. This leads to the expansion of the functionality of the circuit and increases the speed. The circuit of the multifrequency optoimmittance logical R -element "NOT" is shown in Fig. 3.

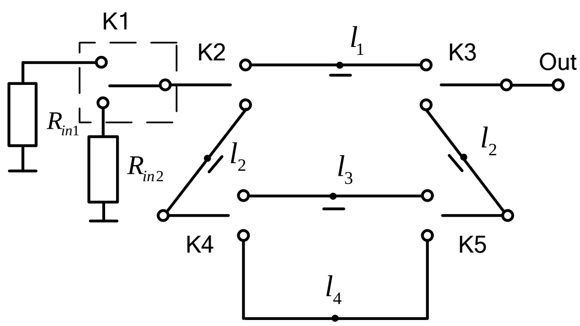


Fig. 3. Multifrequency optoimmittance logical R -element "NOT".

The multifrequency optoimmittance logical R -element "NOT" contains the quarter-wave transmission line segment l_1, the transmission line segments $l_2 - l_4$ in the length of the smaller value $\lambda/4$ (λ - the length of the electromagnetic wave of the input signal), the switches $K_1 - K_5$. The switch K_2 is connected with the switch K_1 and the quarter-wave transmission line segment l_1, the switch K_3 is connected to the output of the device, the quarter-wave transmission line segment l_1 and through the transmission line segment l_2 with the switch K_5, which is connected to the switch K_4 through the transmission line segments l_3 and l_4 and quarter-wave transmission line segment l_1.

To the input of the multifrequency optoimmittance logical R -element "NOT", through the switch K_1 connected two immittance two-poles with resistances R_{in1} and R_{in2}, the values of which correspond to the levels of the logic zero and the logical unit.

3. THE DESIGN OF MATHEMATICAL MODEL OF MULTIFREQUENCY OPTOIMMITTANCE LOGICAL R-ELEMENT “NOT”

The aim of designing a mathematical model of multifrequency optoimmittance logical R-element "NOT" is to obtain analytical expressions that determine the dependence of the output resistance of the multifrequency optoimmittance logic element R_{out} from the parameters of the transmission line segments and the input resistance R_{in}.

The transmission line segment can be considered as a resistance converter, the output impedance R_{out} of which depends on the input resistance R_{in}, and is determined by the expression [9]:

$$R_{out} = R_{in} \cdot \frac{1 + j \cdot \frac{Z_0}{R_{in}} \cdot tg\left(kl\right)}{1 + j \cdot \frac{R_{in}}{Z_0} \cdot tg\left(kl\right)}, \tag{2}$$

where: $k = 2\pi/\lambda$ – the wave number; $\lambda = \frac{c}{f \cdot \sqrt{\varepsilon_{eff}}}$ – the wavelength; c – the speed of light; f – the operating frequency; $\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \frac{1}{\sqrt{1 + 12h/t}}$ – the effective dielectric constant; ε_r – dielectric constant of the material; h – the thickness of the substrate; t – trace thickness.

Multiplied in (2) the numerator and denominator on R_{in}, we obtain:

$$R_{out} = R_{in} \cdot \frac{R_{in} + j \cdot Z_0 \cdot tg\left(kl\right)}{R_{in} + j \cdot \frac{R_{in}^{\ 2}}{Z_0} \cdot tg\left(kl\right)} = Z_0 \cdot \frac{R_{in} + j \cdot Z_0 \cdot tg\left(kl\right)}{Z_0 + j \cdot R_{in} \cdot tg\left(kl\right)}. \tag{3}$$

Substituting in (3) the values of a wave number, we obtain: $R_{out} = Z_0 \cdot \frac{R_{in} + j \cdot Z_0 \cdot tg\left(\frac{2\pi f \sqrt{\varepsilon_{eff}}}{c} l\right)}{Z_0 + j \cdot R_{in} \cdot tg\left(\frac{2\pi f \sqrt{\varepsilon_{eff}}}{c} l\right)}$.

The principle of the device operating is as follows. When operating at frequency f_1, for one $l_1 = \frac{n \cdot \lambda_1}{4}$ (n = 1,2,3…; λ_1 – the length of the electromagnetic wave of the input signal at the frequency f_1), the transmission line segment l1 can be considered as a resistance converter, the output resistance R_{out} of which depends on the input resistance R_{in}, and is determined by the expression:

$$R_{out} = Z_0 \cdot \frac{R_{in} + j \cdot Z_0 \cdot tg\left(\frac{2\pi f_1 \sqrt{\varepsilon_{eff}}}{c} l_1\right)}{Z_0 + j \cdot R_{in} \cdot tg\left(\frac{2\pi f_1 \sqrt{\varepsilon_{eff}}}{c} l_1\right)}. \tag{4}$$

If the length of this transmission line segment is $l_1 = \lambda_1/4$, then the output resistance will be determined by the expression:

$$R_{out} = Z_0^2 / R_{in}\ . \tag{5}$$

The analysis of expression (5) shows that if the input immittance has a purely active character and the input of the transmission line segment l1 through the switch K_1 is connected to the two-pole with the immittance $R_{in1} < Z_0$ (that corresponding to the logical zero at the input), then the immittance on the output of the device $R_{out} > Z_0$ (that corresponding to the logical unit on output). If the input to the transmission line segment l1 through switch K_1 is connected to the immittance two-pole with the immittance $R_{in2} > Z_0$ (that corresponding to the logical unit at the input), then the immittance on the output of the device $R_{out} < Z_0$ (that corresponding to the logical zero in the output) [12-15]. Thus, the represented logical levels correspond to the truth table of the immittance logic element NOT.

4. COMPUTER SIMULATION OF MULTIFREQUENCY OPTOIMMITTANCE LOGICAL R-ELEMENT "NOT"

To verify the adequacy of the developed mathematical model, a computer simulation of the multifrequency optoimmittance logical R-element "NOT" was performed. The circuit according to Fig. 3, was drawing at AWR Microwave Office 13 and shown in Fig. 4.

The circuit of multifrequency optoimmittance logical R-element "NOT" contains two resistors R_1, R_2, keys $S_1 - S_5$, the transmission line segments $TL_1 - TL_5$ and output port P_1 with a resistance of 50Ω. A pair of input resistors provides the required input impedance (15Ω and 170Ω), the keys switch the corresponding transmission lines by setting the value of the control bit (0, 1). The substrate on which was research element was used fiberglass with a thickness of 500μm, a dielectric constant of 4.3, a tangential angle of dielectric losses of 0.014 and a thickness of copper film of 18μm.

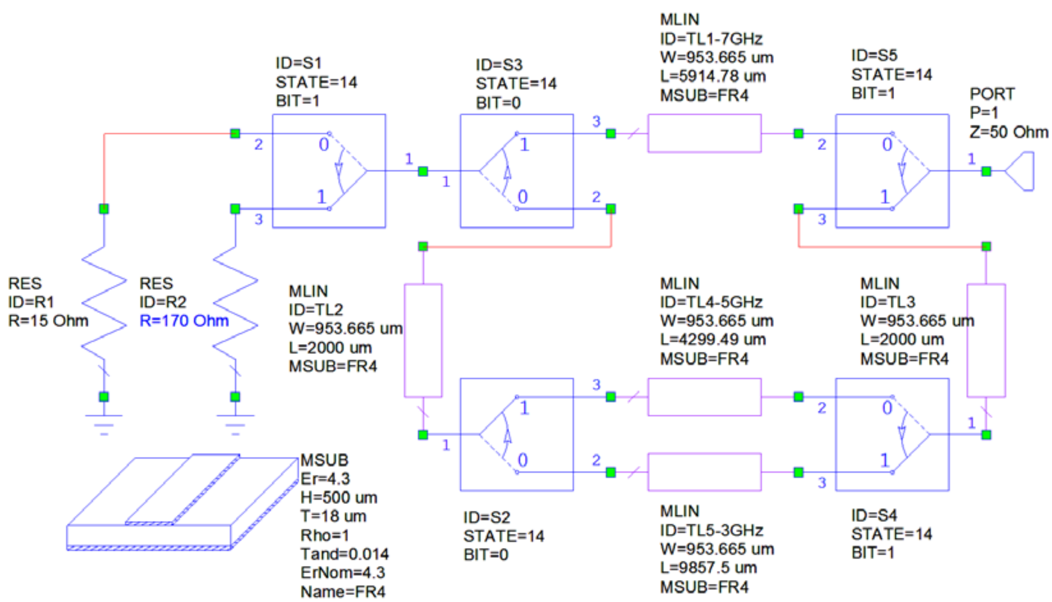


Fig. 4. The circuit of multifrequency optoimmittance logical R-element "NOT" in AWR Microwave Office.

The simulation was performed for frequencies: 3GHz, 5GHz and 7GHz. According to these values, the width and length of each transmission line were calculated in such a way that its total length $\lambda/4$. As width value for each transitions line (for the convenience of further design of this logic element), was selected the highest of the calculated value, namely 953,655μm. The key S_3 is set to the position "1", S_5 – to the position "0" to get the transient characteristic at a frequency of 7 GHz. The transient characteristic of the multifrequency optoimmittance logical R-element "NOT" for the three frequencies is shown in Fig. 5.

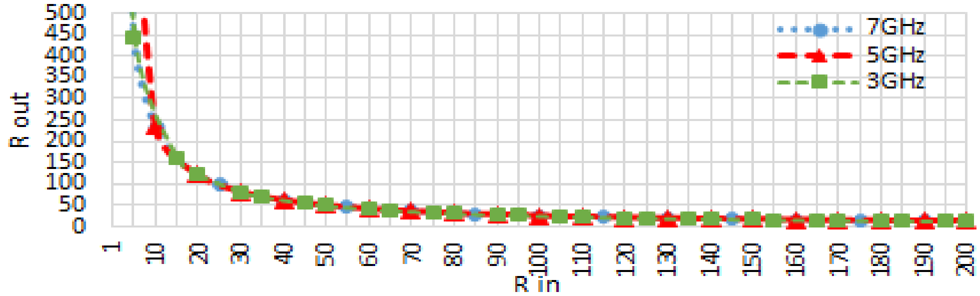
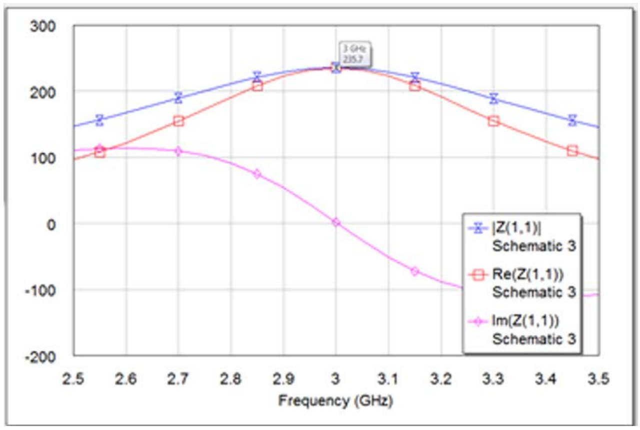
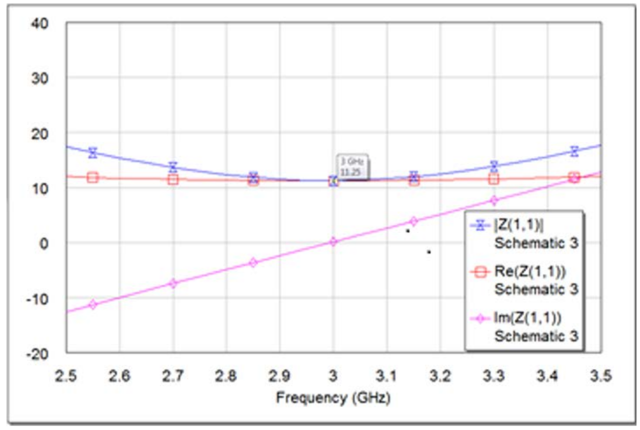


Fig. 5. Transient characteristics of multifrequency optoimmittance logical R-element "NOT" when operating at frequencies of 3 GHz, 5 GHz, 7 GHz.



a)



b)

Fig. 6. Frequency dependences of the output resistance and its active and reactive components at the input resistance, which corresponds to: the logic level "0" and working at frequency of 3 GHz (a), the logic level "1" and working at frequency of 3 GHz (b).

The obtained graphs (Fig. 5) are fully consistent with the graph shown in Fig. 2 b. The graphs on fig. 5 show that for $R_{in} > Z_0$ the output impedance $R_{out} < Z_0$ and for $R_{in} < Z_0$ the output impedance $R_{out} > Z_0$, which corresponds to the formulated conditions for designing a multifrequency optoimmittance logical R-element "NOT".

The graphs of the dependence of the output resistance and its active and reactive components from the frequency for different values of the input resistance, which corresponding to the levels of the logical "0" and the logical "1" are also obtained (Figs 6). The maximum value of resistance 15Ω is taken for the level of the logical "0"at the input, and the minimum value 170Ω is taken for the logical "1".

The graphs shown that at input resistance of 15Ω, the output impedance is about 240Ω at a frequency of 3 GHz and is within the level of the logical unit in the frequency range from 2.7 GHz to 3.3 GHz. At an input resistance of 230Ω the output impedance is about 10Ω at a frequency of 3GHz and is within the logic zero in the frequency range of 2.7GHz to 3.3GHz.

5. CONCLUSIONS

The immitans method of synthesizing logic elements has been further developed. In this method, unlike the known ones, the use of switches allows to ensure the operation of logic elements at different fixed operating frequencies, which enables to increase the frequency range of these elements. For the first time, a mathematical model of a multi-frequency optoimmittance logical R-element "NOT" was developed. It allowed determining the transient characteristics at different operating frequencies and determining its sensitivity to changes in the parameters of the circuit elements. The circuit of a multifrequency optoimmittance logical R-element "NOT" was developed. The results of the study of its transient characteristics may find application in the development of passive immitance logic elements with an extended operating frequency range. It is shown that the developed optoimmittance logical R-element "NOT" can operate, for example, at frequencies of 3GHz, 5GHz and 7GHz.

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