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A New Method to Deduce the Voltage Transfer Characteristic for Some Two-Port Networks

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Abstract - **A new method to deduce the voltage transfer characteristic for two-port networks containing bias sources is presented. The method allows the deduction of the transfer characteristic only by translating a known transfer characteristic in the input voltage-output voltage plane; this way the analysis of the whole circuit is no longer necessary. Also the method can help to redesign a circuit in order to obtain a circuit that keep unchanged the shape of the transfer characteristic, while changing its location in the input voltage-output voltage plane.**

The method is important from the didactical point of view, giving to the students new insights about some electronic circuit analysis and design.

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A NEW METHOD TO DEDUCE THE VOLTAGE TRANSFER CHARACTERISTIC FOR SOME TWO-PORT NETWORKS

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Abstract : A new method to deduce the voltage transfer characteristic for two-port networks containing bias sources is presented. The method allows the deduction of the transfer characteristic only by translating a known transfer characteristic in the input voltage-output voltage plane; this way the analysis of the whole circuit is no longer necessary. Also the method can help to redesign a circuit in order to obtain a circuit that keep unchanged the shape of the transfer characteristic, while changing its location in the input voltage-output voltage plane.

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I. INTRODUCTION

In most of basic electronic circuit courses [1], [2], the analysis of the two-port networks to determine their voltage transfer characteristic is performing over the whole circuit, even if the two-port is a variant of a simple one, (whose voltage transfer characteristic is well known), having in addition a number of bias sources connected in series or parallel with it. Our didactical experience shows that this analysis procedure can take a significant amount of class time and overload many students.

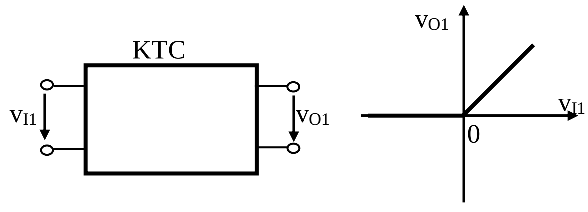
Based on these observations we propose here a new method to determine the voltage transfer characteristic for the two-port DR networks containing one or more bias sources. First, the studied two-port will be decompose into one two-port with a **k**nown (or very easy to find) **t**ransfer **c**haracteristic, labelled KTC, and other(s) two-port(s), everyone containing a single bias source and nothing else. Afterwards we can immediately sketch the desired transfer characteristic, translating the KTC in the input voltage - output voltage plane according to a direction that results from the connection topology between the KTC and the other two-ports.

As it will be shown, this new approach can simplify the analysis of basic two-port networks, thus reducing the computational time for students, and also offers an algorithmic approach to problem solving.

II. THE NEW METHOD

Our proposed method implies two steps. In the first step, we will redraw the studied two-port in the form of a KTC two-port connected with one or more two-port(s) containing only one bias source each, and nothing else. Then, in the second step, we deduce the transfer characteristic of the studied two-port by translating the KTC according to the connecting topology between KTC and the bias-source two-ports, as it will be shown in the following.

For simplicity we consider for now that the studied two-port requires only two two-port decomposition: the KTC two-port (Fig. 1.a)) and another two-port with a bias source. The KTC can have a certain shape, let's suppose like in Fig. 1.b).



a) b)

***Fig.1.** KTC two-port*
a) circuit representation; b) voltage transfer characteristic

In this situation we can have the following connecting topologies between two-ports:

a) Chain connected, KTC being the first (Fig. 2.a))

As we can see in Fig. 2.a), we use v_I and v_O to denote the input and output voltages for the global two-port that we want to study. Using the voltage Kirrchhoff's law we can write:

$$v_I = v_{I1} \qquad (1)$$

$$v_O = v_{O1} + V_{POL} \qquad (2)$$

According to these relations, the transfer characteristic $v_O(v_I)$ results by translating the transfer characteristic $v_{O1}(v_{I1})$ along the output voltage direction with V_{POL}, up if

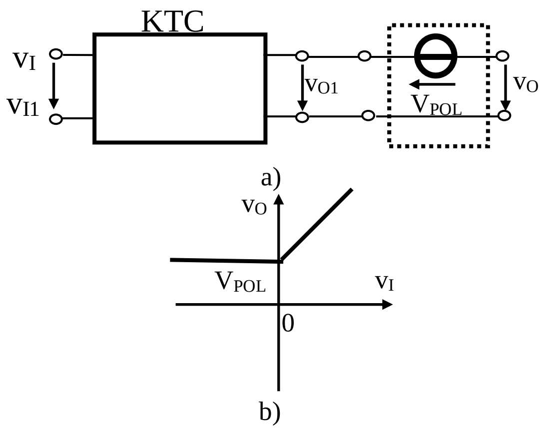


Fig. 2. *Chain connected, KTC first*
a) circuit representation; b) voltage transfer characteristic, $V_{POL}>0$

$V_{POL}>0$ (Fig. 2.b)), or down if $V_{POL}<0$.

b) Chain connected, KTC being the latter (Fig. 3.a))

For this connection the following relations stand:

$$v_I=v_{I1}+V_{POL} \qquad (3)$$
$$v_O=v_{O1} \qquad (4)$$

So, we deduce that now the $v_O(v_I)$ characteristic will be obtained by translating the $v_{O1}(v_{I1})$ characteristic along the input voltage axis with V_{POL}, to the right for $V_{POL}>0$ (Fig. 3.b)), or to the left for $V_{POL}<0$.

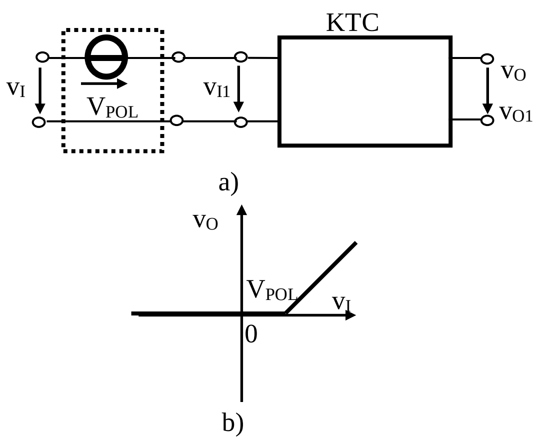


Fig. 3. *Chain connected, KTC the latter*
a) circuit representation; b) voltage transfer characteristic, $V_{POL}>0$

c) Series connected (Fig. 4.a))

We have the following relations:

$$v_I=v_{I1}+V_{POL} \qquad (5)$$
$$v_O=v_{O1}+V_{POL} \qquad (6)$$

We can easily deduce that the translation will be along the first bisector, otherwise said, along both the input and the output voltage direction with same quantities, V_{POL}. Therefore the translation will be up and to the right if $V_{POL}>0$ (Fig. 4.b)), and down and to the left if $V_{POL}<0$.

We analysed the possibility of other connection topologies too, but we saw that the results are electrically incorrect situations, so they do not present any interest for

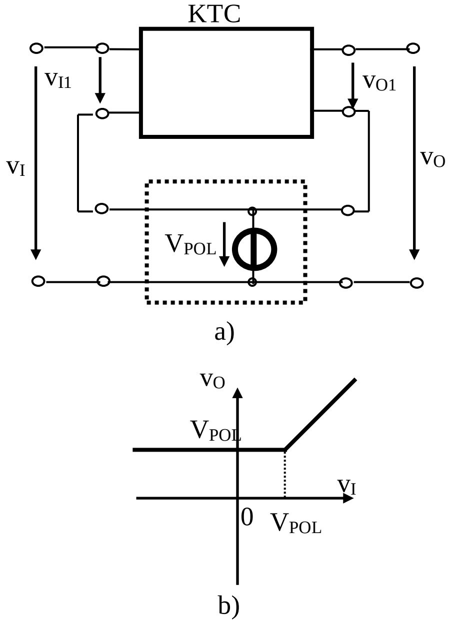


Fig. 4. *Series connected*
a) circuit representation; b) voltage transfer characteristic, $V_{POL}>0$

us (for example connecting in parallel the two-ports used in Fig. 4.a), we will have two voltage sources parallel connected, v_I and V_{POL}).

The three previous situations can be combined to obtain a circuit with more single bias source two-ports. The voltage transfer characteristic for the studied two-port will result by successive translation of the KTC, according to the connection topologies of the bias source two-ports with the KTC two-port.

This method can be used to analyse a circuit with bias sources in order to find its transfer characteristics. We will illustrate this for a DR two-port, in the following section. Also the method can be very useful to redesign a circuit in order to obtain a transfer characteristic placed somewhere else in the input voltage-output voltage plane compared to the initial transfer characteristic. We will illustrate this for a simple op-amp comparator in the next section.

III. EXAMPLES

1) Two-port DR network analysis

In this example the problem is to find the voltage transfer characteristic for the two-port DR network shown in Fig. 5. For the diode the constant-voltage-drop model will be used [2] (Fig. 6.).

First we identify on the circuit the KTC two-port and other two voltage-source two-ports, chain connected (Fig. 7.). To find the $v_O(v_I)$ characteristic we should know the $v_{O1}(v_{I1})$ characteristic. To do this we redraw the two-port

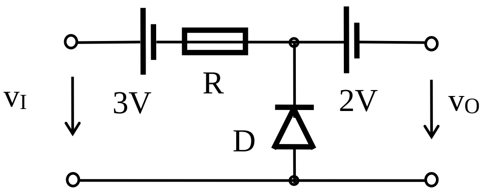


Fig.5. *The studied two-port DR network*

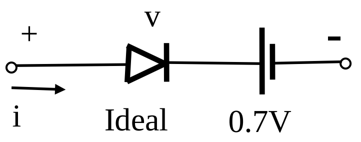


Fig.6. *The constant-voltage-drop diode model*

containing D and R using the constant-voltage-drop model for diode (Fig. 8.). One more time we decompose

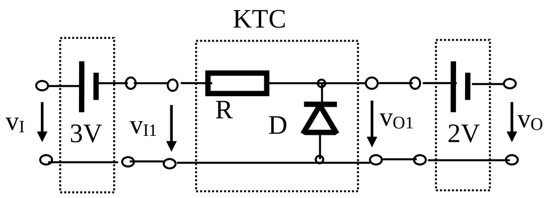


Fig.7. *The two-ports chain-connected in the circuit*

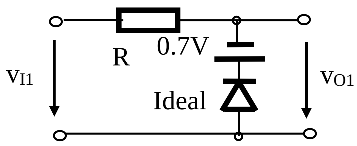


Fig.8. *Two-port with just 1R and 1D*

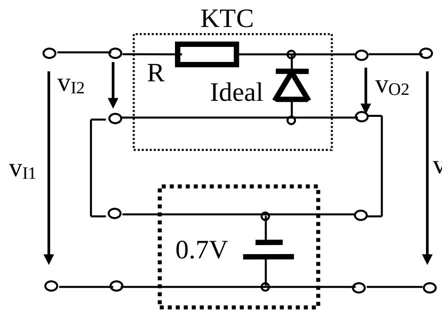


Fig. 9. *The equivalent circuit for circuit in Fig. 8.*

this circuit like in Fig. 9.

The $v_{O2}(v_{I2})$ characteristic is very easy to deduce and it is shown in Fig. 10.a). Now as we saw earlier the $v_{O1}(v_{I1})$ characteristic can be obtained by translating the $v_{O2}(v_{I2})$ characteristic with 0.7V down and to the left (Fig. 10.b)).

Returning to the Fig.7. the voltage transfer characteristic $v_O(v_I)$ will result by translating the $v_{O1}(v_{I1})$ characteristic with 3V to the right and with 2V down. The

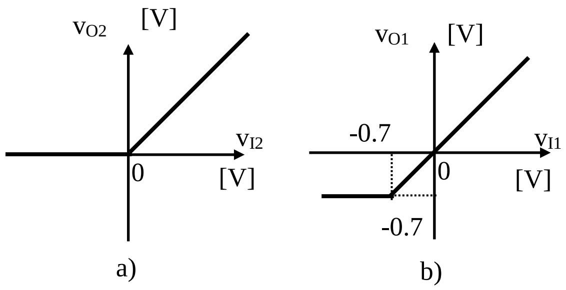


Fig. 10. *Voltage transfer characteristics*
a) v_{O2} vs. v_{I2}; b) v_{O1} vs. v_{I1}

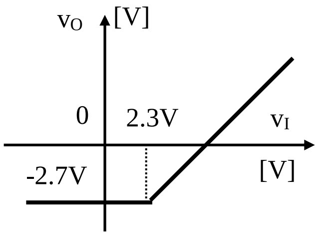


Fig.11. *The voltage transfer characteristic, v_O vs. v_I*

desired voltage transfer characteristic $v_O(v_I)$ is shown in Fig. 11.

2) Op-amp comparator redesign

For the op-amp comparator in Fig. 12.a) we know the transfer characteristic as it is shown in Fig. 12.b). The op-amp is considered to be an ideal one.

We want to obtain a transfer characteristic presented in Fig. 13. We will do this by redesigning the circuit shown in Fig. 12.a). We can easily observe that the

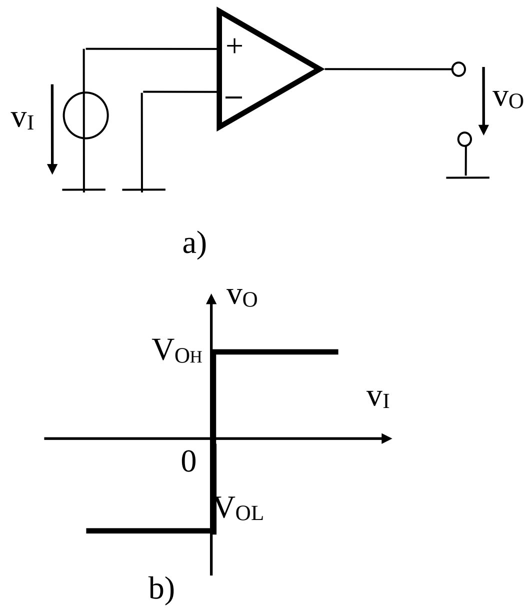


Fig. 12 *a) Op-amp comparator **;** b) Voltage transfer characteristic*

desired transfer characteristic (Fig.13) can be obtained by translating the given transfer characteristic (Fig.12.b)) on the v_I direction, to the right with V_P quantity. This is the

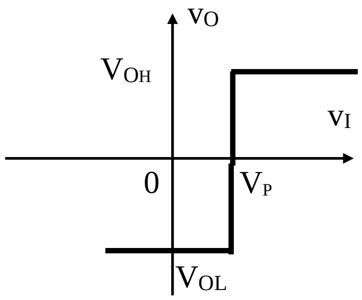


Fig.13. *The desired transfer*

case presented before in section II, point b).

So we will redraw our circuit as a two-port network. The resulting circuit is shown in Fig. 14. To make the necessary translation of the transfer characteristic for the two-port network in Fig. 14 we should connect another

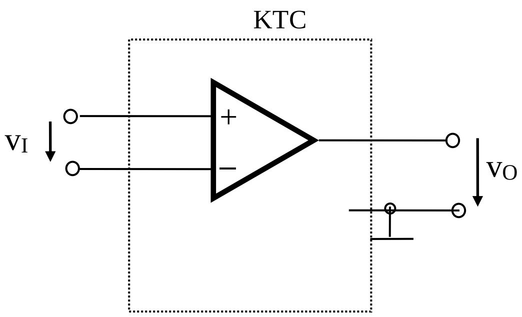


Fig. 14. *The op-amp comparator as a two-port*

two port containing V_P bias source; the necessary connection being in a chain, KTC the latter (Fig. 15)

Once again by redrawing we obtain the solution, as it is shown in Fig. 16.

As the reader can see, to solve a problem using our proposed method, someone should draw a lot of schematics, instead to write equations on the circuits. This way we believe that the method is intuitive and easy to understand and apply.

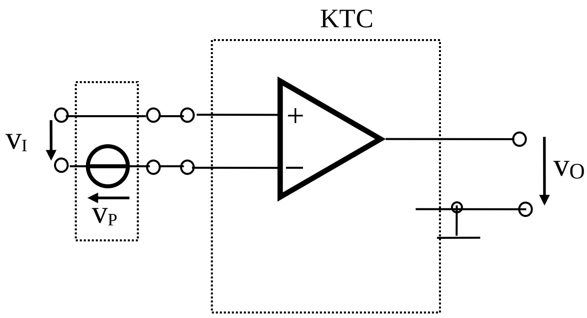


Fig.15. *Bias source two-port and op-amp comparator two-port chain connected*

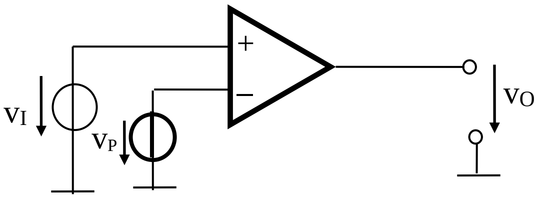


Fig.16. *The desired op-amp comparator*

IV. CONCLUSION

We have presented a new method to deduce the voltage transfer characteristic for two-port networks, containing dc bias sources too, without analysing the whole circuit. To illustrate the method, two examples have been presented: one for analysis of the DR two-port network and the other for redesigning an op-amp comparator. This method can save classroom instruction time and help the students to understand and easy solve this kind of problems. Also this method is intuitive, using a lot of schematics instead of overwhelming circuit equations.

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