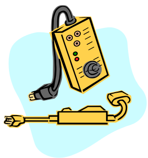
DR SWITCHING CIRCUITS, TWO-PORT AND MULTI-PORT NETWORKS

I. OBJECTIVES

a) Finding out the VTC of a two-port DR network.
b) The deduction of the applications of a two-port DR network for different shapes of time-variation of the input voltage.
c) Finding out the electric function of a three-port network DR of space extreme.



II. COMPONENTS AND INSTRUMENTATION

You will use the experimental assembly equipped with 2 semiconducting diodes and resistors. Because you will apply and measure both dc and ac voltages you will need a dc regulated voltage supply, a signal generator, a digital multimeter and a dual channel oscilloscope.

III. THEORETICAL ASPECTS

1. SWITCHING DR TWO-PORT NETWORKS

1.1. Analysis of DR two-port networks

For the DR two-port networks, we are interested in the forward transfer properties, especially in the *transfer characteristic*. For this, we have to know the nature of the input and output signals. Generally, the DR two-port networks are driven by voltage sources and the output is a voltage, too. In this case we have a voltage-to-voltage transfer, so we are talking about a VTC-*voltage transfer characteristic* $v_O(v_I)$.

To get the VTC, meaning to know the value of the output voltage for each value of the input voltage, one can use the subsequent algorithm:

i) consider all the possible situations resulting from the combination of the diode states;
ii) for each situation we deduce: - the equivalent circuit;
- the value of v_O;
- the range of values for v_I;
iii) draw the VTC: $v_O(v_I)$.

Let us consider as an example the DR two-port network in Fig. 1 where the output is taken across the resistor R.

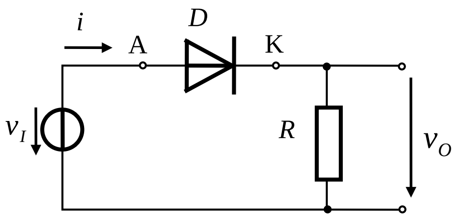


Fig. 1. Two-port DR network with output across R.

For the diode we assume the ideal model. Because on a single diode we have only two possible situations: D-(*off*) and respectively D-(*on*). The equivalent circuits for the two situations are presented in Fig. 2.

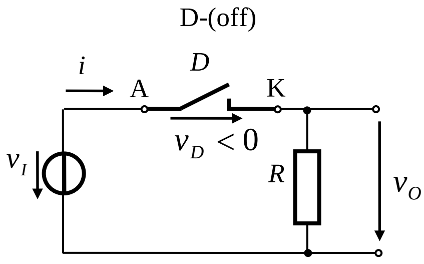


Fig. 2. a) Equivalent circuit for D-(*off*);

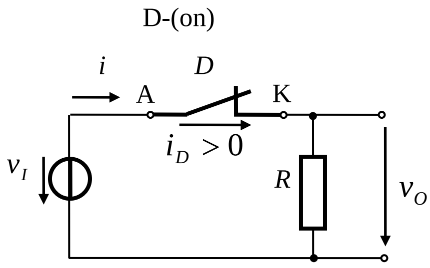


Fig. 2. b) Equivalent circuit for D-(*on*).

The diode is equivalent with an open-circuit, the current through the circuit is zero, and we have:

$$v_O = 0$$

To determine the range of v_I we use the following condition:

$$v_D < 0$$

$$v_D = v_I - v_O$$

It results:

$$v_I < 0$$

As long as $v_I < 0$, the diode is cutoff and $v_O = 0$.

The diode is equivalent with a short-circuit, so:

$$v_O = v_I$$

To determine the range of v_I we have the following condition:

$$i_D > 0$$

The current flows through v_I and *R* and it has the value:

$$i_D = \frac{v_I}{R}$$

It results:

$$v_I > 0$$

As long as $v_I > 0$, the diode is on and $v_O = v_I$.

The resulted VTC is presented in Fig. 3.

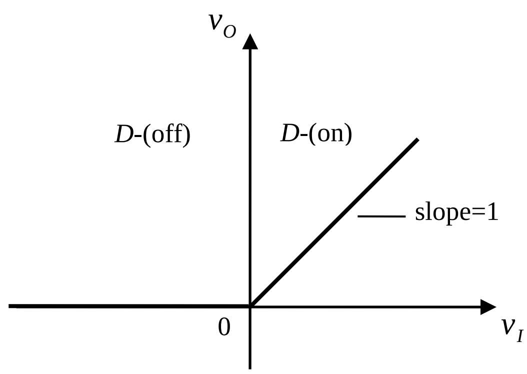


Fig. 3 VTC for the DR two-port network in Fig. 1.

Of course, there are also other ways to connect the voltage source, the diode, and the resistor in a circuit. Keeping the series connection of the 3 elements we can obtain other three circuits by reversing the connection direction of the diode in the circuit, and by exchanging the places of *R* and *D*.

The *constant-voltage-drop model* adds to the ideal model a voltage drop during the conduction. For this voltage drop we consider a constant value of 0.7V, independent of the current flowing through the diode.

Next we will analyze the effect of using the constant-voltage-drop model for the diode vis a vis the results obtained using the ideal model. For the two-port network in Fig.1 consider for the diode the new constant-voltage-drop model. The equivalent circuit is shown in Fig. 4.

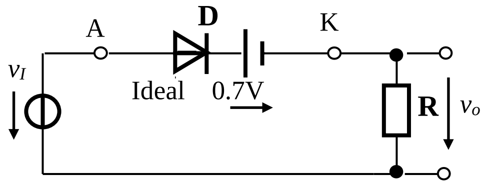


Fig. 4. DR two-port DR network, constant-voltage-drop model for the diode.

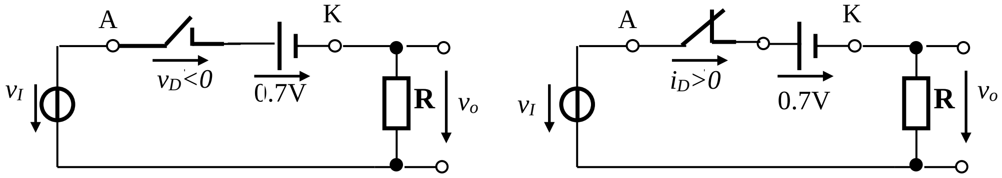


Fig. 5. Equivalent circuits for the DR two-port network in Fig. 4

D-(off)

$v_O = 0;$

Ideal diode is cutoff for $v_D < 0$

$v_D = v_I - 0.7\text{V} - v_O$

$v_I < 0.7\text{V}$

As long as $v_I < 0.7\text{V}$, D-(off)

$v_O = 0\text{V}$.

D-(on)

$v_O = v_I - 0.7\text{V}$

Ideal diode is on for $i_D>0$;

$$i_D = \frac{v_I - 0.7}{R} > 0$$

$v_I > 0.7\text{V}$

As long as $v_I > 0.7\text{V}$ D-(on)

$v_O = v_I - 0.7\text{V}$

This part of the VTC is parallel with the first bisector, but translated to the right with 0.7V from the origin.

The voltage transfer characteristic is shown in Fig. 6.

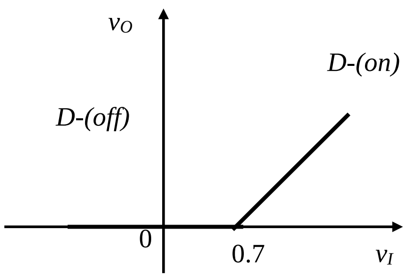


Fig. 6. VTC for the DR two- port network in Fig. 4.

Comparing the actual VTC with the voltage transfer characteristic deduced considering the ideal diode, we observe that it has the same shape, but it is translated to the right with 0.7V, the voltage drop across the conducting diode.

1.2. DR Two-Port Networks with Biasing Voltage

To obtain some VTC arbitrarily placed in the v_I - v_o plane, we can enhance the initial DR two-port network with biasing sources, V_{BIAS}, as in Fig. 7.

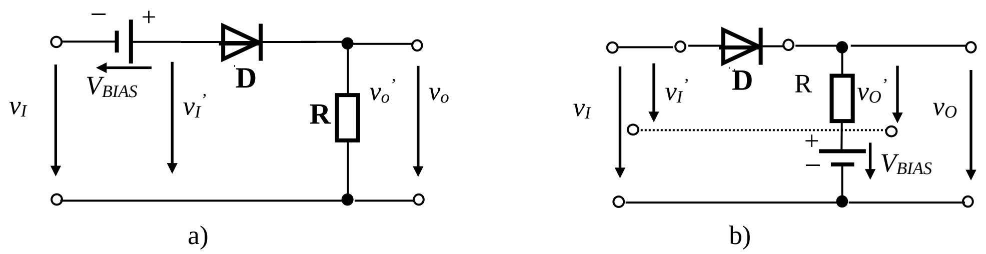


Fig.7 DR two-port network with a biasing voltage source:
a) at the input port; b) common to the input and output port.

Depending on the position of the biasing voltage sources, the desired VTC results by translating the known VTC after one or both axis. In this way, for the two-port network in Fig. 7a) we have:

$$v_I = v_I' - V_{BIAS}$$

$$v_O = v_O'$$

The $v_O(v_I)$ characteristic results by translating $v_O'(v_I')$ VTC to the left, along the v_I axis with V_{BIAS} as it is shown in Fig. 8. a)

For the circuit in Fig.7. b) we have:

$$v_I = v_I' + V_{BIAS}$$

$$v_O = v_O' + V_{BIAS}$$

$v_O(v_I)$ results by translation to the right, along the v_I axis with V_{BIAS} , and translation up along v_O axis with V_{BIAS}; actually a translation along the first bisector, as it is shown in Fig. 8.b).

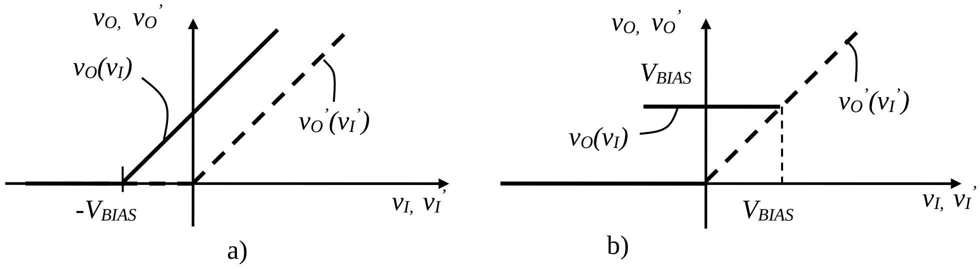


Fig. 8. VTC for two-port networks with a biasing voltage source:
a) translation of the VTC along the v_I axis with V_{BIAS}; b) translation of the VTC along the first bisector with V_{BIAS}.

2. SWITCHING DR MULTI-PORT NETWORKS

Maximum DR Multi-Port Networks

DR multi-port networks are circuits that contain *D* and *R* as circuit elements and they have more than two ports. Usually, one port is the output, and the others are input ports.

Let us consider the DR multi-port network with two inputs and one output as in Fig. 9. Because it has three ports, the circuit is also called three-port network.

For the DR multi-port networks we need to know how the output voltage v_O depends on the input voltages $v_O(v_A,v_B)$.

In the following analysis we will use for the diodes the ideal model (with 0V voltage drop across the conducting diode) to determine and understand the operating principle of the circuits. Where it will be needed, we will make specifications considering the effects of using the constant-voltage-drop model for the conducting diode.

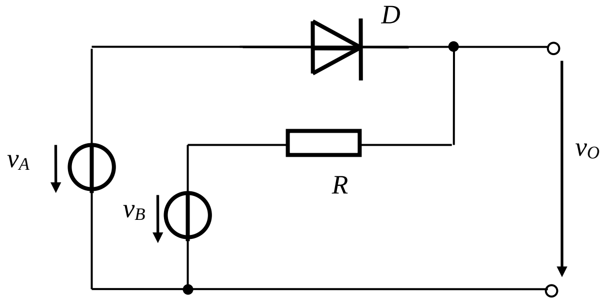


Fig. 9. Maximum three-port network.

Because the diode has two states (*on, off*), we have two equivalent circuits. When the diode is *on*, the ouptul voltage will be equal to v_A. For diode off, the output voltage will be v_B. So, the output voltage is equal with the greatest of the input voltages. Therefore, the mathematical relationship that describes the operation of the circuit is:

$$v_O = max(v_A; v_B)$$

If we consider the time variation of the voltages we have:

$$v_O (t) = max(v_A(t); \ v_B(t))$$

It is obvious now the name of maximum multi-port network for this circuit, because at any moment of time the output voltage is equal to the maximum value of the input voltages (maximum in space– maximum between voltages).

Observation: There is a particular significant case, and that is $v_B = 0$. By re-drawing the circuit for this situation we will find again the DR two-port network previously discussed (Fig.1). This time its operation is mathematically described as:

$$v_O = max(v_A ; 0).$$

In a lot of situations the particular case with $v_C = 0$ appears, resulting the multi-port in Fig. 10, with *R* grounded.

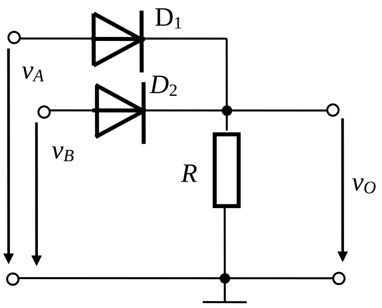


Fig. 10. Maximum multi-port network.

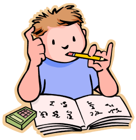
In this case :

$$v_O = max(v_A , v_B , 0).$$

We notice that for v_A, $v_B < 0$, regardless their numerical value, the output voltage will always be zero.

If we consider for the diodes a model much closer to the real diode, with constant-voltage-drop in conduction, when one of the diode is in conduction, the output voltage will always be smaller with approximately 0.7V than the voltage applied at the anode of that diode. For this situation we have:

$$v_O = max(v_A - 0.7\text{V}, v_B - 0.7\text{V}, 0).$$



IV. PREPARATION

For all the circuits, consider for the diode the constant voltage drop model, with v_D=0.7V.

1.P. CLAMP TWO-PORT DR NETWORK

1.1.P. VTC

- For the circuit in Fig. 11. deduce VTC, considering that the $v_I(t) \in [-10V,10V]$. How does the VTC look like, if $v_I(t) \in [1,1.5][V]$?
- What is the circuit's function?
- What is the expression of the output voltage for both branches of the VTC?
- Draw $v_O(t)$ for $v_I(t)$ – sinusoidal voltage with 10V amplitude and 100Hz frequency.

1.2.P. VTC TRANSLATION

- How does VTC look like for the circuit in Fig. 12, considering v_{BIAS} =5V and $v_i(t) \in [-10V,+10V]$?
- What is the expression of the output voltage for each branch of the VTC?

2.P. SPACE EXTREME THREE-PORT DR NETWORK

2.1.P. THE ELECTRIC FUNCTION

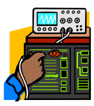
- What is the electric function of the three-port DR network represented in Fig. 13.? What is the mathematical expression of this function?
- For the circuit shown in Fig. 13., what is the time variation of the output voltage $v_O(t)$, for $v_A(t)$ =5V and $v_B(t)$=10 sinωt[V]?
- But for $v_B(t)$=10sinωt[V] and $v_A(t)$=-1V?

V. EXPLORATIONS AND RESULTS

1. CLAMP TWO-PORT DR NETWORK

From the four types of possible circuit configurations with 1R, 1D and a voltage source we have chosen, for the experiment, the one shown in Fig. 11 which is less familiar than the one with the output on R, but having the same importance.

1.1. VTC



Exploration

Build the assembly from Fig. 11.

a) VTC using the point-by-point method.

- The v_I =10V is obtained from the dc regulated voltage supply.
- You will measure v_I and v_O with a digital multimeter.
- You will also measure v_o for the following values of v_I : 5V, 1.5V, 0.8V, 0.4V, 0V, -1V, -5V, -10V.

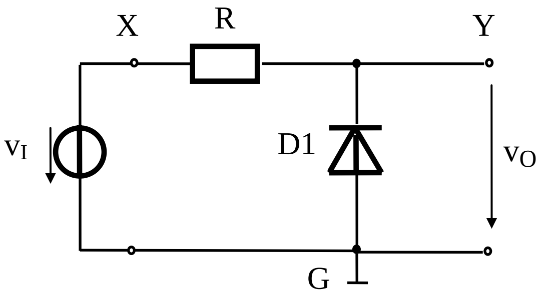


Fig. 11. Clamp two-port DR network

Results

a) VTC using the point-by-point method.

- Table with v_I and v_O for v_I=-10V, -5V, 0V, +5V, +10V.
- Table with v_I and v_O for v_I=-1V, 0V, +0.4V, +0.8V, +1.5V.
- Draw two graphs representing $v_O(v_I)$ for the data from the two tables.
- Specify on the graphs the on and the off states of the diode.
- In what situation the threshold voltage different from zero should be taken into account? Why?

Exploration

b) VTC on the oscilloscope.

- You will obtain v_I from the signal generator, which is set to generate a sinusoidal voltage having an amplitude of 10V and a frequency of 100Hz.
- With the oscilloscope set on the Y-X mode you will set the origin of the system axis in the centre of the screen and then you will connect the input of the circuit to the X terminal and the output to the Y terminal.
- With the oscilloscope set on the Y-t mode you will set the reference for both channels in the middle of the screen and then you will connect the input of the circuit to the X terminal and the output to the Y terminal. Visualize simultaneously $v_I(t)$ and $v_O(t)$.

Results

b) VTC on the oscilloscope.

- Draw and compare the VTC obtained on the screen of the oscilloscope with the one obtained using the point-by-point method. For what value of the input voltage the diode goes from the on state to the off one?
- Draw the $v_I(t)$ and $v_O(t)$ waveforms.

1.2. VTC-TRANSLATION

Exploration

You will use the assembly from Fig. 12.

- V_{Bias} – is obtained from a dc voltage supply set at the value of 5V.
- You will visualise on the oscilloscope the VTC. The experiment is the same as the one in paragraph 1.1.b. Exploration

Results

• Draw and analyse the VTC obtained. Compare this characteristic with one obtained at 1.1. Comment on the results.
• For what value of the input voltage does the diode change its state from the off to on one?
• On which direction did the VTC move in comparison to the one obtained at section 1.1.? How do you explain?

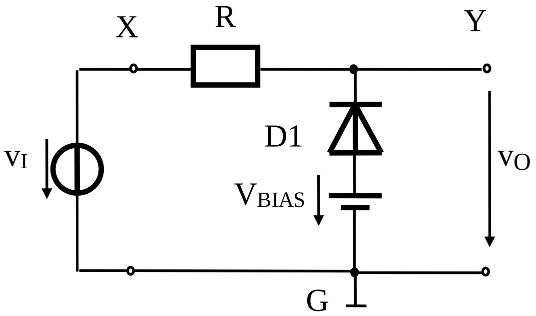


Fig. 12. Clamp two-port DR network with V_{Bias}

2. SPACE EXTREME THREE-PORT DR NETWORK

For the experiment you will use the three-port network from Fig. 13 with A, B as inputs and Y as output.

2.1. THE ELECTRIC FUNCTION

Build the assembly from Fig. 13.

Exploration

• v_A is a sinusoidal voltage with 100Hz frequency and 10V amplitude from the signal generator.
• v_B =5V is a dc voltage.
• With the oscilloscope having 0V in the centre of the screen you will visualize v_O and v_A.
• You will repeat the visualisation of v_A and v_O for v_B=-1V.

Results

• Plot the waveforms for v_A, v_B, v_O, for $v_B(t)$=5V and then for $v_B(t)$=-1V.
• Show the time domains, on the waveforms, which represent the on and off states of the diode.
• Compare these results with the ones obtained at 2.1.P. Analyse them.
• Is it possible for both diodes to be simultaneous turned on? What about turned off?

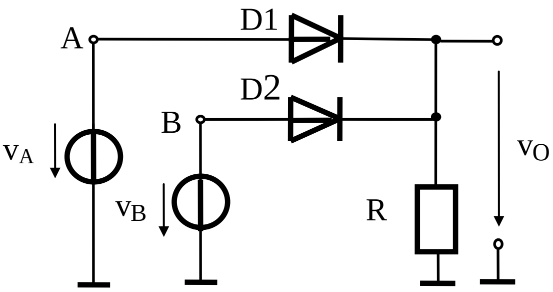


Fig. 13. DR three-port

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