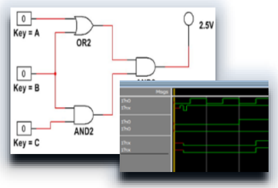
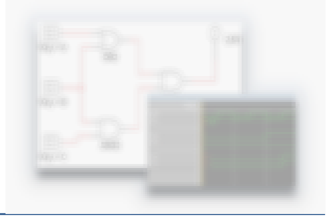


ECE119 – Ψηφιακή Σχεδίαση

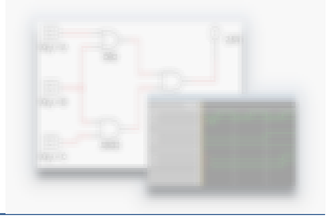
Διδάσκοντες Εργαστηρίου: Δ. Καραμπερόπουλος
Δ. Γαρυφάλλου

Lab 3: Logic Gates Explored and Boolean Algebra



Περιεχόμενα Εργαστηριακού Μαθήματος

Logic Gates Explored and Boolean Algebra



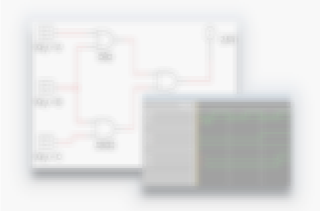
In the previous lab, we were introduced to the two basic logic gates – **AND** and **OR** in detail. There is also **NOT (Inverter)** gate.

Building on these, we can create a few other types of logic gates.

These are: **NAND, NOR, XOR,** and **XNOR**.

Let’s take a look at each one in greater detail.

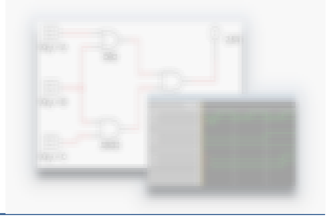
Learning Objectives



In this lab, students will:

- Explore the function of various different **logic gates**
- Create circuits with varying logic gates in theory and in practice.
- Calculate and build combinational logic circuits from **Sum-of-Products** and **Product-of-Sums** derived from truth tables.
- Learn how to write a **Combinational Logic Circuit** (CLC) in Verilog.
- Learn how to **test a module** and take True Table in Verilog.

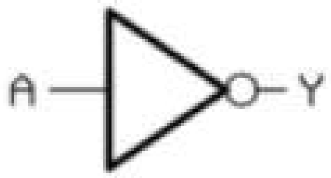
Expected Deliverables



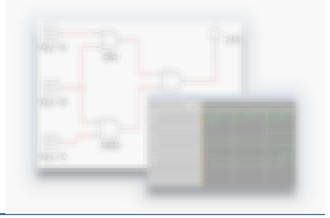
In this lab, you will collect the following deliverables:

- SOP and POS Boolean expressions
- Design circuits
- Truth Tables
- Multisim Files
- Conclusion questions
- Verilog File

Inverters



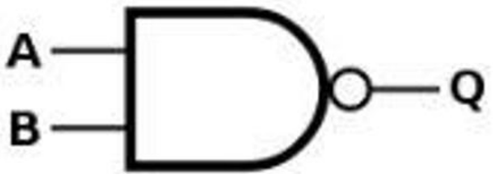
- Inverters are also known as **NOT** gates.
- They have only **one input** and **one output**.
- The truth table for an inverter is simple. The output is always the opposite of the input.
- For example, if the input is **1**, the output will be **0** and vice versa. Visually this is depicted by a **circle** at the input and/or output ends of the logic gates.
- In this situation, the circle is at the output, which means that the output is inverted. If it was at the input, then it is the input that would be inverted.

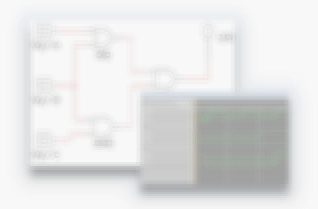


NAND Logic Gates

- **NAND** gates invert the output of the AND gate.
- The inputs do not change from those of the AND truth table, but the output is the opposite.
- As a rule, if any of the inputs are **0**, the output will always be **1**.
- See the truth table and the symbol.

A	B	O
0	0	1
0	1	1
1	0	1
1	1	0

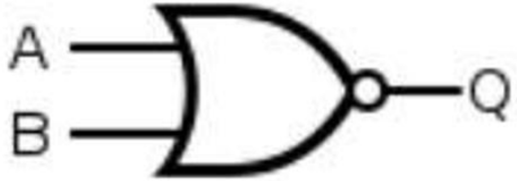


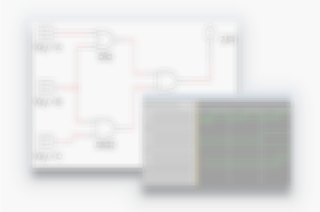


NOR Logic Gates

- The **NOR** logic gate inverts the output of the OR gate.
- The inputs of the truth table for the OR gate do not change, but the output is the opposite.
- As a rule, if any of the inputs are 1, the output will always be 0.
- See the truth table and symbol.

A	B	O
0	0	1
0	1	0
1	0	0
1	1	0

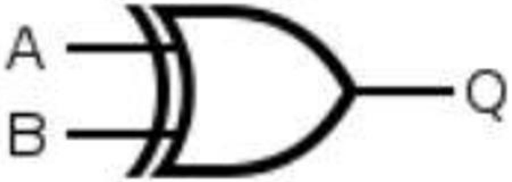


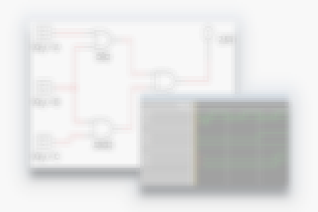


XOR Logic Gates

- An **XOR** gate is also known as an **eXclusive OR** gate.
- The output will be 1 if only one of the inputs is 1. The output will be 0 if both inputs are 0 or both are 1.
- See the truth table and symbol.

A	B	O
0	0	0
0	1	1
1	0	1
1	1	0



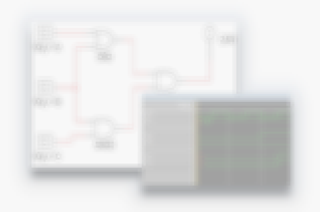


XNOR Logic Gates

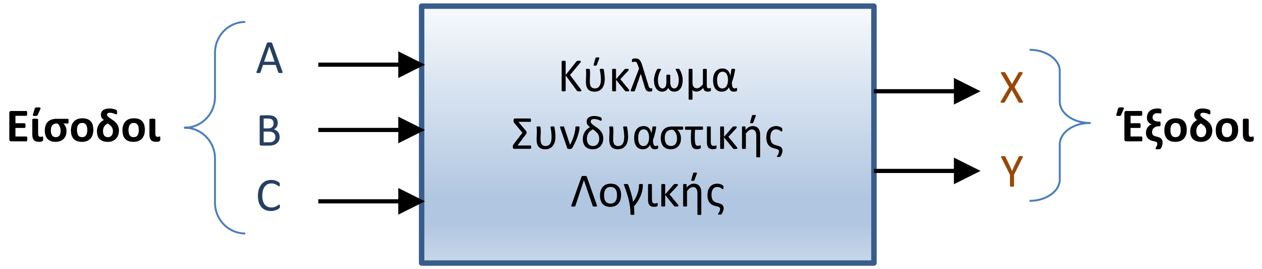
- The **XNOR** gate does the opposite of the XOR gate.
- The output will be 1 if the inputs are the same and the output will be 0 if the inputs are not the same.
- See the truth table.

A	B	O
0	0	1
0	1	0
1	0	0
1	1	1

Combinational Logic Circuits (CLCs), Συνδυαστικά κυκλώματα

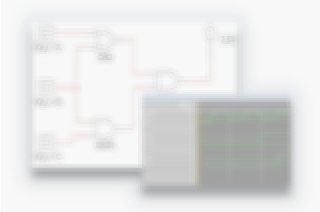


- **CLCs** are a classification of circuits whose output is only **dependent on the current inputs** and are implemented by Boolean circuits.
- Using combinations of logic gates, different results can be achieved.
- A truth table is often used to define the behavior of a CLC, but sometimes we start with a truth table and need to design a CLC.



Συνδυαστικό Κύκλωμα

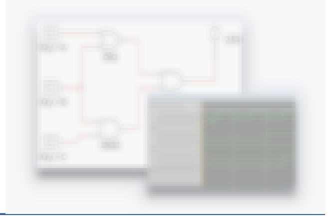
Boolean Algebra (1/2)



Boolean algebra is an algebraic system where two values are used to represent the properties of bi-stable electrical switching circuits, namely **on** and **off**, or simply **1** and **0**. The rules for the two **binary operators** (addition and multiplication) and complement (’) for a two-valued Boolean algebraic expression are presented in the tables on the next slide.

- It can be seen that the binary addition, multiplication and complement are the same as the OR, AND and NOT logic operations.
- For the **complement**, several notations are used: apostrophe after the variable, exclamation mark, tilde or the word NOT before the variable or an over-bar on top of it.
- Because it works with digital systems with only the values 0 and 1, the algebra used is simply called **“binary logic”**.

Boolean Algebra (2/2)



- Any logic function, no matter how complex it is, can be implemented using only the three basic logic operations.
- A function represented by a truth table can be expressed using different methods.
- Knowing the logic expression and the function, the circuit can be then realized.

x	y	x · y
0	0	0
0	1	0
1	0	0
1	1	1

Binary Multiplication (AND logic operation)

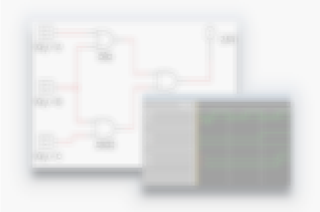
x	y	x + y
0	0	0
0	1	1
1	0	1
1	1	1

Binary Addition (OR logic operation)

x	x′
0	1
1	0

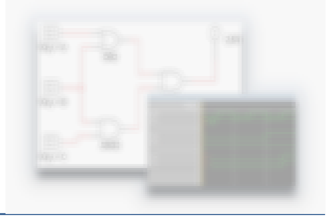
Compliment (NOT logic operation)

Sum-of-Products (άθροισμα γινομένων)



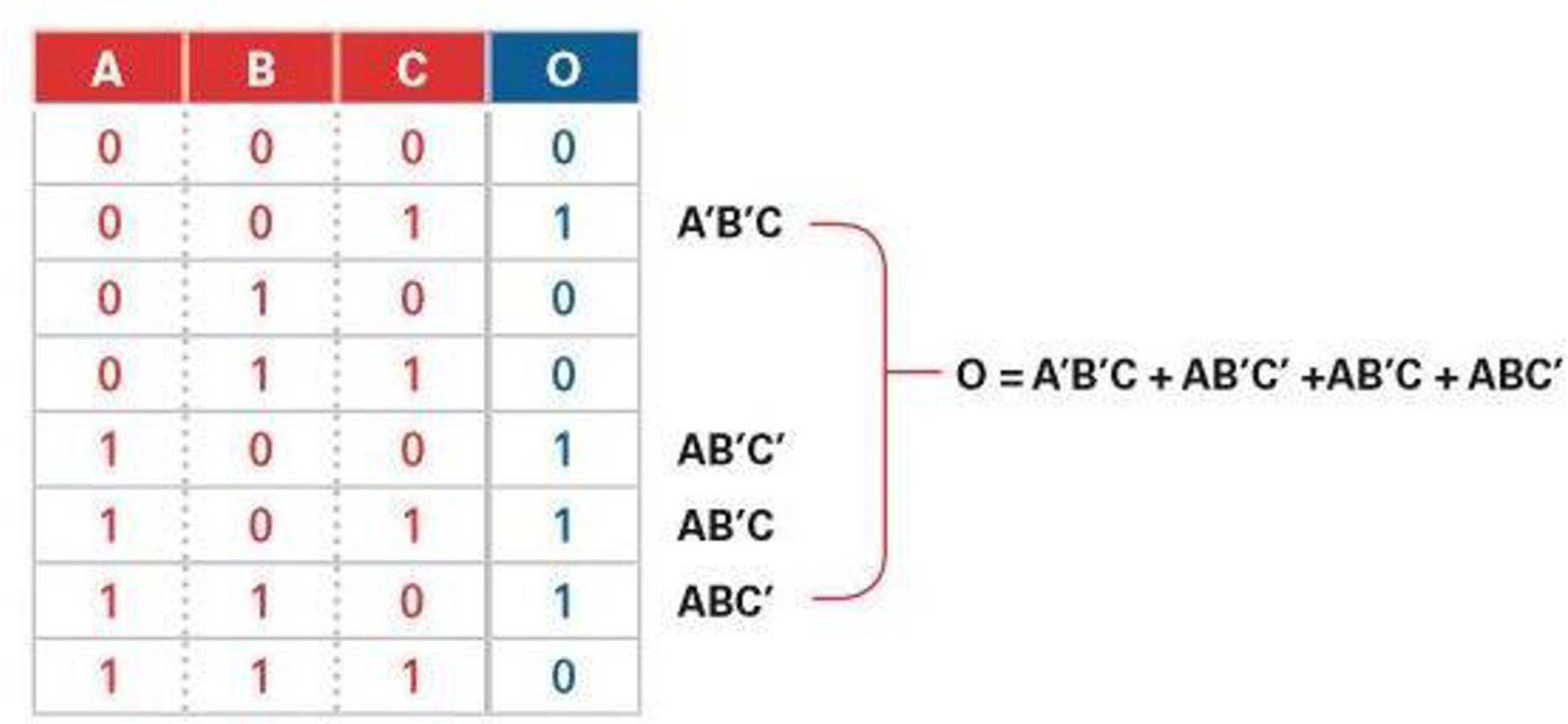
A simple method for **converting a truth table into a CLC** is found in a standard form of Boolean expression called the **Sum-of-Products (SOP).**

- An SOP expression is literally a sum of Boolean terms called **minterms (ελαχιστόροι)**.
- A minterm is a multiplicative combination of Boolean variables whose output equals 1.
- An example of an SOP expression is ABC + AB’C’, where ABC, AB’C’ are minterms.
- SOP expressions may be generated from truth tables using the following steps:
  1. Determine which rows of the table have an output of 1.
  2. Derive each row’s minterm, such that the output is 1 given that row’s input state.
  3. Sum the minterms.

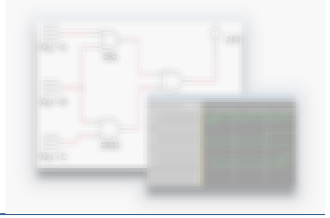


Sum-of-Products (άθροισμα γινομένων)

Below is an example of a **truth table conversion to an SOP** expression.



A	B	C	O
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	0

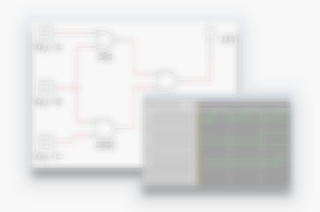


Product-of-Sums (γινόμενο αθροισμάτων)

Product-of-Sums (POS) expressions are another way of **representing truth tables**.

- A POS expression is a product of Boolean terms called **maxterms (μεγιστόροι)**.
- A maxterm is a summation of Boolean variables whose output equals 0.
- To generate a POS expression from a truth table, perform the following steps:
    1. Determine which rows of the table have an output of 0.
    2. Derive each row’s maxterm, such that the output is 0 given that row’s input state.
    3. Multiply the maxterms.

Product-of-Sums (γινόμενο αθροισμάτων)



Below is an example of a **truth table conversion to an POS** expression.

A	B	C	O
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	0

$A + B + C$

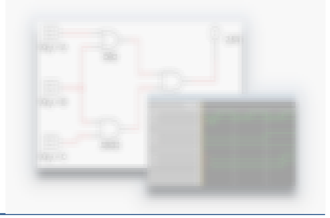
$A + B' + C$

$A + B' + C'$

$A' + B' + C'$

$$O = (A + B + C)(A + B' + C)(A + B' + C')(A' + B' + C')$$

SOP and POS

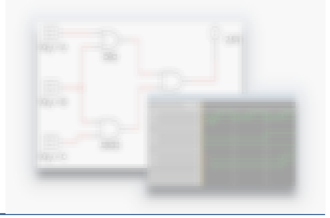


The **SOP** and **POS** standard Boolean forms are powerful tools when applied to truth tables.

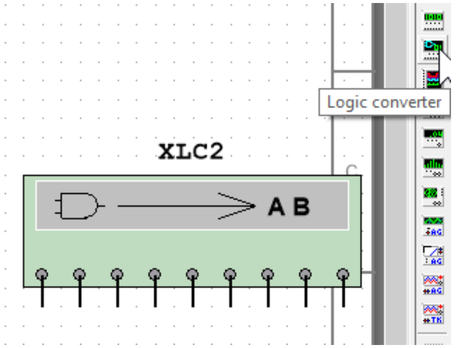
They can be used to derive a Boolean expression—and ultimately, an actual logic circuit.

- When creating a circuit from **SOPs**, it would be constructed of **AND gates feeding into an OR gate**.
- When creating a circuit from **POSs**, it would be constructed of **OR gates feeding into an AND gate**.

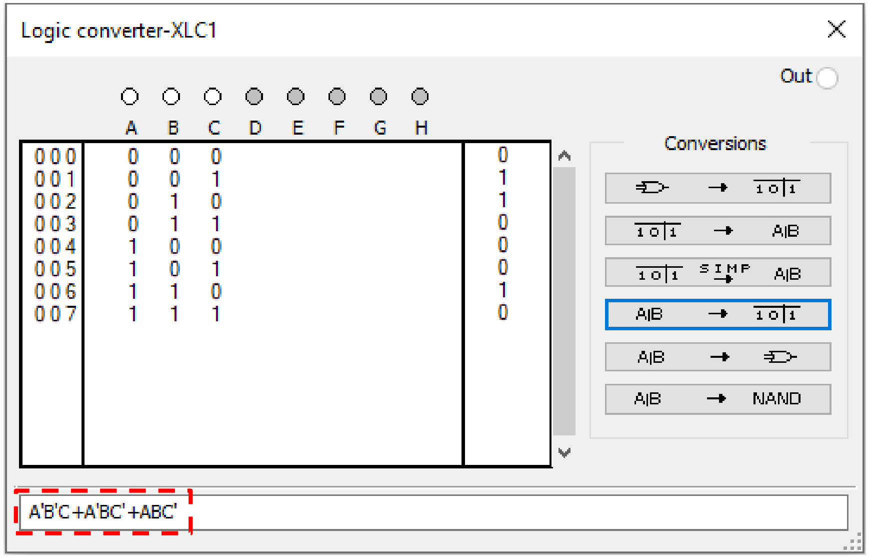
MultiSim - Logic Converter (Expression to Truth Table)

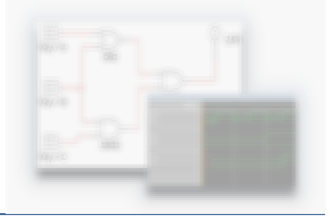


The **Logic Converter** is a great tool for checking truth tables and logic expressions. To build a Logic Converter circuit:



- Place the **Logic Converter** from the instruments toolbar on the right screen onto the circuit.
- **Double click** the Logic Converter to open its user interface.
- **Enter the SOP expression** that you want in the text field at the bottom of the window.
- Click the fourth button, **Expression to Truth Table**.

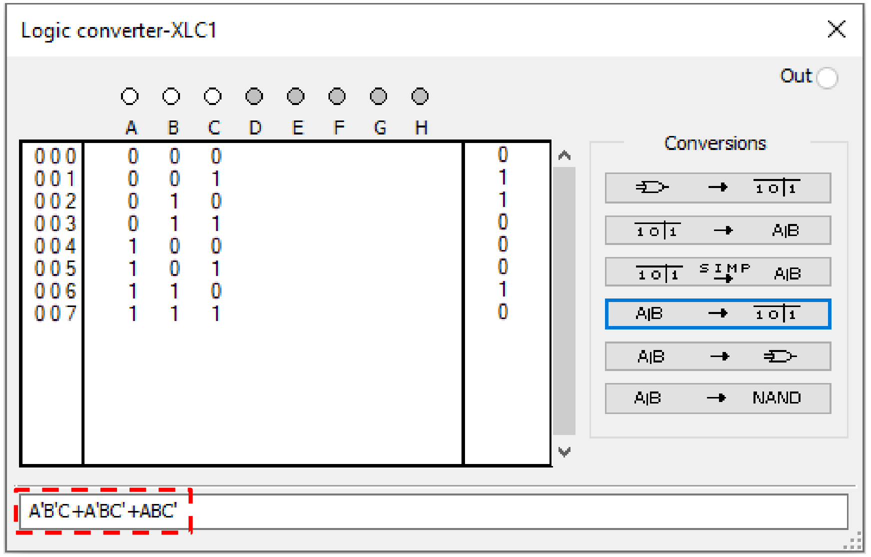


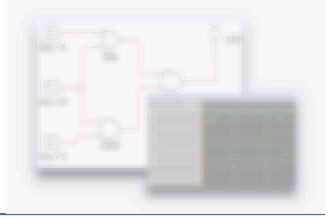


MultiSim - Logic Converter (Simplified Expression)

The **Logic Converter** can also **generate circuits** from POS and SOP expressions. This can save some time from doing the work manually.

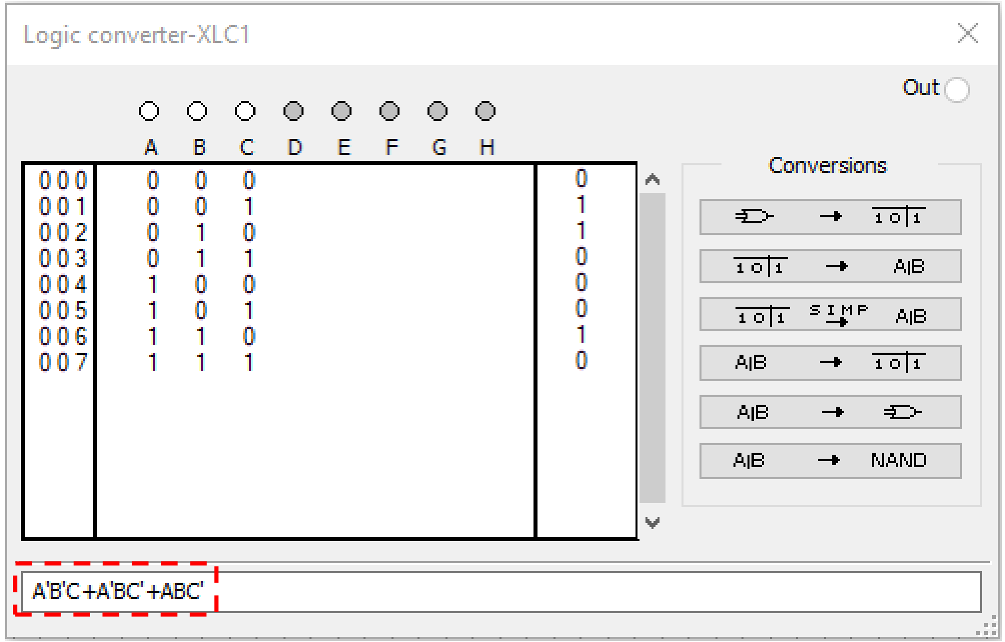
- **Enter the SOP expression** that you want in the text field at the bottom of the window.
- Click the fourth button, **Expression to Truth Table**.

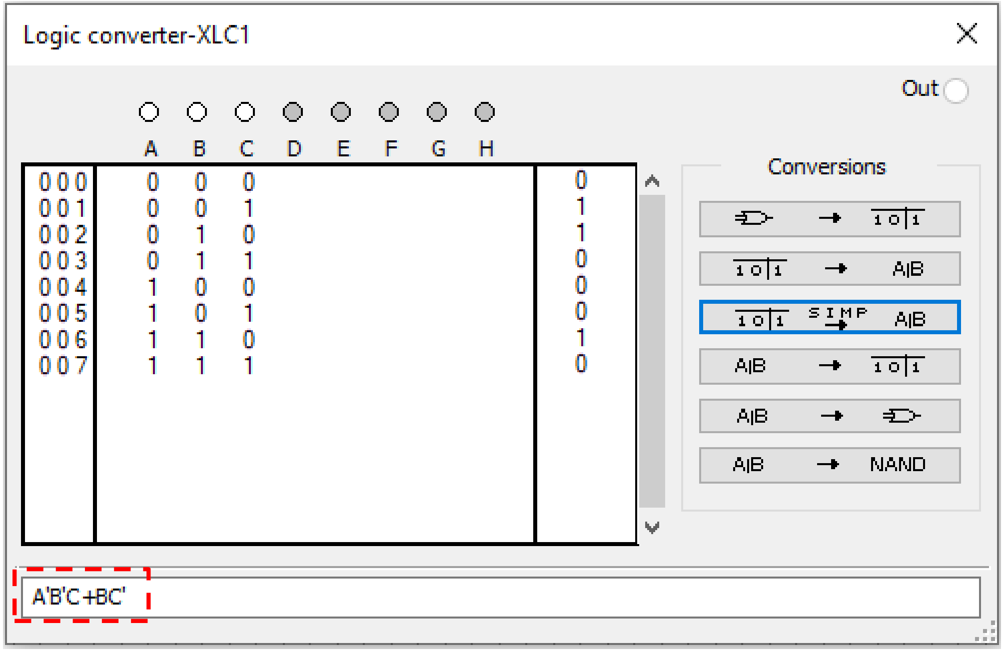


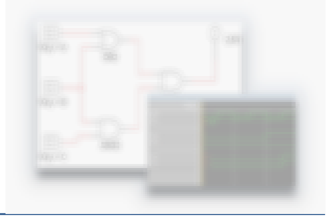


MultiSim - Logic Converter (Simplified Expression)

- Click the third button, **Truth Table to Simplified Expression**. This will simplify the expression if it can be simplified.

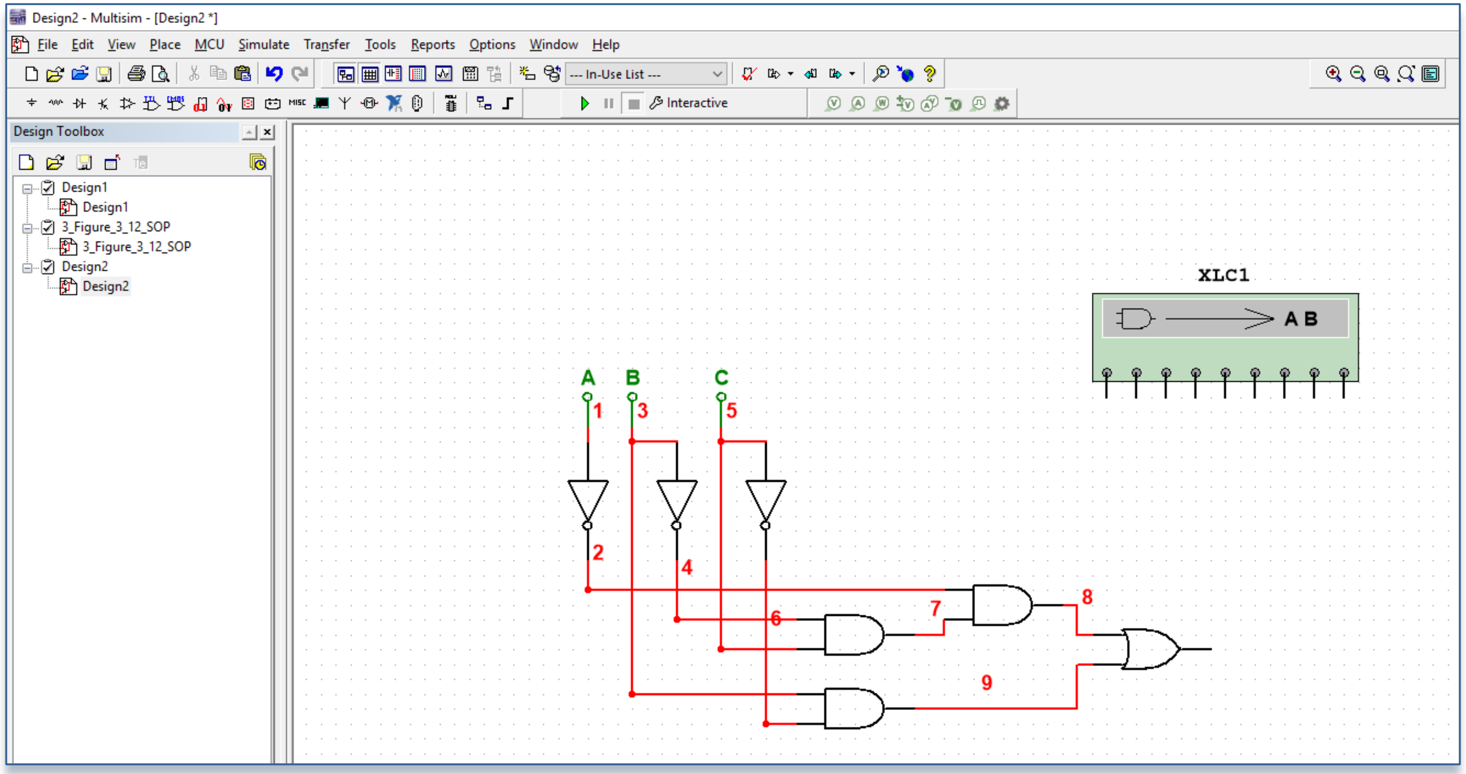




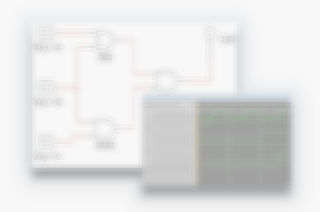


MultiSim - Logic Converter (Expression to Circuit)

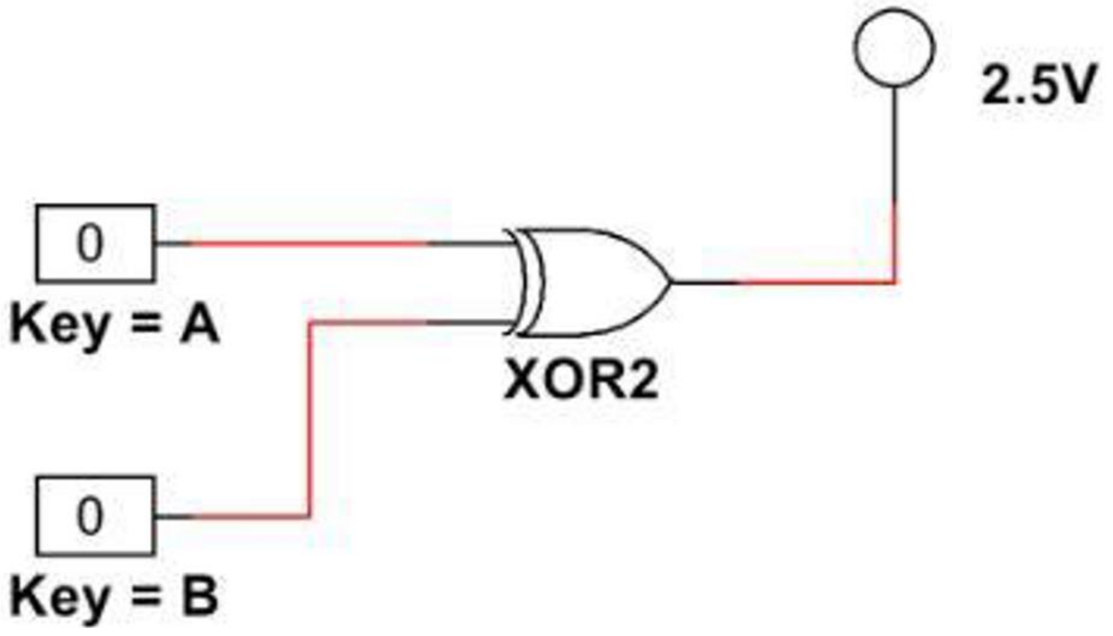
- Next, click the fifth button, **Expression to Circuit**.
- **Place the circuit** that it generates.



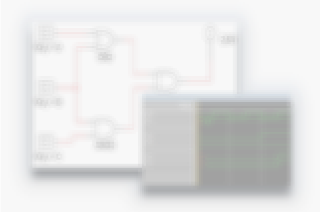
Exercise: Building an XOR Logic Gate in Multisim



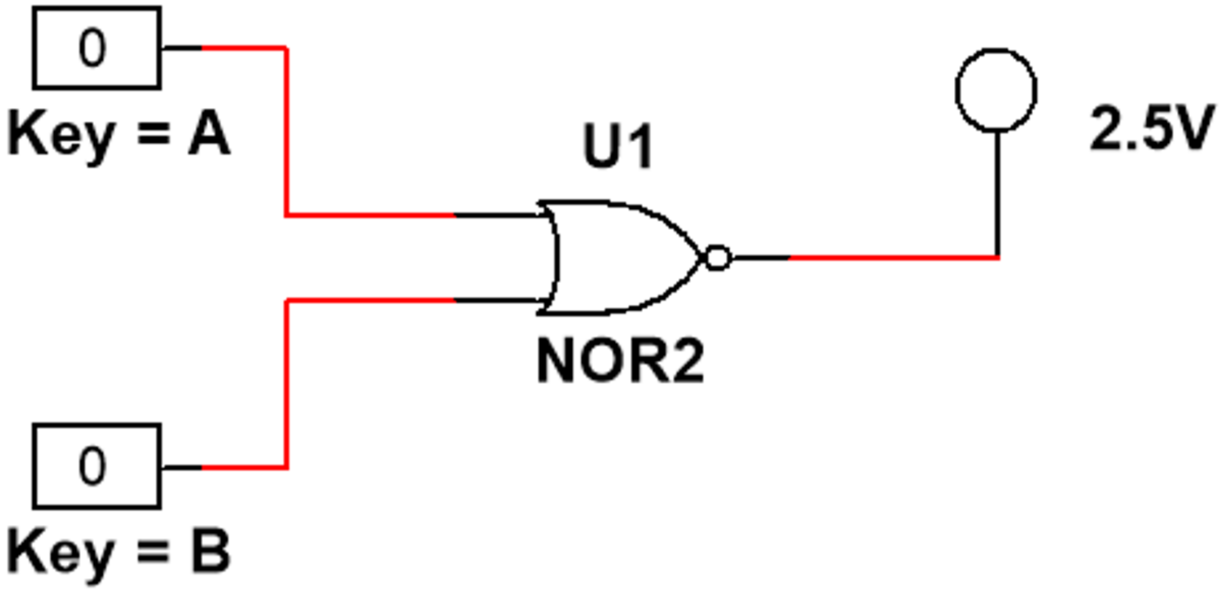
- Build the following circuit using an XOR gate:



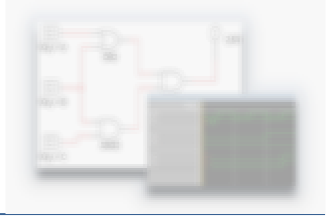
Exercise: Building a NOR Logic Gate in Multisim



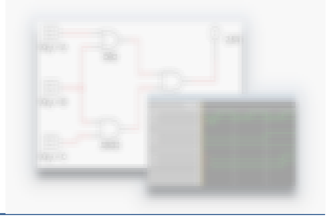
- Build the following circuit using an NOR gate:



Exercise: NOT - Gate

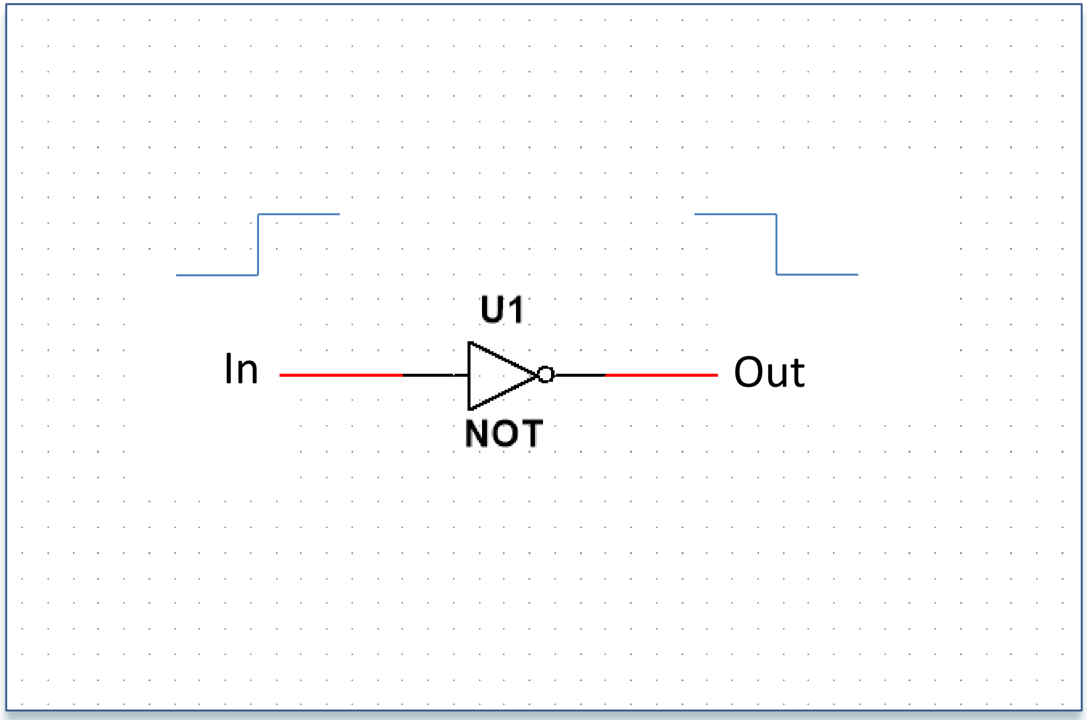


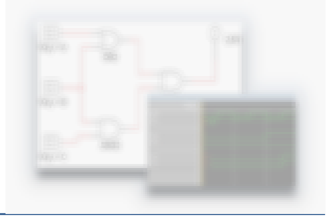
- Θέλουμε να μετρήσουμε και να συγκρίνουμε την **καθυστέρηση διάδοσης** του σήματος από την είσοδο μέχρι την έξοδο δύο αντιστροφέων διαφορετικής τεχνολογίας.
- Οι αντιστροφείς που θα συγκριθούν είναι οι εξής:
  - CMOS / CMOS_5V / **4009BD_5V**
  - TTL / 74STD / **7404N**
- Συνδέστε στην είσοδο και των δύο πυλών ένα ρολόι παραγωγής τετραγωνικών παλμών με συχνότητα 1 MHz.
- Χρησιμοποιώντας έναν **παλμογράφο** παρατηρείστε την είσοδο του παλμού στο κύκλωμα και την έξοδο της κάθε πύλης χρησιμοποιώντας τρία κανάλια της συσκευής.
- Υπολογίστε τον χρόνο καθυστέρησης στη διάδοση του σήματος κάθε αντιστροφέα, για την μετάβασή του από 0→1 καθώς και για μετάβαση από 1→0.
- Η προσομοίωση να γίνει με το Multisim.



Multisim - Παλμογράφος

- Θέλουμε να μετρήσουμε την **καθυστέρηση διάδοσης** του σήματος από την είσοδο ενός αντιστροφέα στην έξοδό του.





Multisim - Παλμογράφος

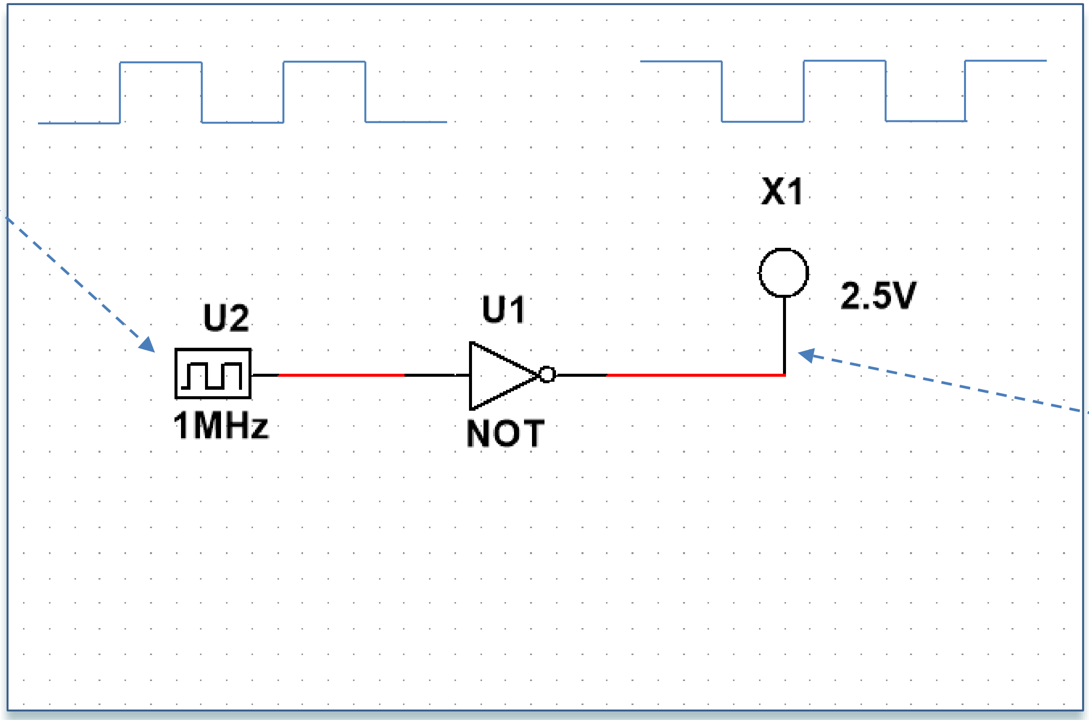
- Θέλουμε να μετρήσουμε την **καθυστέρηση διάδοσης** του σήματος από την είσοδο ενός αντιστροφέα στην έξοδό του.

Συνδέουμε ένα **ρολόι** τετραγωνικών παλμών στην είσοδο

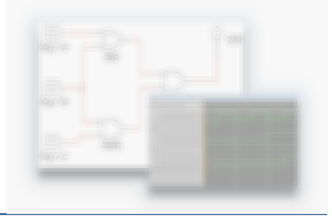
Θα το βρούμε στο: Sources/DIGITAL_SOURCES /DIGITAL_CLOCK

Διπλό κλικ και ρυθμίζουμε την συχνότητα στο 1MHz

Το **clock** είναι μία γεννήτρια σήματος όπου εναλλάσσει την τιμή του από “0” σε “1” επαναληπτικά στην συχνότητα που το έχουμε ορίσει

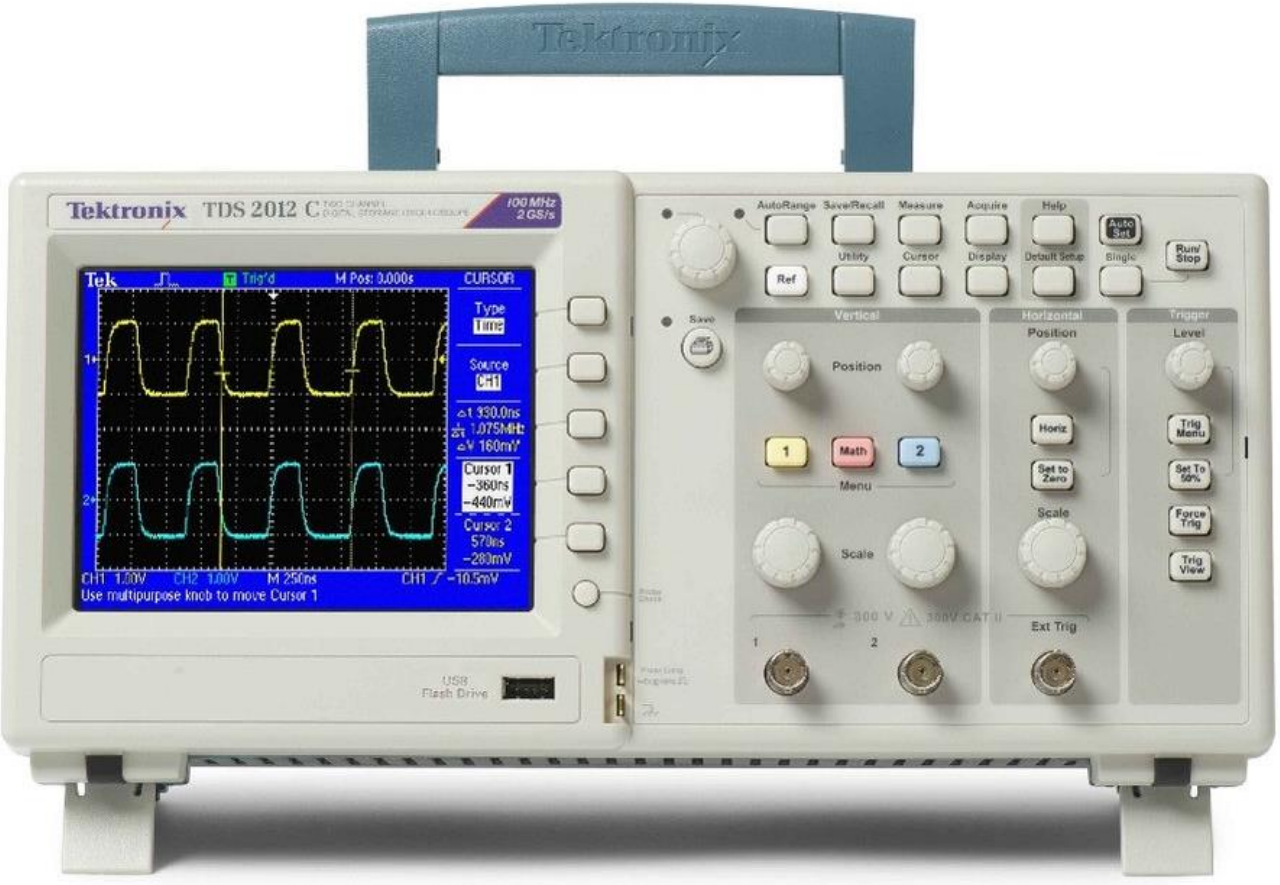


Συνδέουμε ένα Probe στην έξοδο

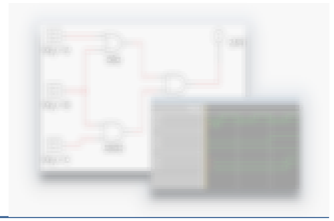


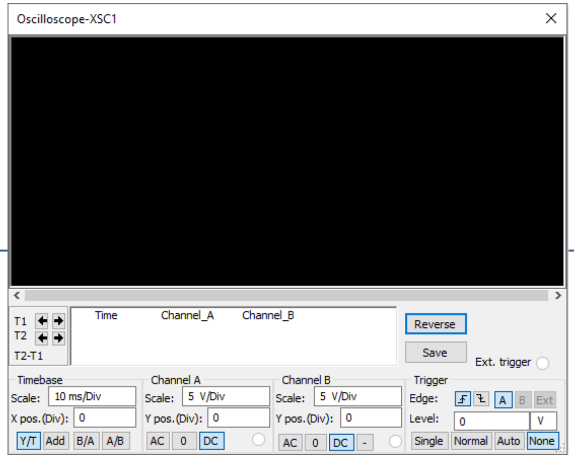
Multisim - Παλμογράφος

- Ο **Παλμογράφος** είναι ένα εργαστηριακό όργανο για την μέτρηση όχι μόνο της τιμής μεγεθών σε ηλεκτρικά/ηλεκτρονικά κυκλώματα αλλά και της χρονικής τους εξέλιξης τους.

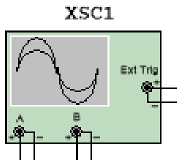


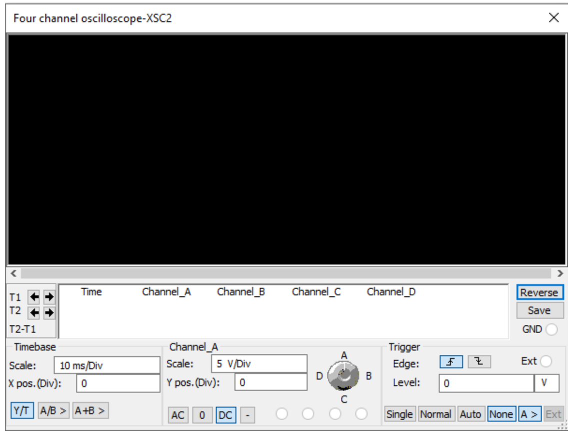
Multisim - Παλμογράφος

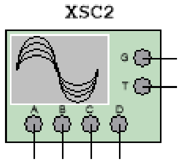




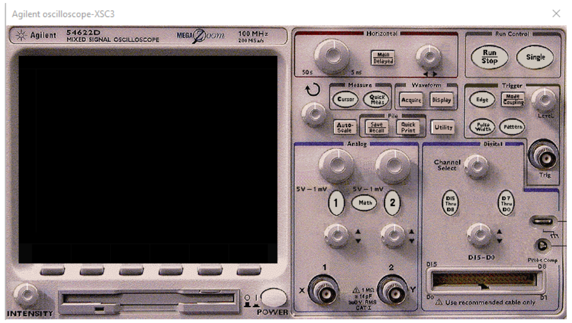
- Στο Multisim υπάρχουν **4 διαφορετικοί παλμογράφοι**
- Βρίσκονται όλοι στην δεξιά μπάρα των οργάνων

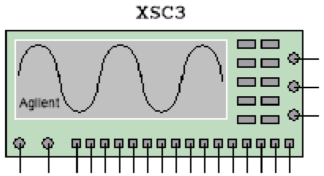


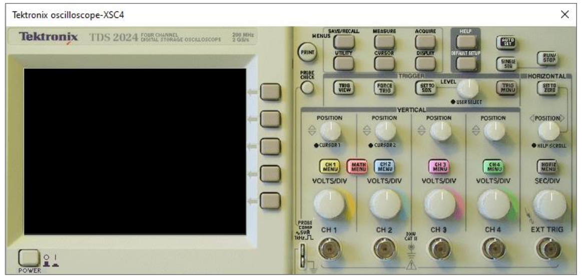


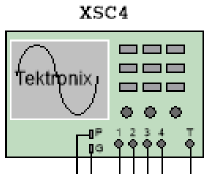


- Με 2 κανάλια (Virtual)
- Με 4 κανάλια (Virtual)
- Agilent oscilloscope – XSC3
- Tektronix oscilloscope – XSC4



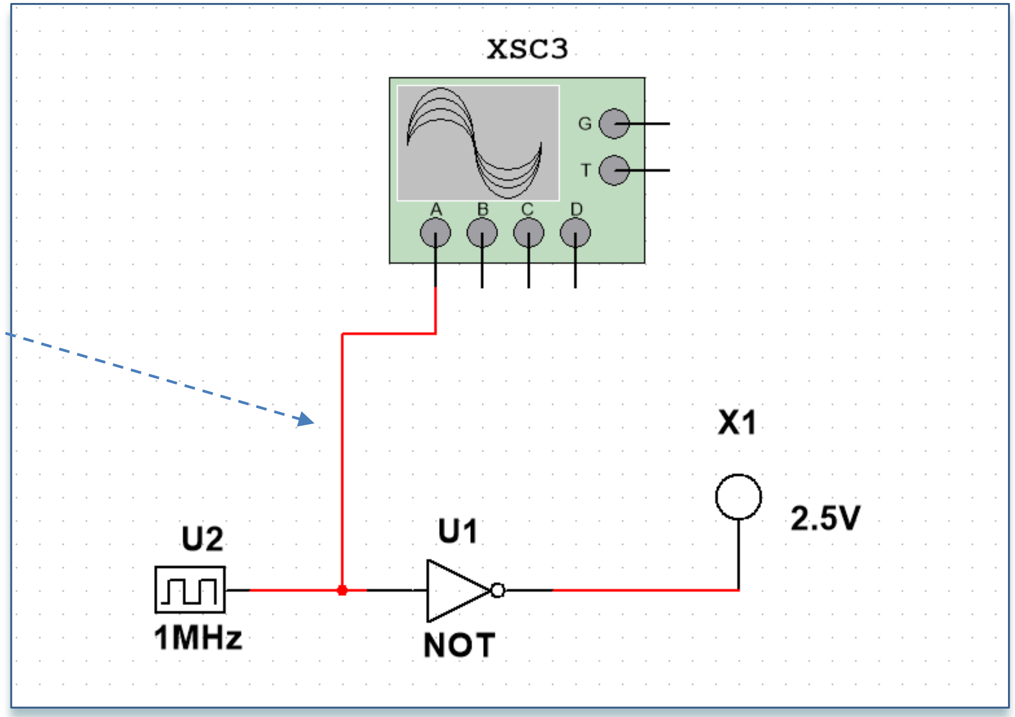


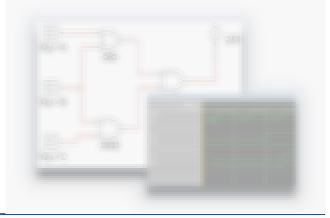




Multisim - Παλμογράφος

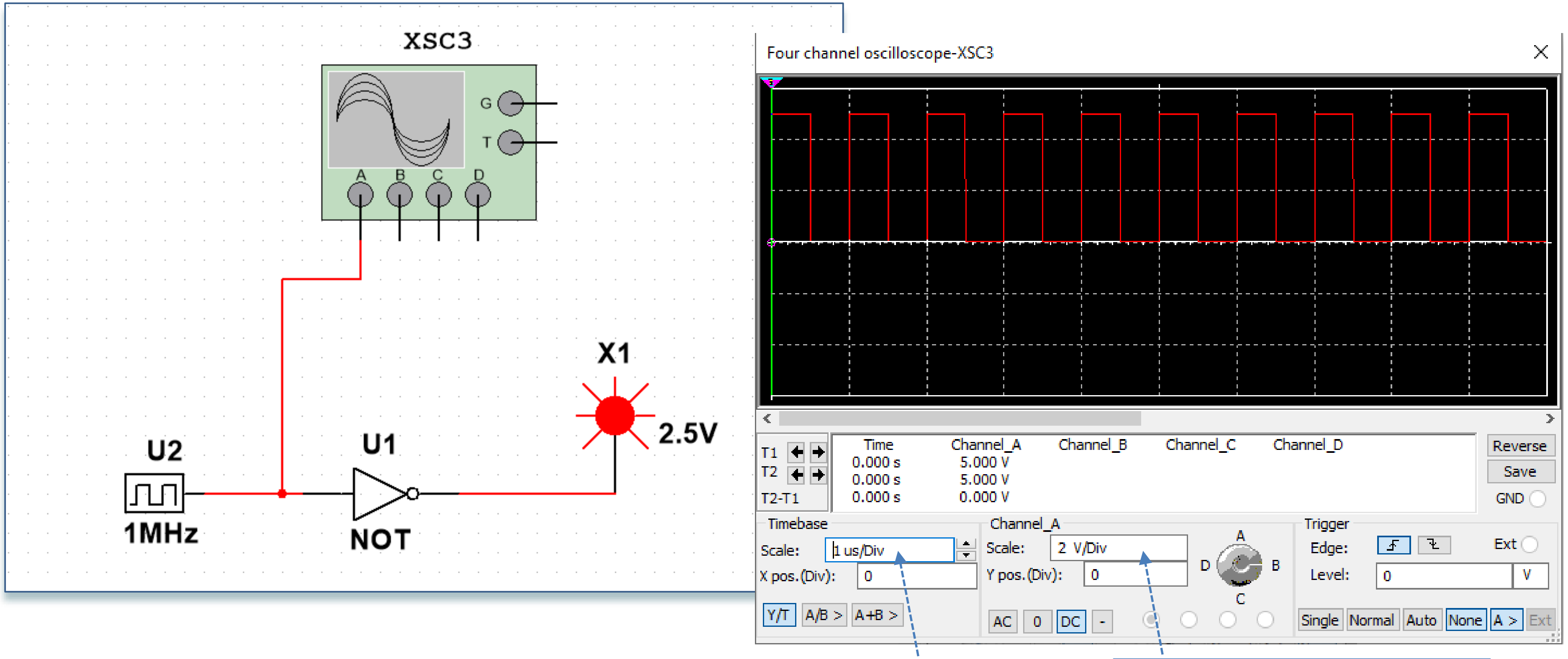
Συνδέουμε το Α κανάλι του παλμογράφου στην είσοδο του αντιστροφέα





Multisim - Παλμογράφος

Πιέζουμε **Run** και έπειτα από λίγο **Stop**

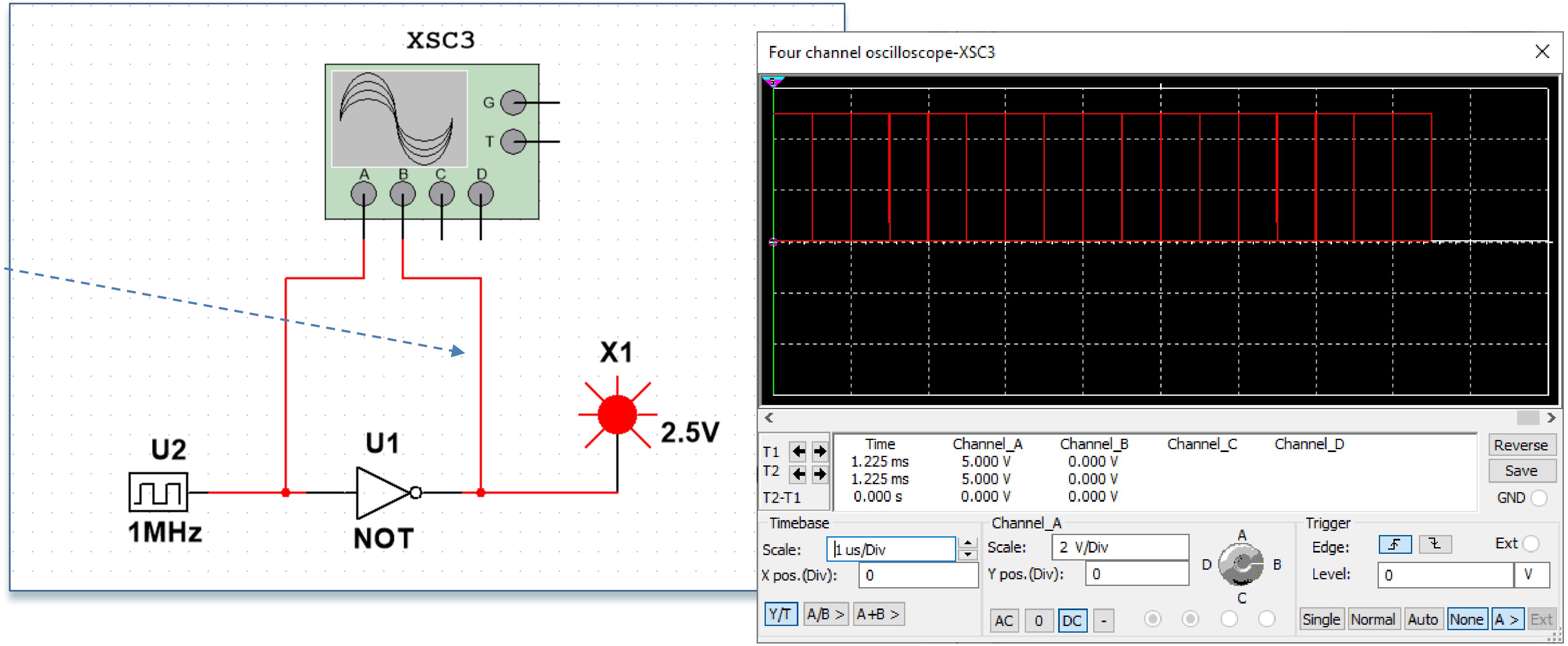


Ρύθμιση κλίμακας χρόνου στον άξονα X

Ρύθμιση κλίμακας τάσης στον άξονα Y

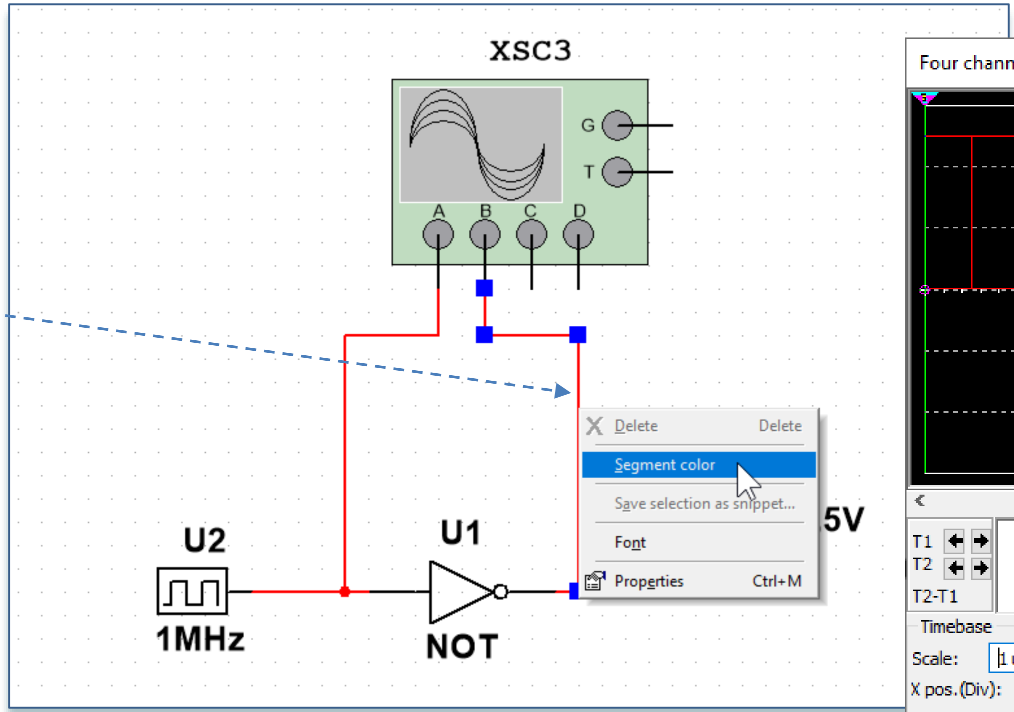
Multisim - Παλμογράφος

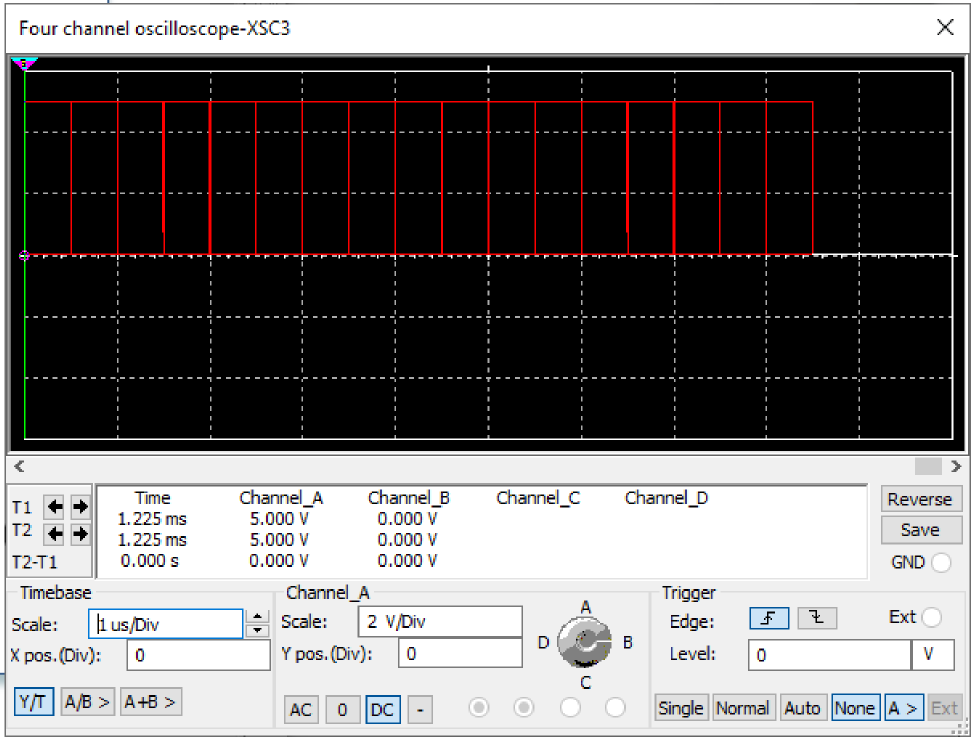
Συνδέουμε και το κανάλι B του παλμογράφου στην έξοδο του αντιστροφέα



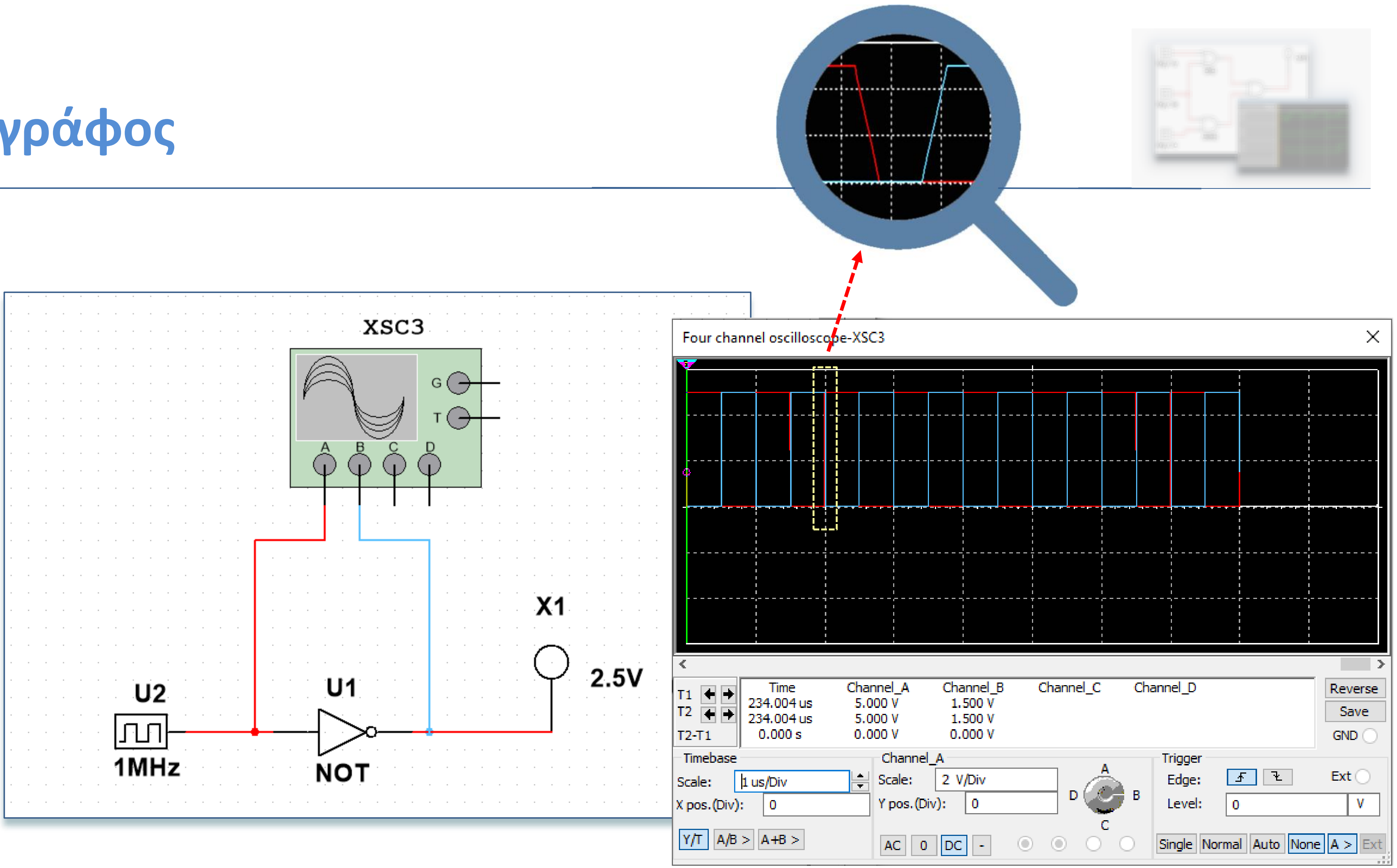
Multisim - Παλμογράφος

Τροποποιούμε το χρώμα απεικόνισης του B καναλιού.

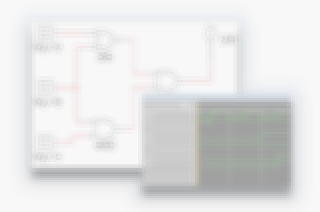




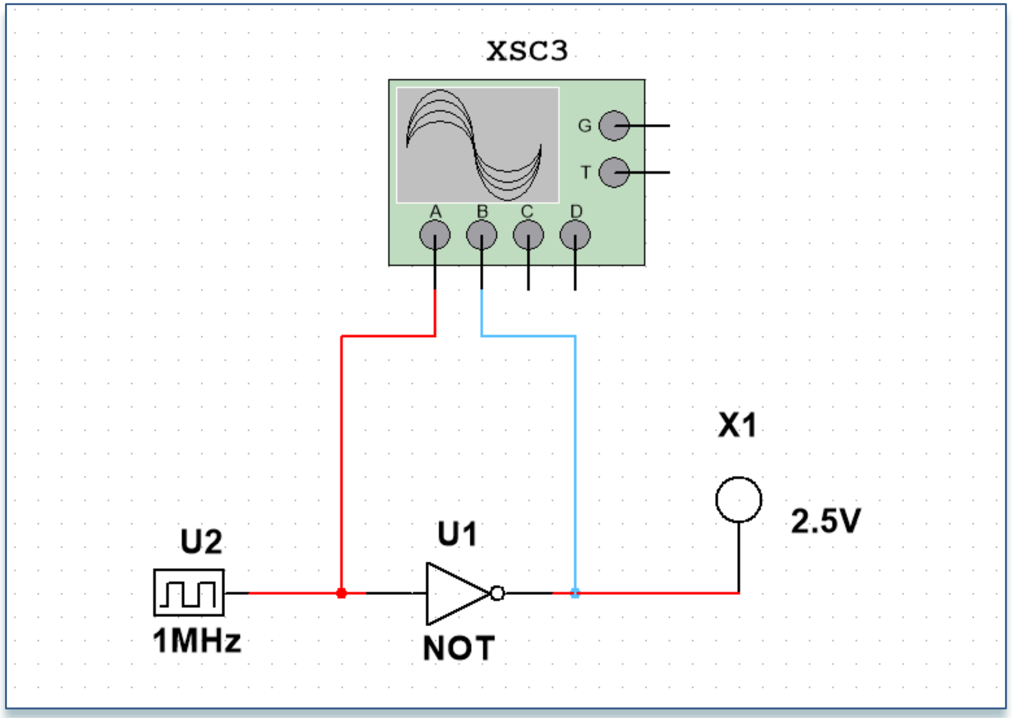
Multisim - Παλμογράφος

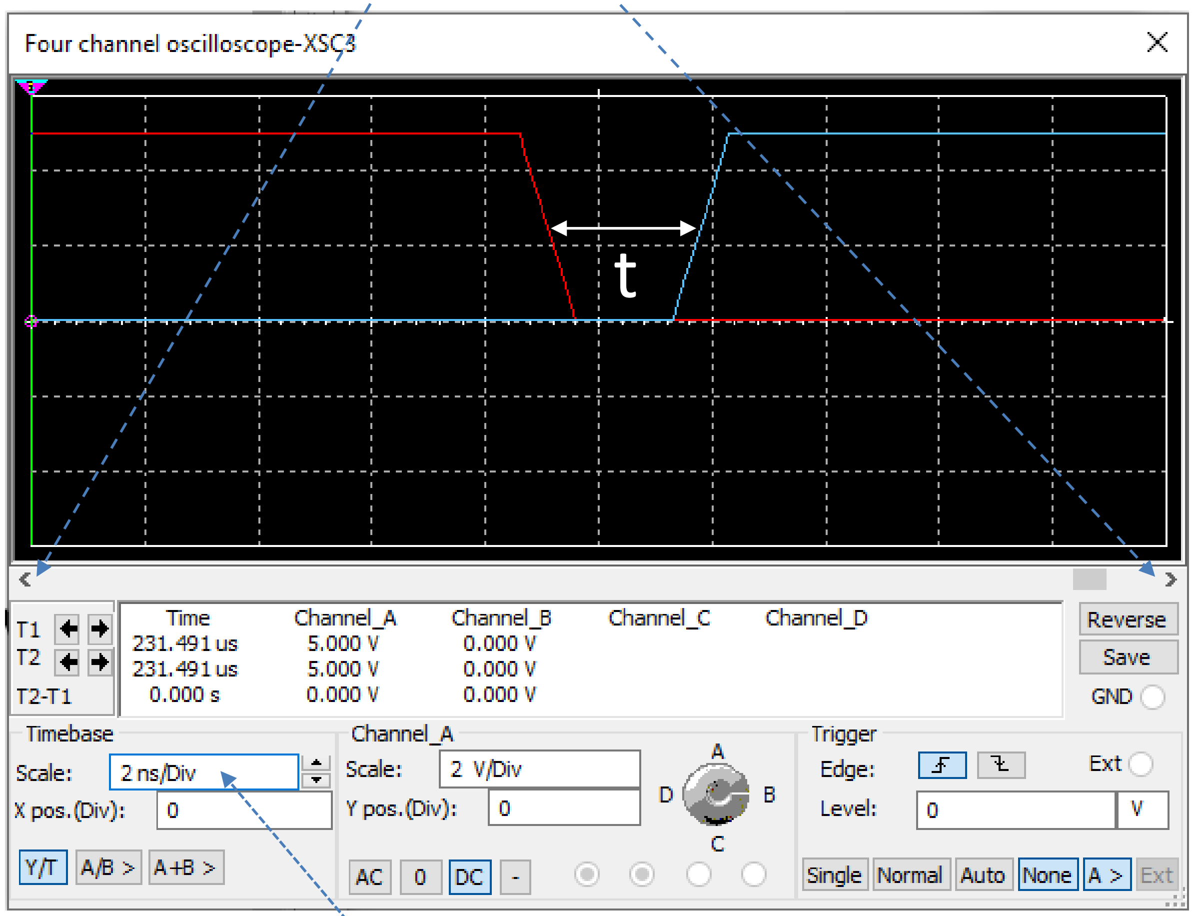


Multisim - Παλμογράφος



Μετακινούμε το γράφημα δεξιά ή αριστερά ώστε να βρούμε το σημείο της μετάβασης





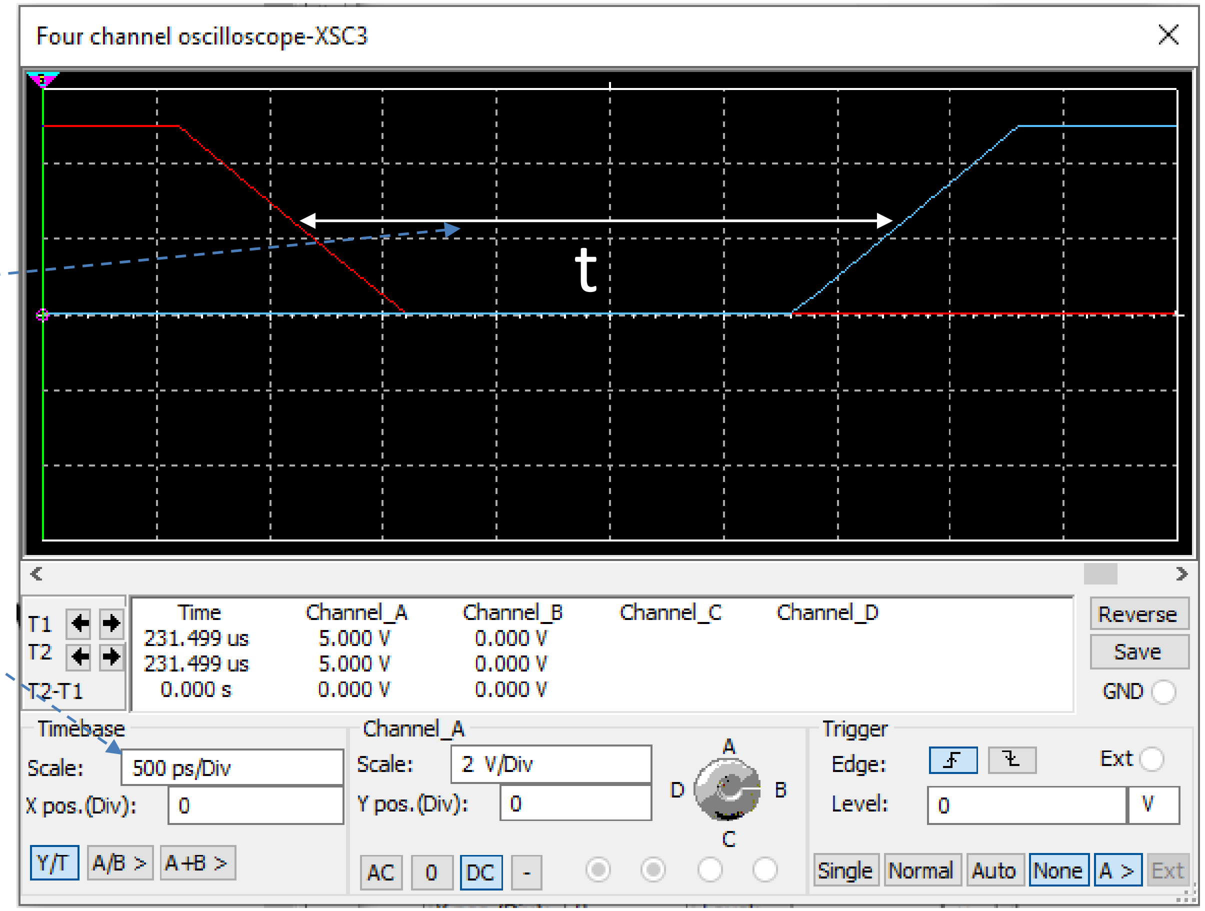
Μειώνουμε την κλίμακα στον άξονα Χ (χρόνος) ώστε να γίνει ορατή η πολύ μικρή χρονοκαθυστέρηση.

Multisim - Παλμογράφος

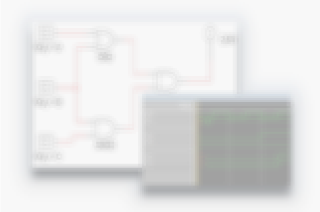
Μειώνουμε την κλίμακα τόσο ώστε να βρίσκονται και οι δύο μεταβάσεις μέσα στο διάγραμμα

Μετράμε περίπου 5,3 “κουτάκια”

Η κλίμακα είναι 500psec/Div οπότε οπτικά για μετάβαση του αντιστροφέα από 0→1 υπολογίζουμε περίπου καθυστέρηση μετάβασης **t = 5,3 x 500ps = 2,65 nsec**

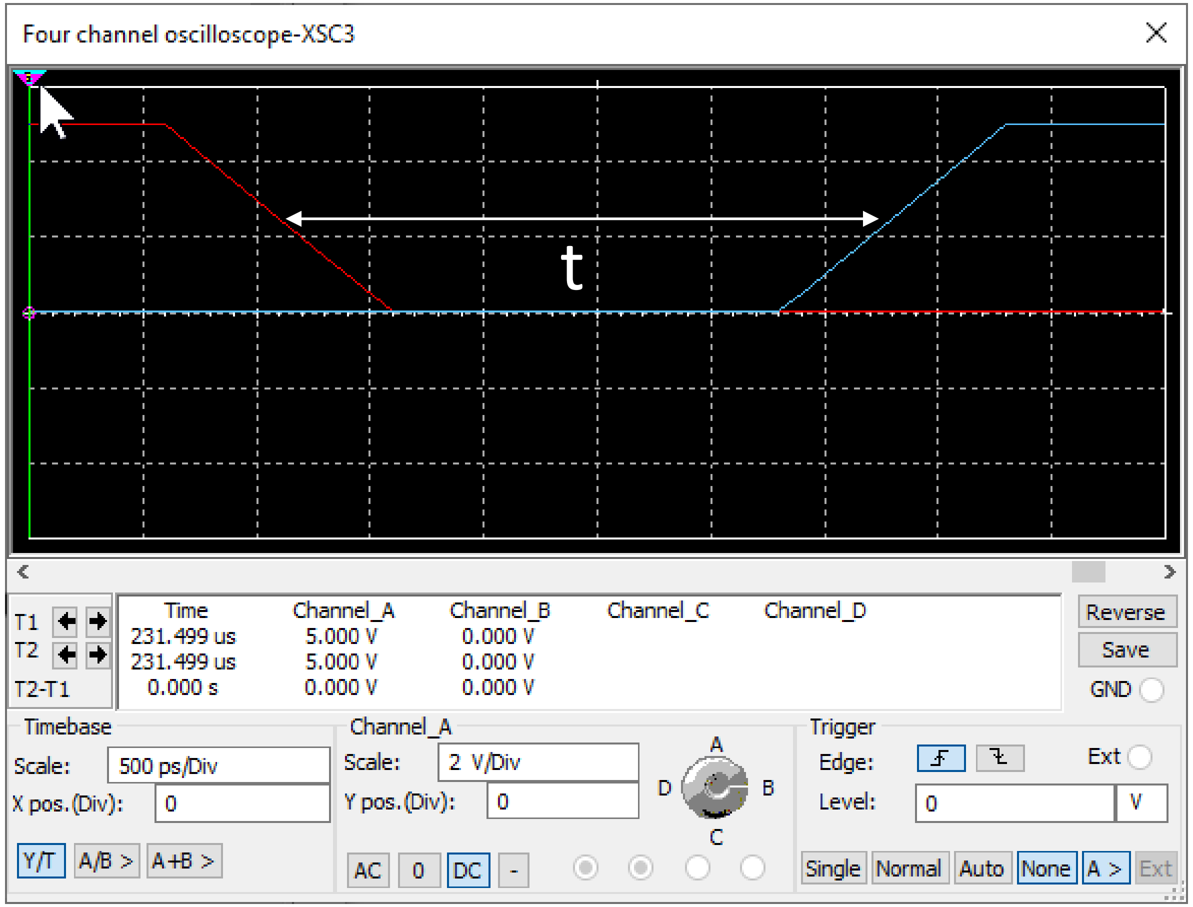


<u>**Σημείωση**</u>: Μετράμε από το μέσο της μεταβολής του σήματος εισόδου μέχρι το μέσο της μεταβολής του σήματος εξόδου.



Multisim - Παλμογράφος

Για ακριβέστερη μέτρηση μπορούμε να χρησιμοποιήσουμε τους cursors που διαθέτει ο παλμογράφος.

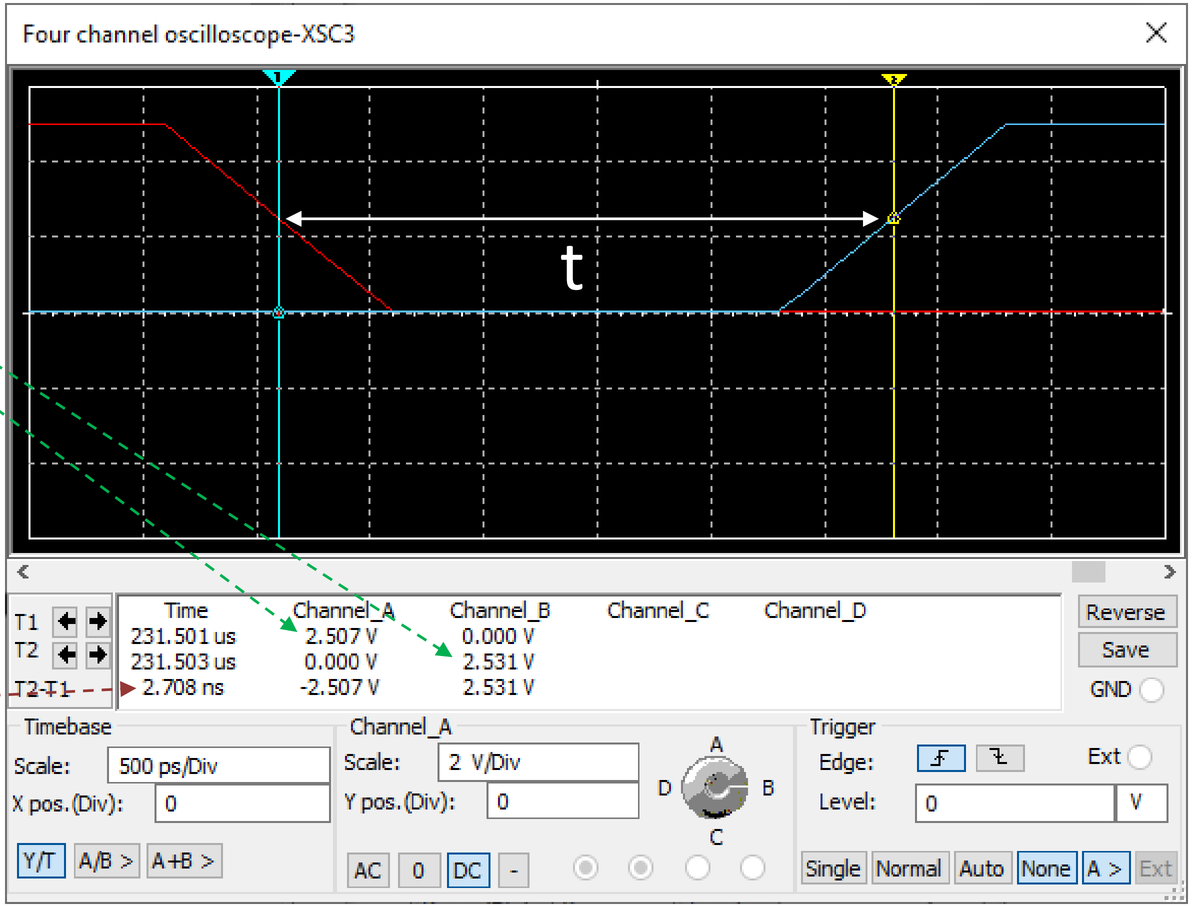


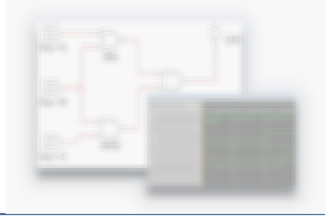
Multisim - Παλμογράφος

Μετακινούμε τους cursors ώστε να βρίσκονται όσο πιο κοντά στο μέσο της μετάβασης τους, το οποίο βρίσκεται στα 2,5 Volt

Ο παλμογράφος υπολογίζει την χρονική διαφορά μεταξύ των δύο cursors.

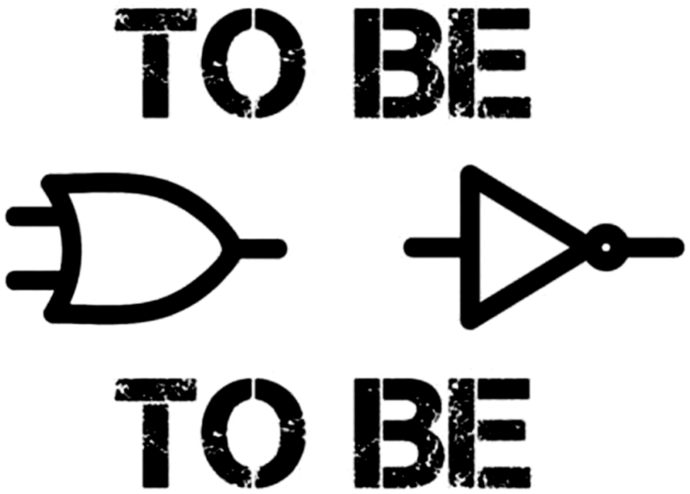
Η χρονική αυτή διαφορά είναι η καθυστέρηση διάδοσης του αντιστροφέα μας για μετάβαση 0→1 και είναι **t=2,708 nsec**





Ευχαριστώ για την προσοχή σας!

- **Ερωτήσεις / Απορίες ;**



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