Memristor - The fourth fundamental element

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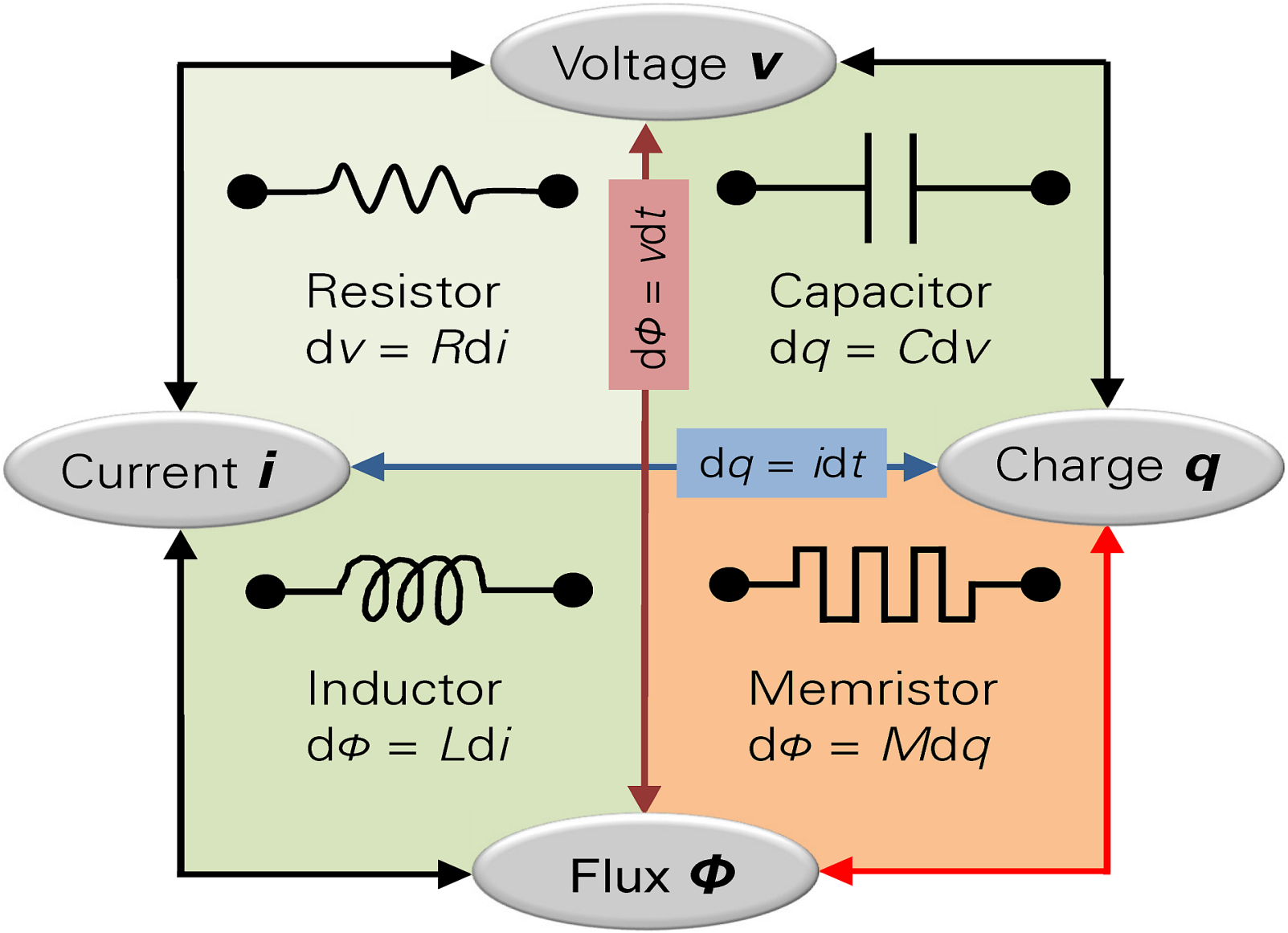
INTRODUCTION

- When Maxwell announces equations relating to electricity and magnetism, Leon Chua argued from theoretical grounds that there should be a fourth circuit element that was equally fundamental as the other three.

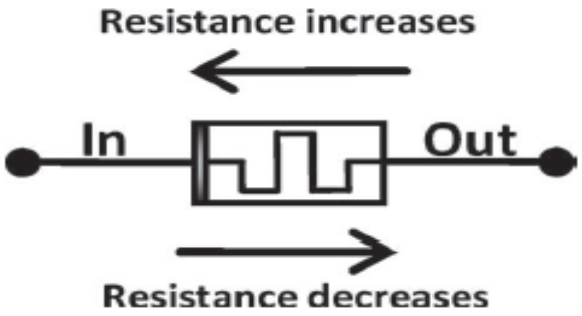
- That element is termed as MEMRISTOR - resistor with memory.

- It was predicted from theory arguments nearly 40 years ago, but not realized as a physical component that time.

- Work of Chua has not recognized until a group at HP labs managed to construct a physical component acting as memristor.


Voltage v
Resistor
dv = Rdi
dΦ = vdt
Capacitor
dq = Cdv
Current i
dq = idt
Charge q
Inductor
dΦ = Ldi
Memristor
dΦ = Mdq
Flux Φ

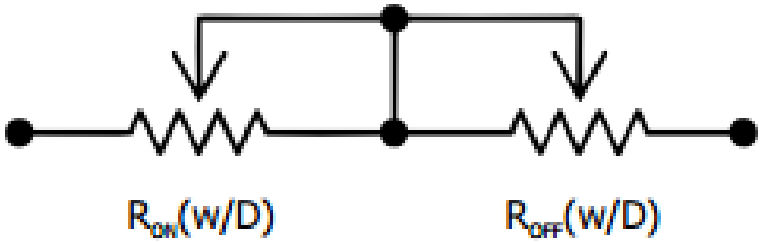
MEMRISTOR



- The memristors exhibit varying resistance when current flows into the device or out of the device.
- When current flows inside memristor (opposite of black strip), its resistance increases.
- When current flows inside memristor (black strip), its resistance decreases.

- Memristor is basically a charge-dependent resistor:

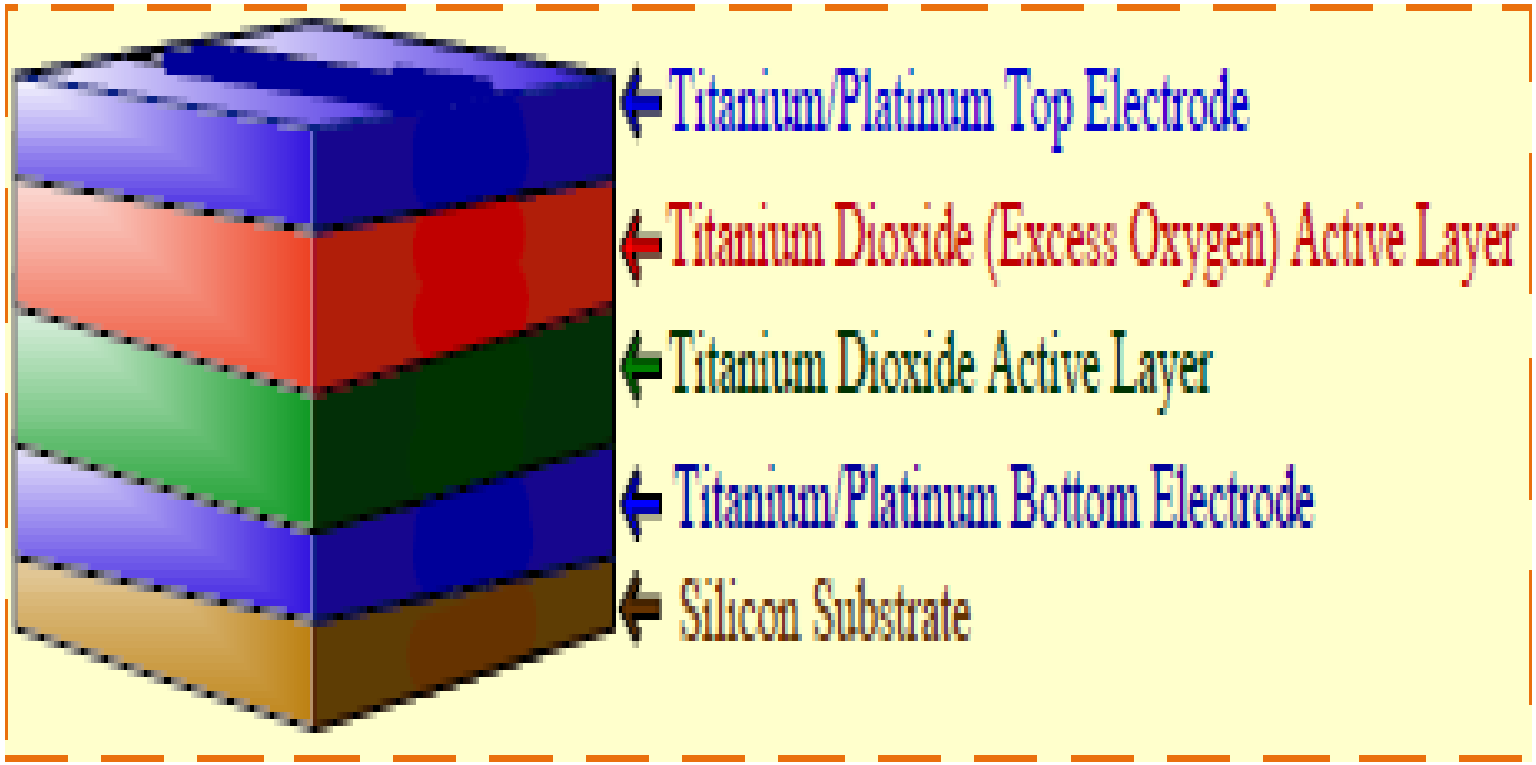
$$V(t) = M(q(t)) * I(t)$$



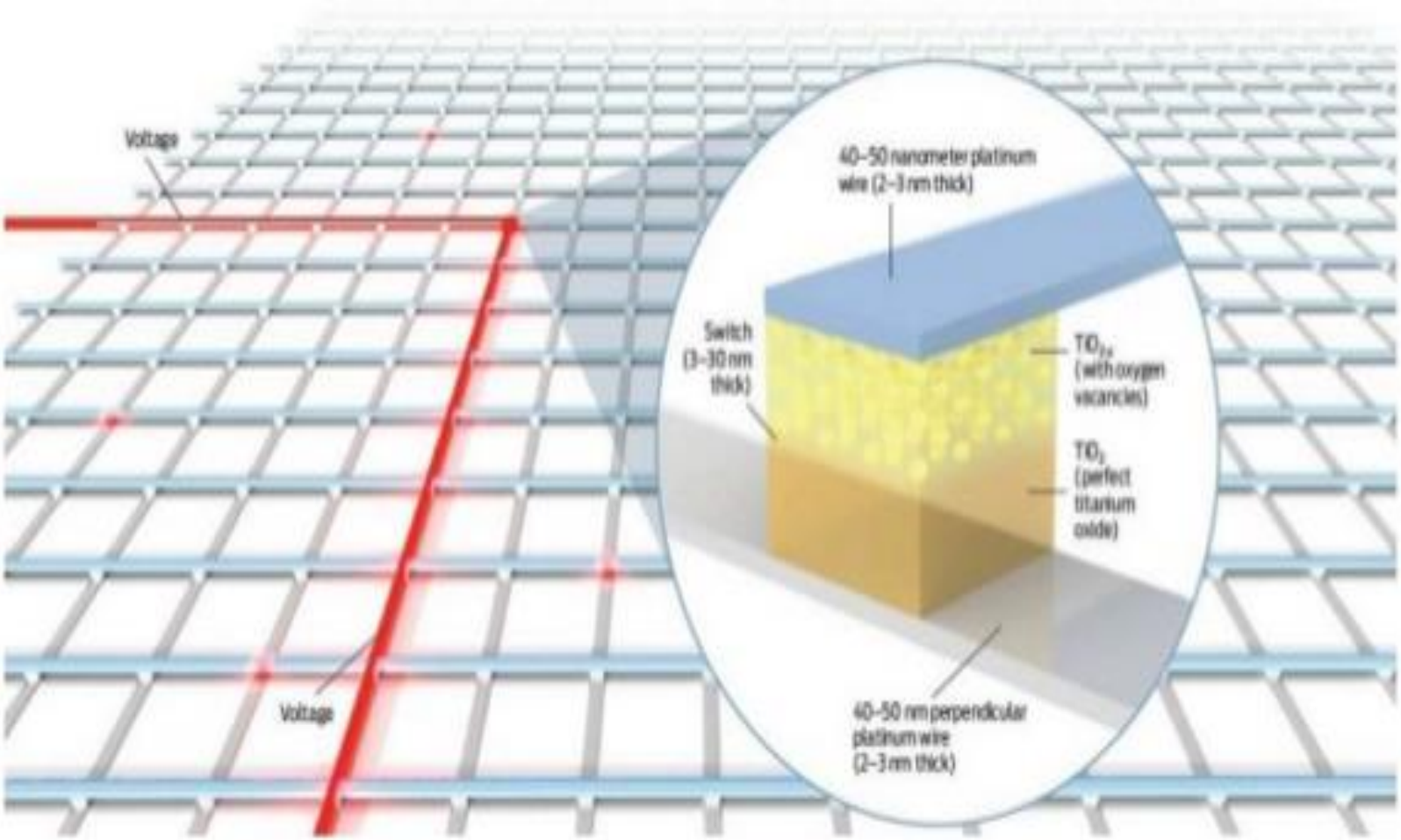
- Memristors can be used for memory implementation, where the logic bits are stored as resistance states.

- Memristors are non-volatile i.e. retain its state even after power is turned off.

Fabrication of memristor



Contd.....


Voltage
40–50 nanometer platinum wire (2–3 nm thick)
Switch (3–30 nm thick)
TiO_{2-x} (with oxygen vacancies)
TiO_2 (perfect titanium oxide)
Voltage
40–50 nm perpendicular platinum wire (2–3 nm thick)

Models

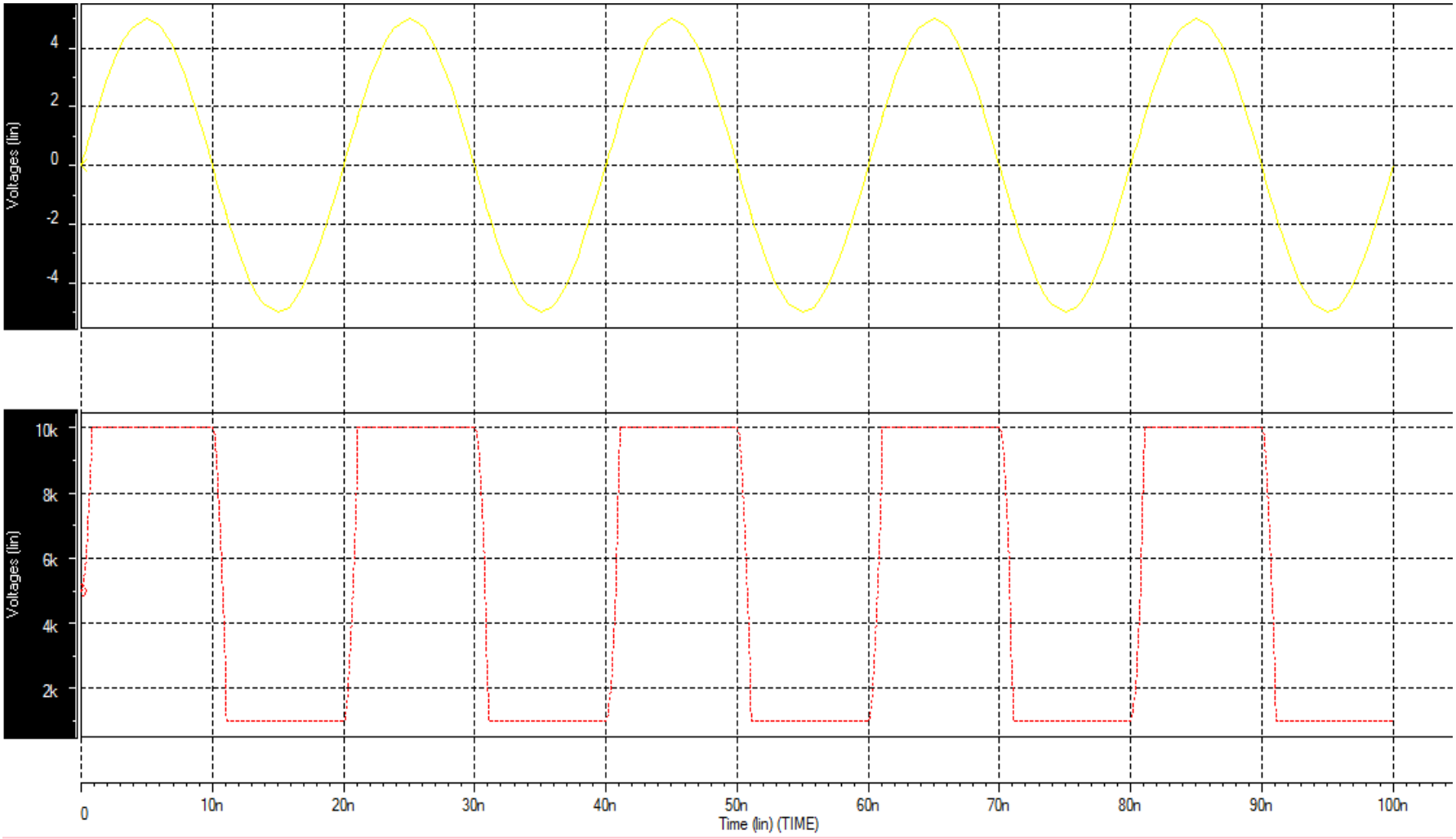
- Several models of ideal and non-ideal memresistive elements in the most popular SPICE versions.

➢ Model R.1: Ideal memristor

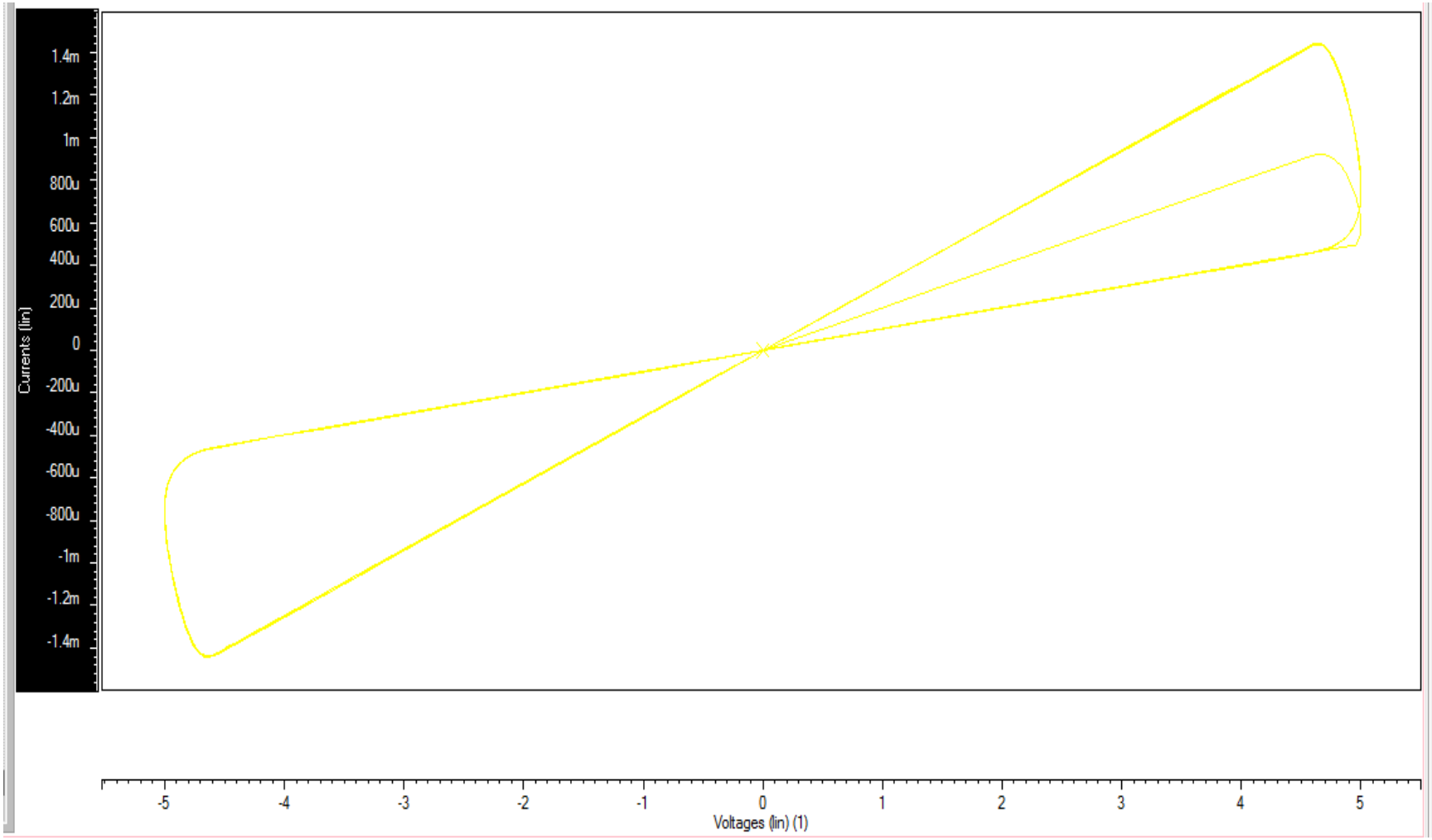
➢ Model R.2: Bipolar memristive system with threshold

- Other model is TEAM model: Threshold Adaptive Memristor Model.

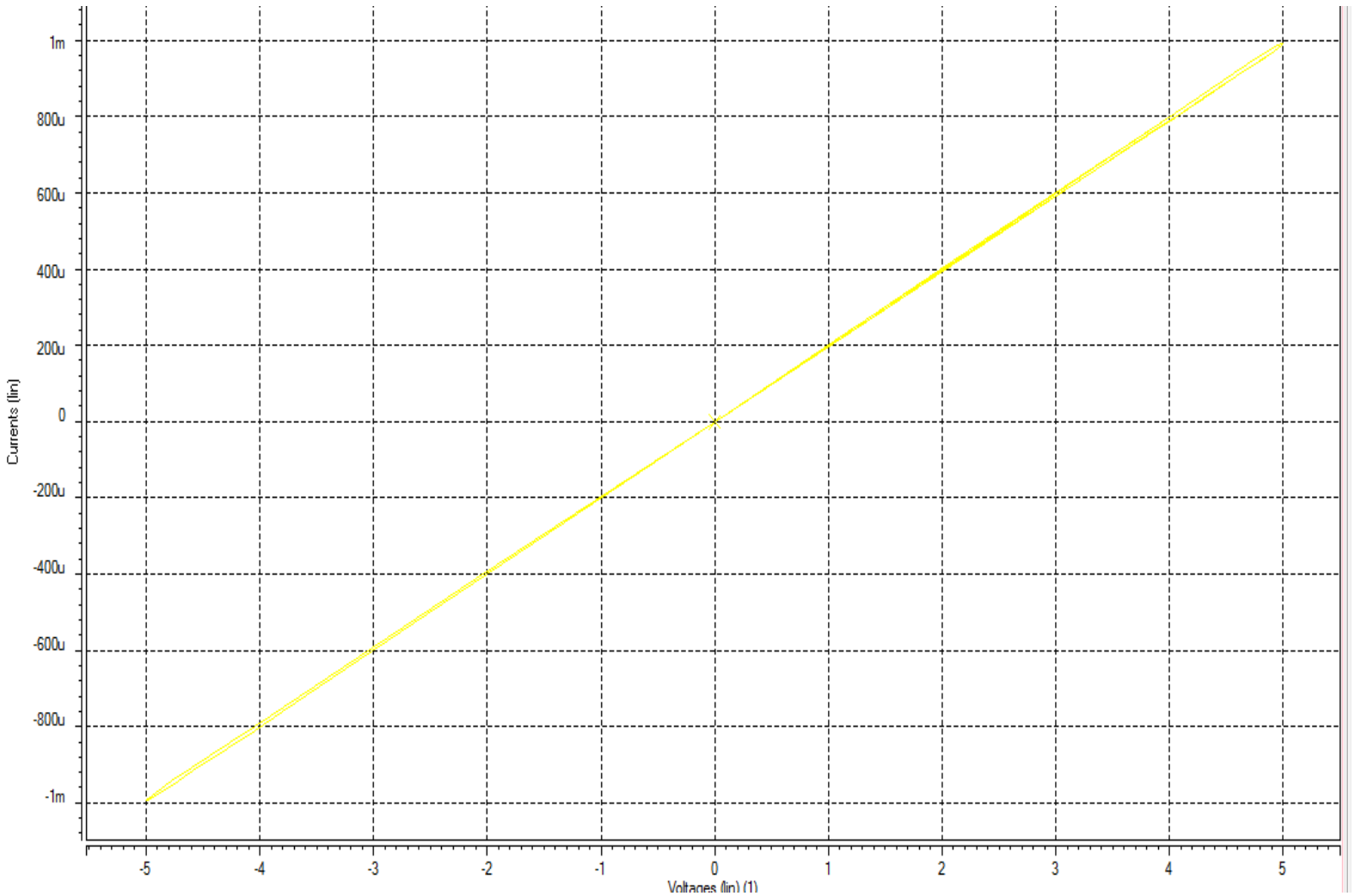
Memresistance States



Frequency- 50MHz



Frequency- 5GHz

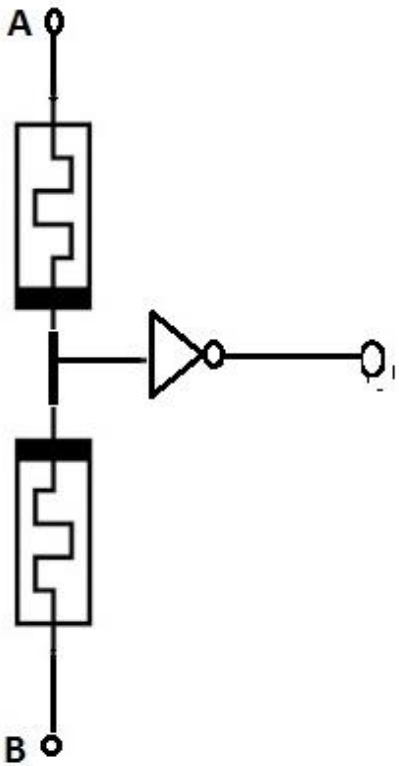


Logic Gates

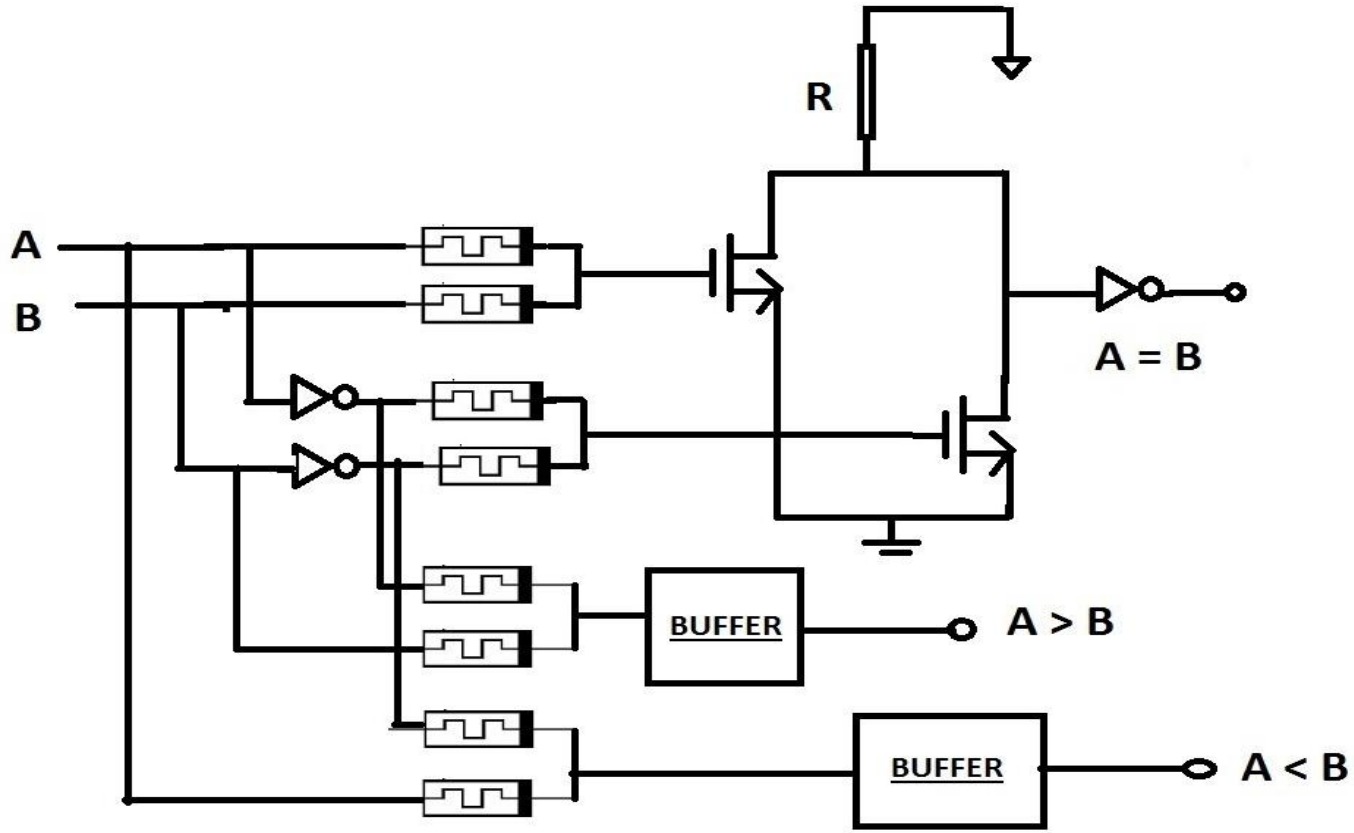
- Four separate logic families can be distinguished:
- Logic in memory, where the logic operations are done within memory cells. In this family the logic values are stored as resistance. Gates in this family include IMPLY and MAGIC.
- Hybrid CMOS Memristor Logic: In this family, requires both CMOS gates along with memristor based gates. Logic values are stored as voltages.
- Novel design using memresistors where only memresistors are used as computational unit . Logic values are stored as memresistance of output memresistor.
- Programmable Logic Memristor Array (PLA). This family is in fact a regular PLA, where the connections between horizontal and vertical wires are done with memristors.

Hybrid CMOS circuits

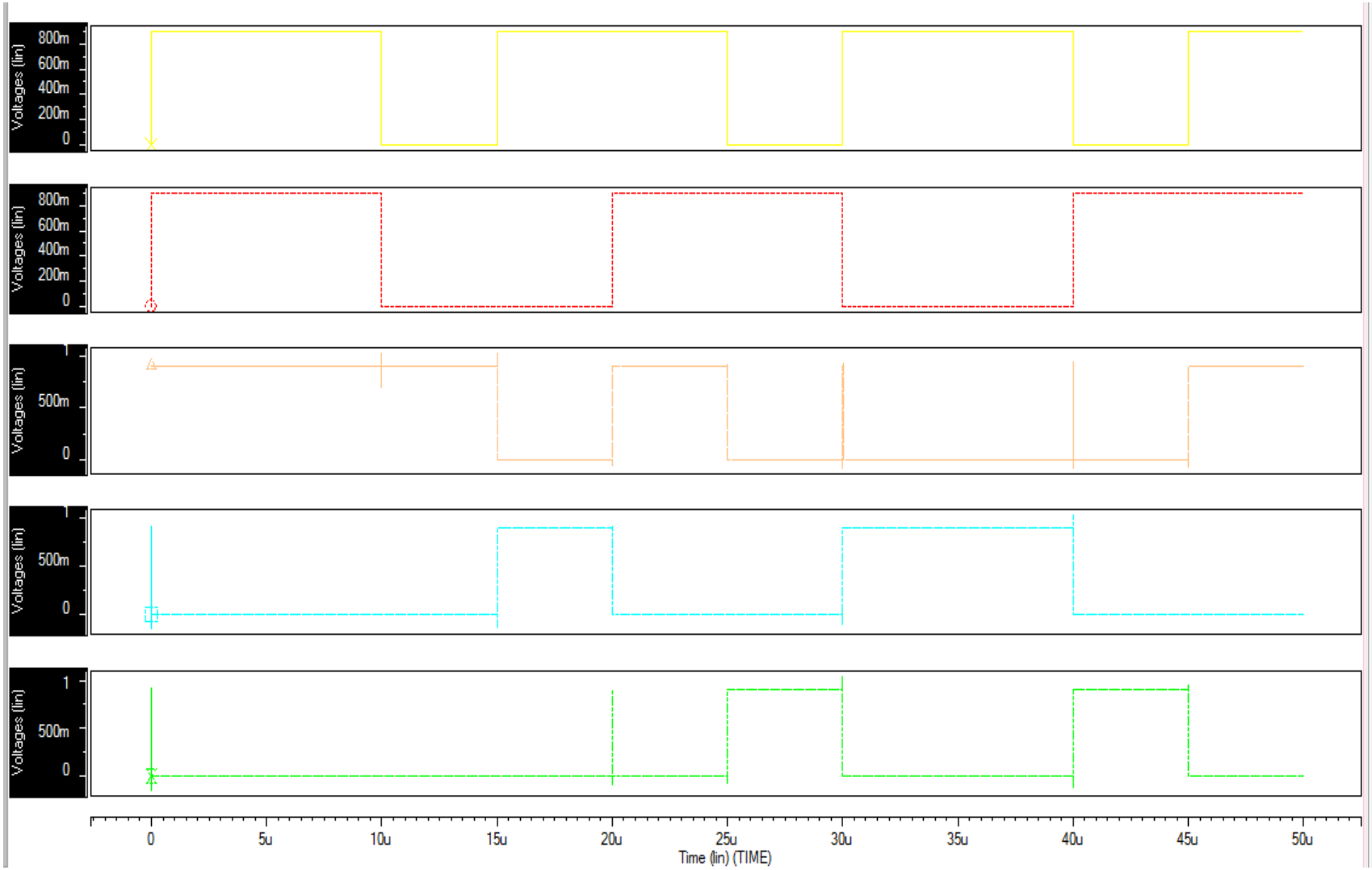
- In this logic, the voltages are used as logic state.
- In this design, output is measured in terms of voltage.
- Buffers are needed to get correct voltage levels.
- For implementing NOR and NAND gates, extra inverters are required at the output side.



Example of Comparator



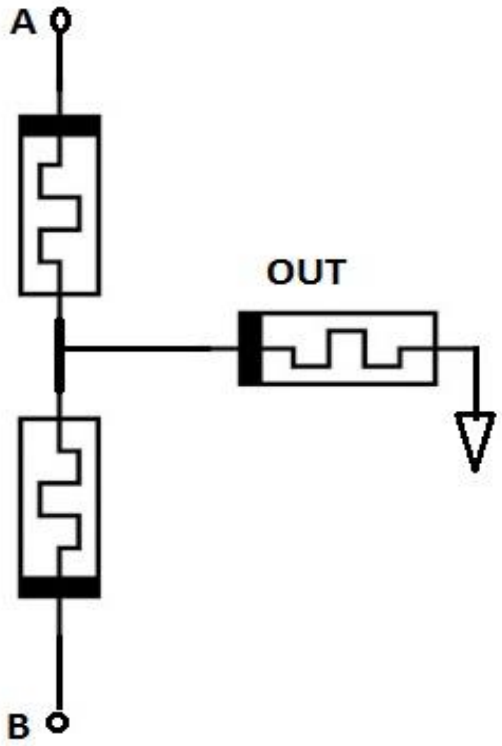
Results


Voltages (lin)
800m
600m
400m
200m
0
Voltages (lin)
800m
600m
400m
200m
0
Voltages (lin)
1
500m
0
Voltages (lin)
1
500m
0
Voltages (lin)
1
500m
0
0
5u
10u
15u
20u
25u
30u
35u
40u
45u
50u
Time (lin) (TIME)

Stand-Alone Memristors

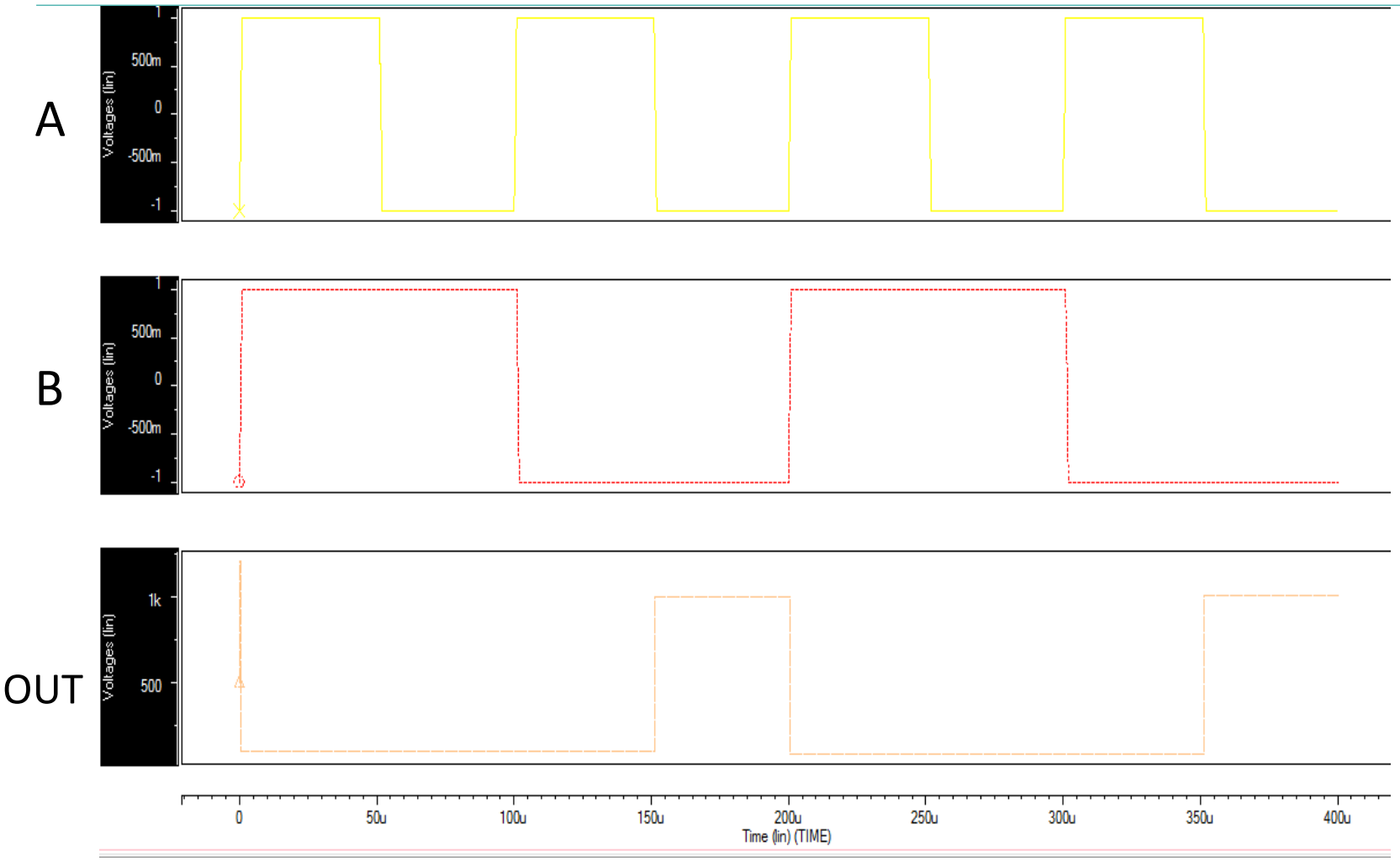
- New kind of memristor-based logic circuits, which need less number of memristors and operation steps.
- The logic operations can be performed and stored in the memory directly.
- Logic states are input voltages applied at input and output is stored as the memresistance of the output memristor.
- Bipolar voltage is applied as the logic state of the memristors.

OR Gate



A	B	OUT	MEMRESISTANCE
0	0	0	R_{off} (1K)
0	1	1	R_{on} (100)
1	0	1	R_{on} (100)
1	1	1	R_{on} (100)

Waveform of OR gate



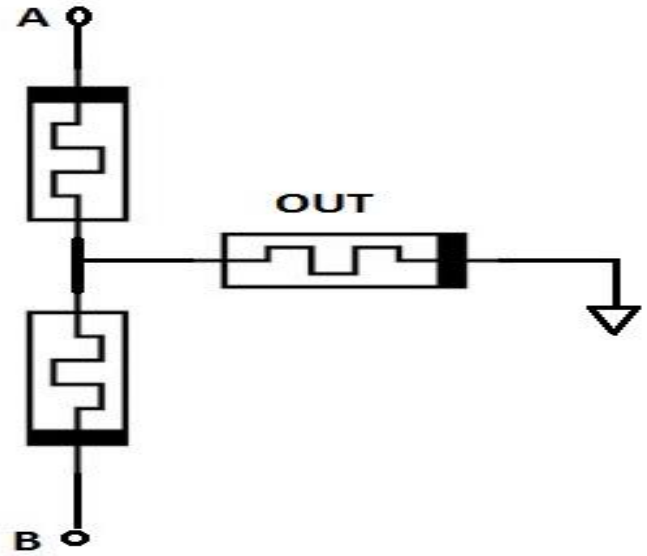
Can you design NOR gate???

What changes required in previous circuit??

What change noticed?

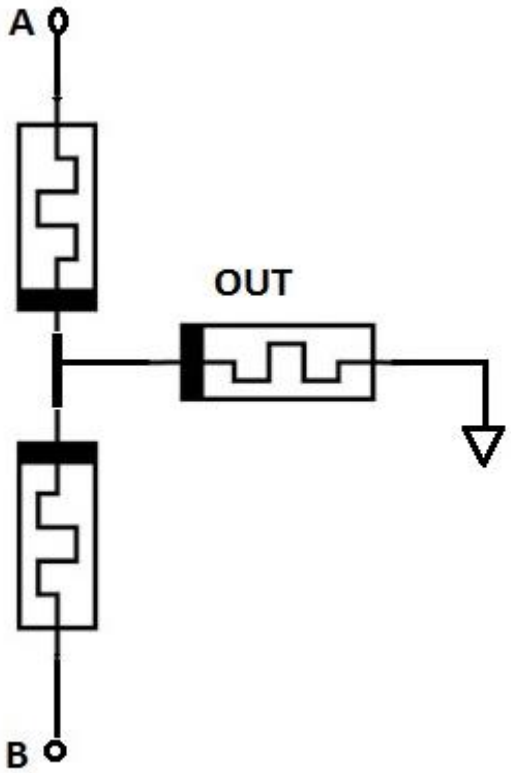
- Only change required is change in the direction of OUT memristor.

- Thus by changing memristor directions, operation reverses but number of memristors remain same.



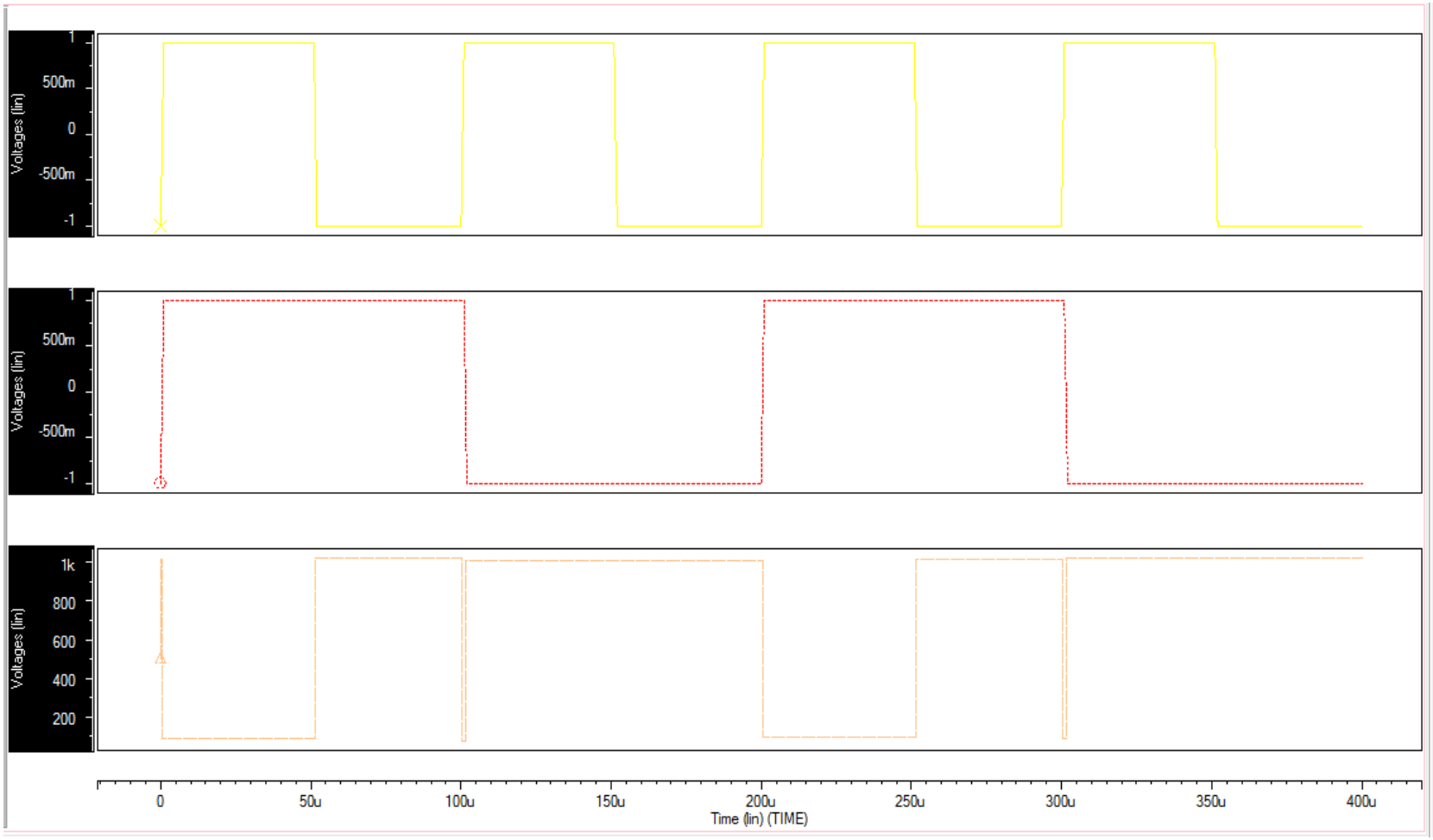
Can try more Logic Gates !!!

AND Gate

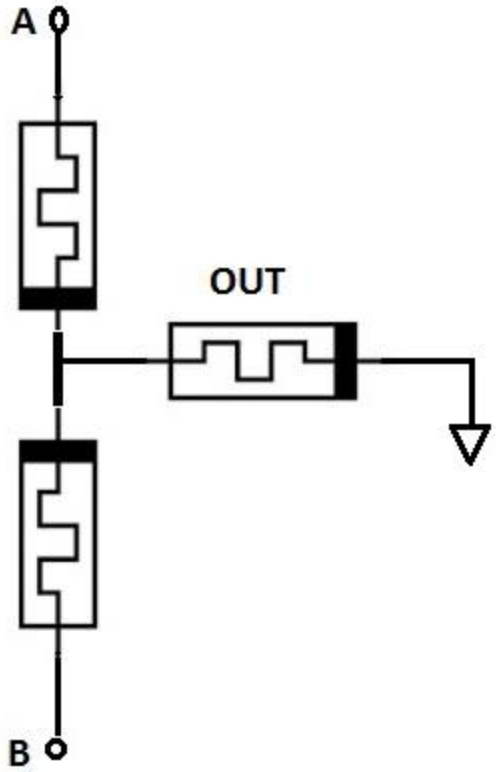


A	B	OUT	MEMRESISTANCE(Ω)
0	0	0	R_{off} (1K)
0	1	0	R_{off} (1K)
1	0	0	R_{off} (1K)
1	1	1	R_{on} (100)

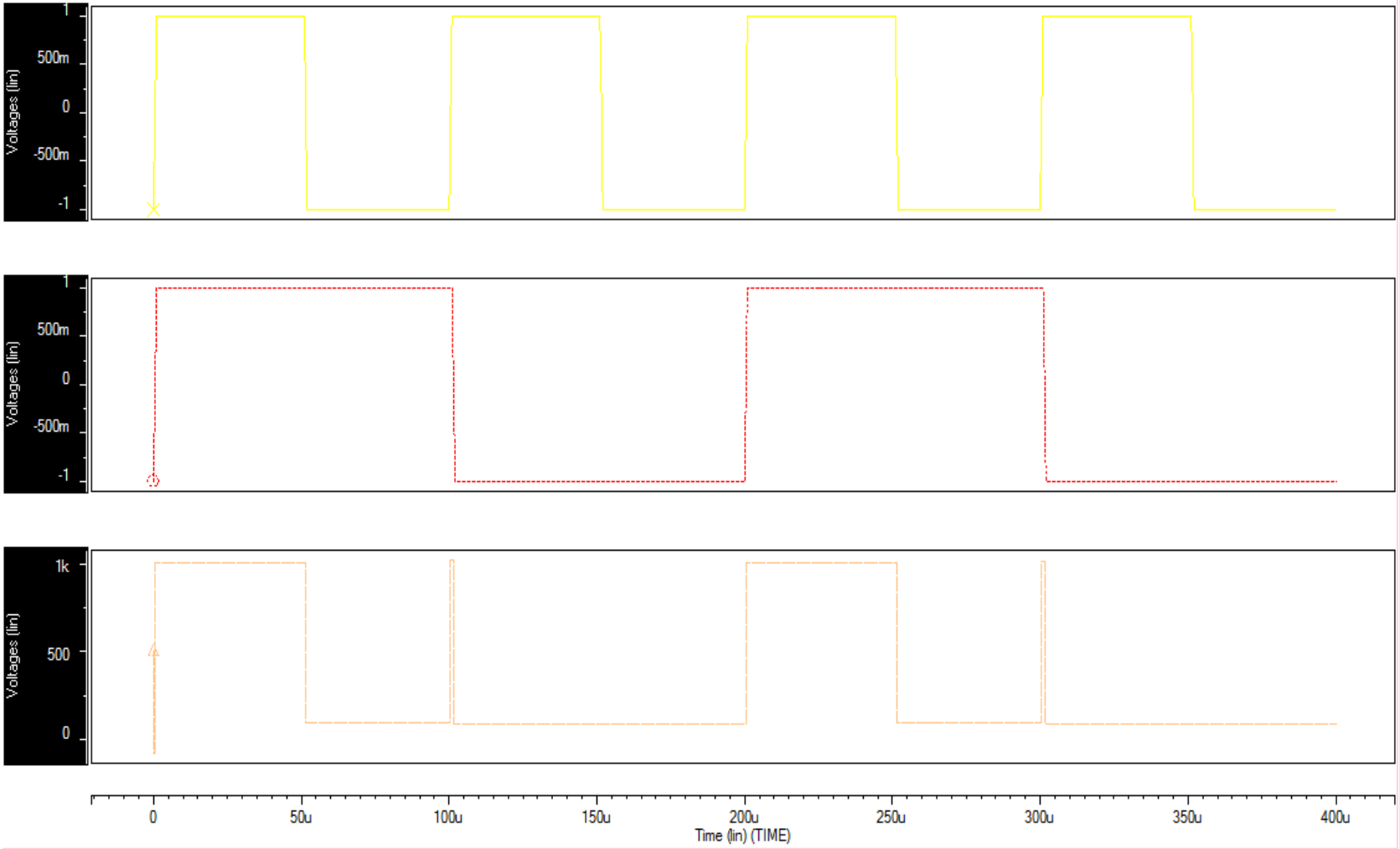
Results


Voltages (lin)
1
500m
0
-500m
-1
Voltages (lin)
1
500m
0
-500m
-1
Voltages (lin)
1k
800
600
400
200
0
50u
100u
150u
200u
250u
300u
350u
400u
Time (lin) (TIME)

NAND Gate

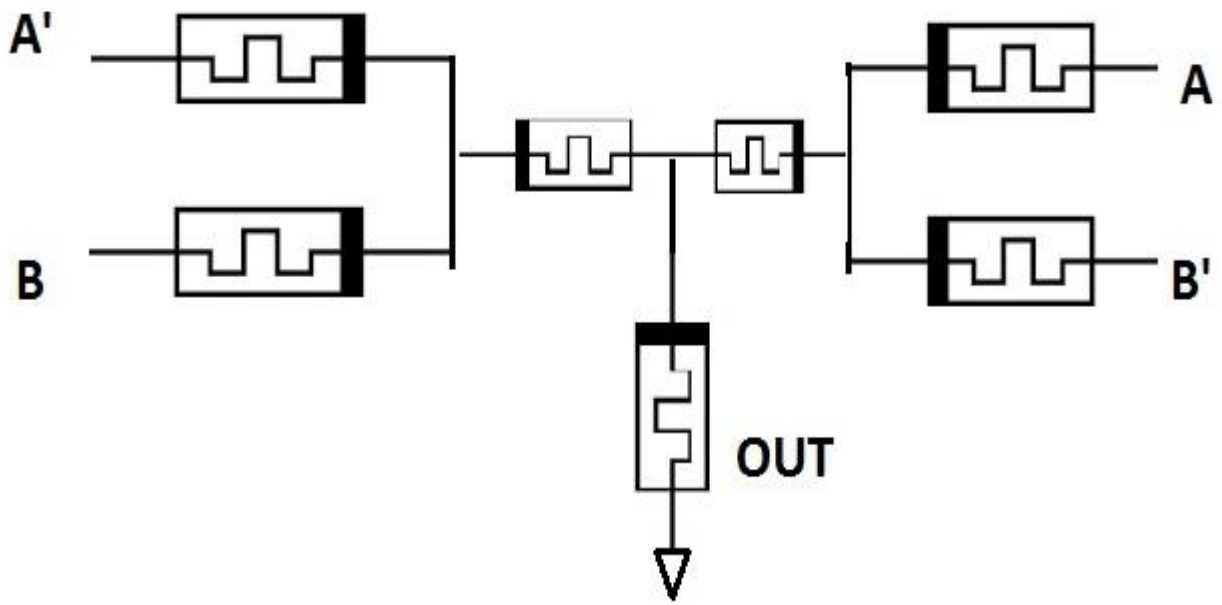


A	B	OUT	MEMRESISTANCE
0	0	1	R_{on} (100)
0	1	1	R_{on} (100)
1	0	1	R_{on} (100)
1	1	0	R_{off} (1K)

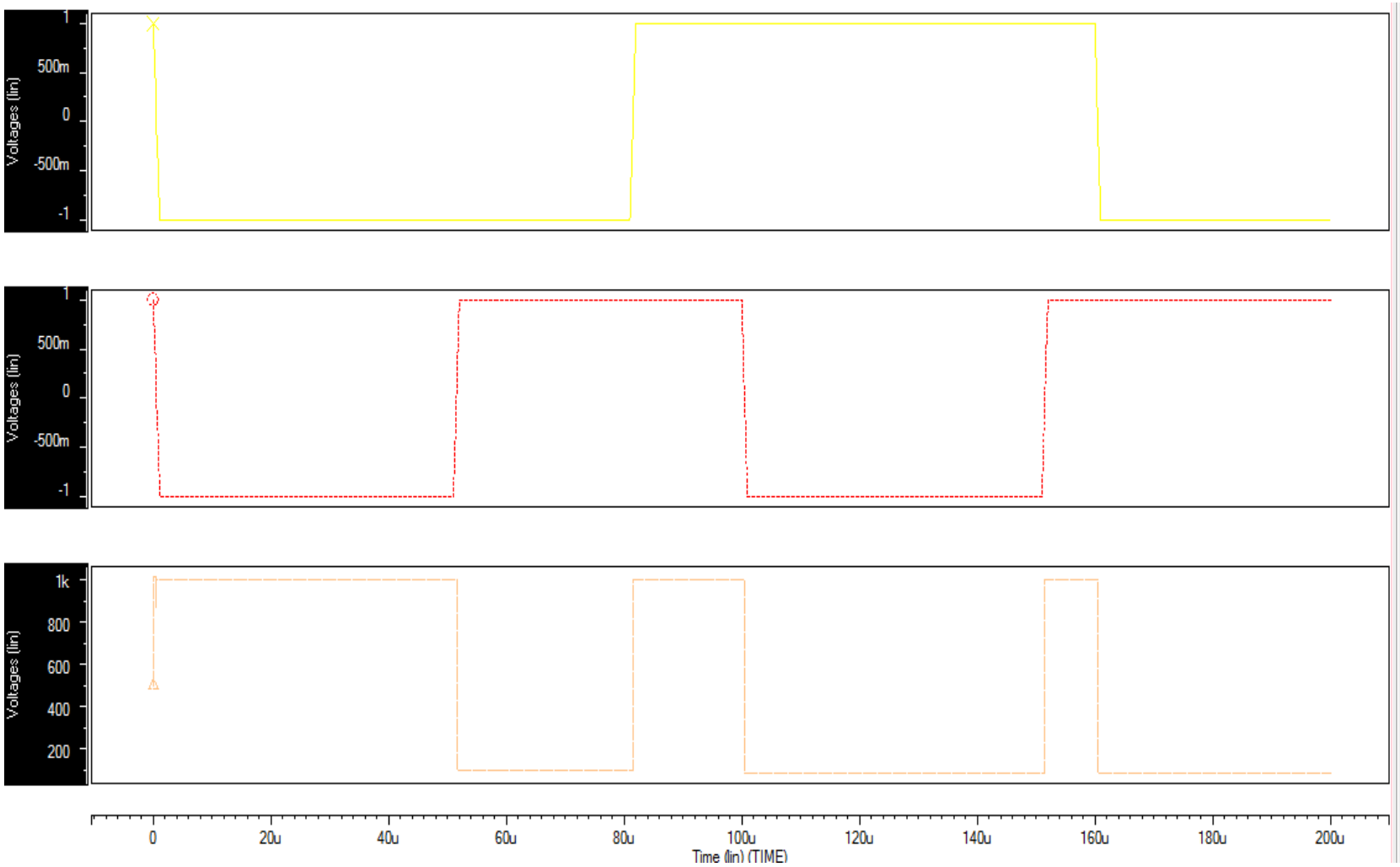

Voltages (lin)
1
500m
0
-500m
-1
Voltages (lin)
1
500m
0
-500m
-1
Voltages (lin)
1k
500
0
0
50u
100u
150u
200u
250u
300u
350u
400u
Time (lin) (TIME)

- **TRY EXOR Gate!!**

EXOR Gate



- It require inverters at input side.


Voltages (lin)
1
500m
0
-500m
-1
Voltages (lin)
1
500m
0
-500m
-1
Voltages (lin)
1k
800
600
400
200
0
20u
40u
60u
80u
100u
120u
140u
160u
180u
200u
Time (lin) (TIME)

Combinational Circuits

Name few of them??

- Full Adder
- Logic Comparators
- Binary to Gray Code Converters

and many more…..

Full-adder

Truth Table of Full Adder:

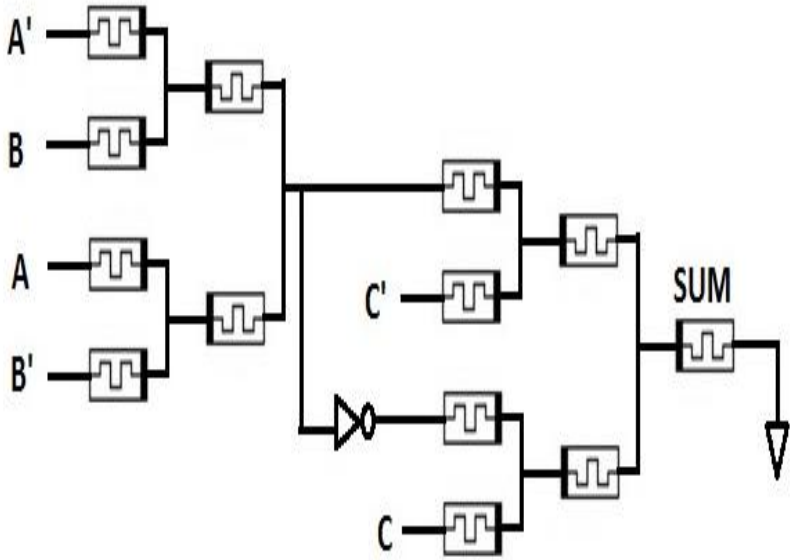
A	B	C	SUM	CARRY
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

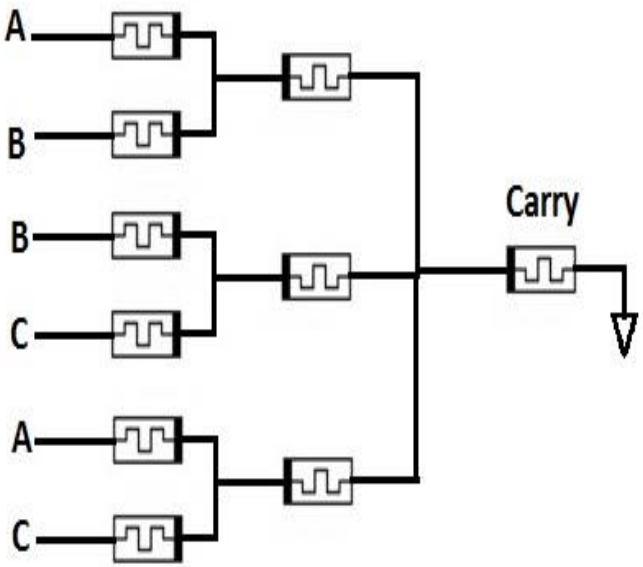
SUM = A $\oplus$ B $\oplus$ C

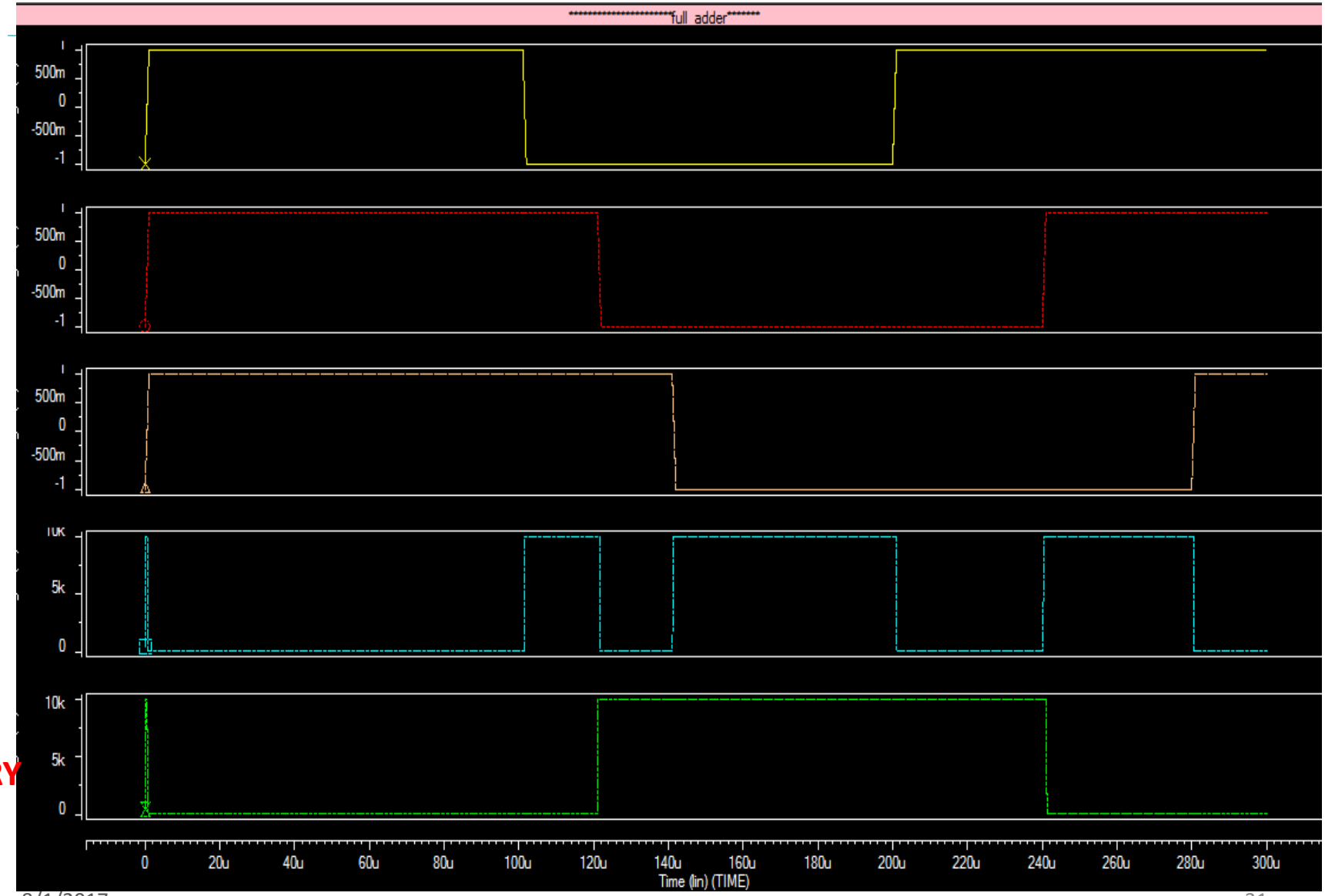
CARRY = AB + BC +AC

Few Examples of Logic Circuits

- Full Adder with the help of Memristors






full adder
A
B
C
SUM
CARRY
500m
0
-500m
-1
10k
5k
0
0
20u
40u
60u
80u
100u
120u
140u
160u
180u
200u
220u
240u
260u
280u
300u
Time (lin) (TIME)

Summary

- Memristor considered as a fourth fundamental, is a 2-terminal electrical circuit element that changes its resistance depending on the total amount of charge that flows through the device.

- Memristor's non-volatility, good scalability, low power consumption and compatibility with CMOS structures makes them an ideal device for various applications.

- Since field is in early stage of research, no perfect model yet describes the physical properties of memristor.

- It is believed that memristor will change the circuit design in 21st century as transistor did in 20th century.


Thank
you