

Measurements for industrial sustainability and environmental safety

PART II
Lesson 7

A.Y. 2026-27
Ludovica Apa



Numerical & Digital instruments

Numerical (and **digital**) instruments display the measurement information directly with numbers in **digit format** !

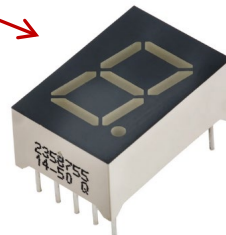
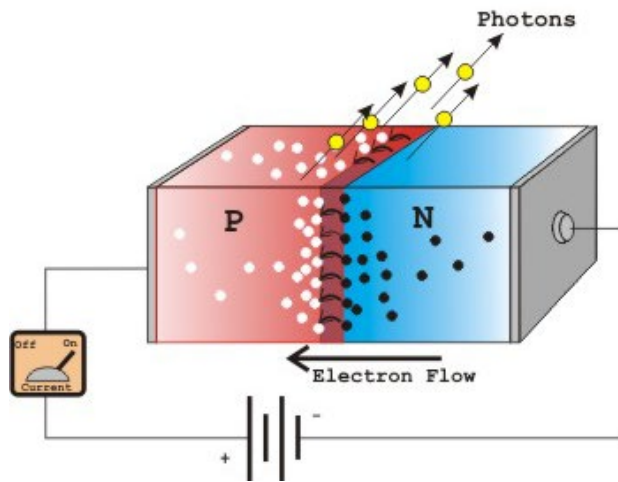


No mechanical indicator;
No indication delay;
No reading errors; ...

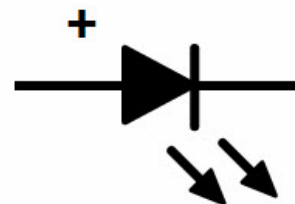
The first numerical indicators were **Light Emitting Diodes (LED)**: a semiconductor light source that emits light when current flows through it.

Made of *gallium arsenide* (GaS) and *gallium phosphide* (GaP) PN junctions directly polarized !

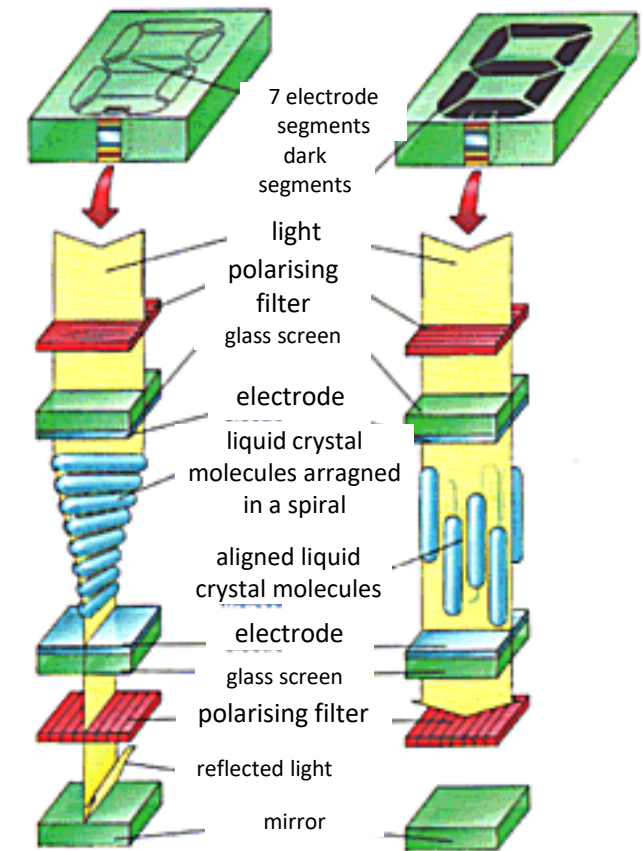
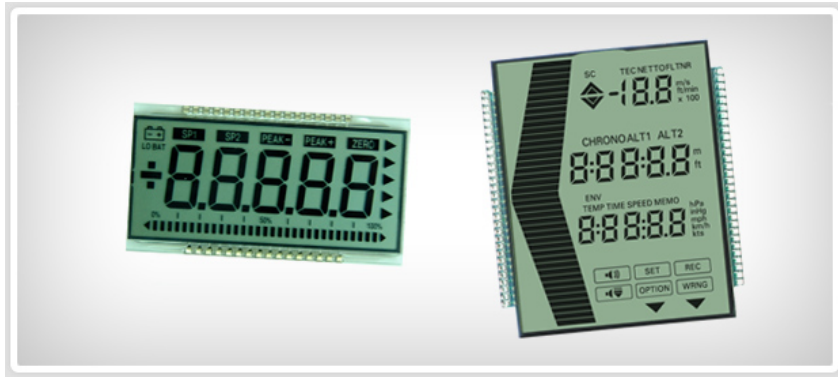
They use current and, therefore, they heat up ... they were highly miniaturized ... each diode is one of the seven light emitting bar !



LED Eletrical Symbol



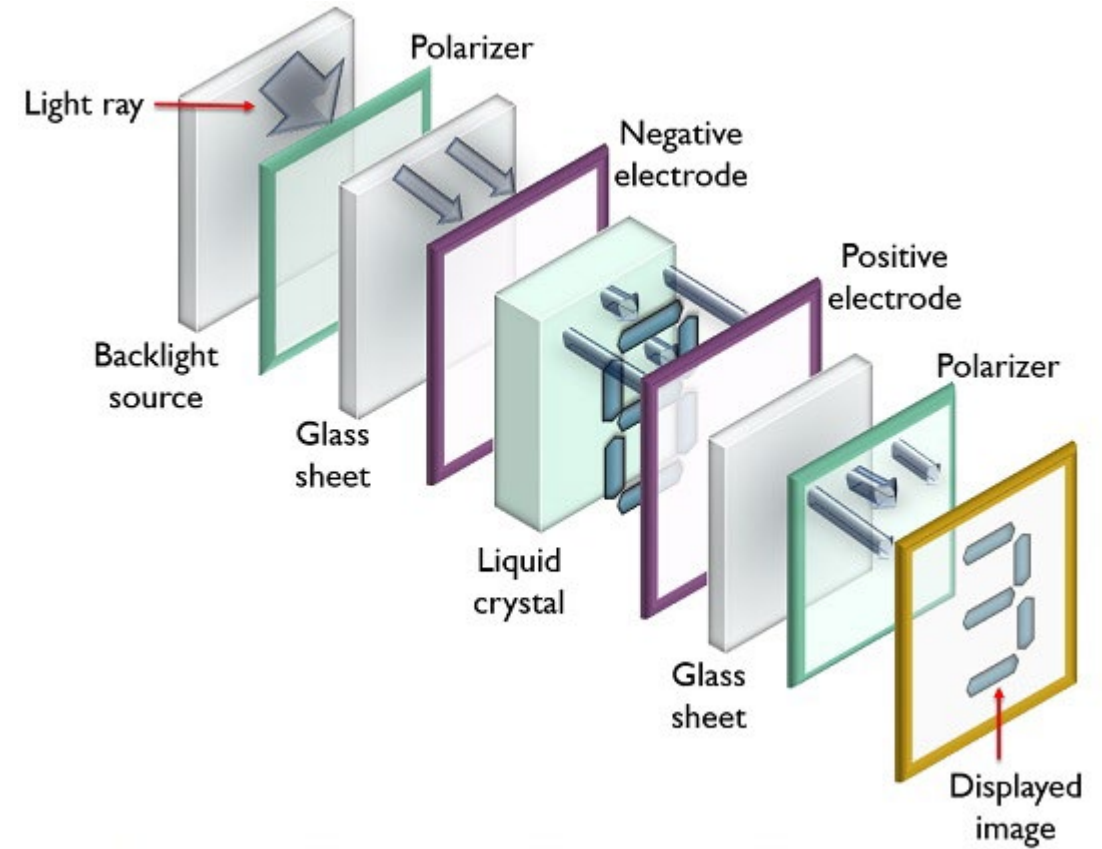
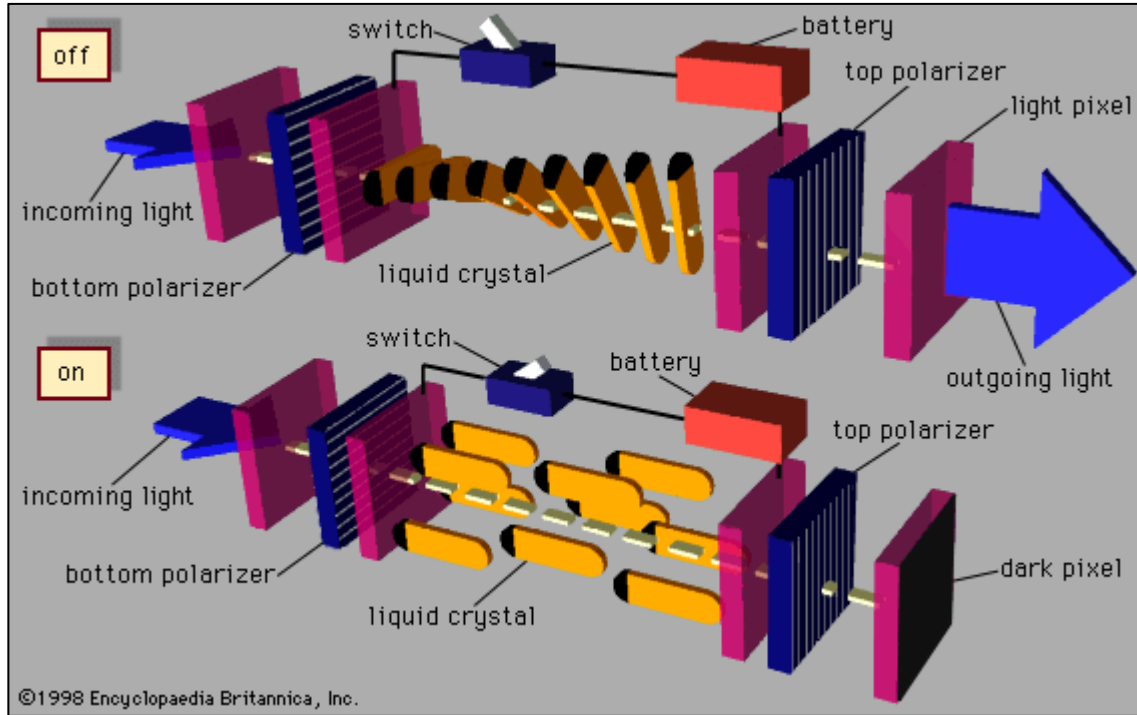
Liquid Cristal Display (LCD) are based on nematic crystal:
much more efficient, because they DO NOT consume current ...



A simple black or white LCD display works by either allowing daylight to be reflected back out at the viewer or preventing it from doing so, in which case the viewer sees a black area.

- The liquid crystal is placed between two polarising filters that are at 90° each other: together they form the part of the system that prevents light from passing through it or not.
- When there is no electric voltage applied to the crystal, it twists light by 90° , which allows the light to pass through the second polariser and be reflected back.
- When a voltage is applied, the crystal molecules align themselves, and the light cannot pass through the polariser: the segment turns black. Selective application of voltage to electrode segments creates the digits.

Need of backlight



Each segment might be a single pixel

Advances in technology (miniaturization/low current) → **LED**

Electronic and Digital Counters:

$$N = k_n x^n + k_{n-1} x^{n-1} + \dots + k_1 x^1 + k_0 x^0 + k_{-1} x^{-1} + \dots$$

$$8725,4 = 8 \cdot 10^3 + 7 \cdot 10^2 + 2 \cdot 10^1 + 5 \cdot 10^0 + 4 \cdot 10^{-1}$$

$$19 = 1 \cdot 2^4 + 0 \cdot 2^3 + 0 \cdot 2^2 + 1 \cdot 2^1 + 1 \cdot 2^0$$

$$147 = 1 \cdot 2^7 + 0 \cdot 2^6 + 0 \cdot 2^5 + 1 \cdot 2^4 + 0 \cdot 2^3 + 0 \cdot 2^2 + 1 \cdot 2^1 + 1 \cdot 2^0$$

Generic way of exploding the representation of a number !

example of a number $N = 8725,4$ expressed in **decadic base**

example of a number $N = 19$ expressed in **binary base**

in summary form: 1 0 0 1 1

example of a number $N = 147$ expressed in **binary base**

in summary form: 1 0 0 1 0 0 1 1

It is easily seen, that in *binary format* the “coefficients” that are needed (the binary digits : **bit**) increase rapidly !
(shorter in the decadic base but with 10 tension levels)

A **bit** is an elementary information carrier !

However, in the *electronic measurement instrumentation* a special code system is employed: the **BCD code** (**Binary Coded Decimal**) which encodes in binary the *individual decimal digits* !

This is a pure binary code that encodes the *ten digits from 0 to 9* with a four bit configuration ...

Remember : with “ n bits” we can count in binary up to $2^n - 1$

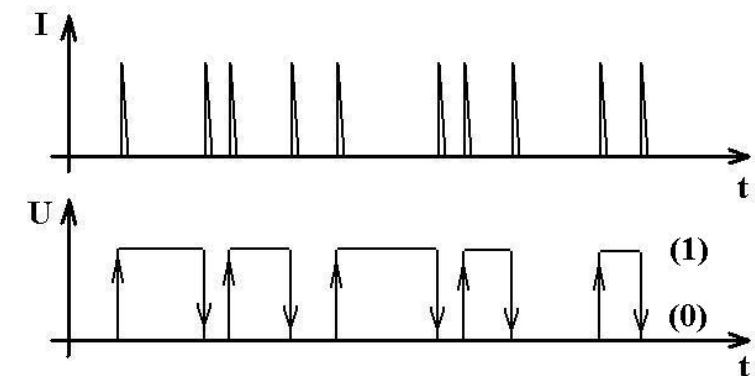
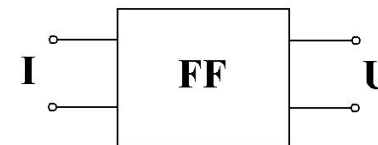
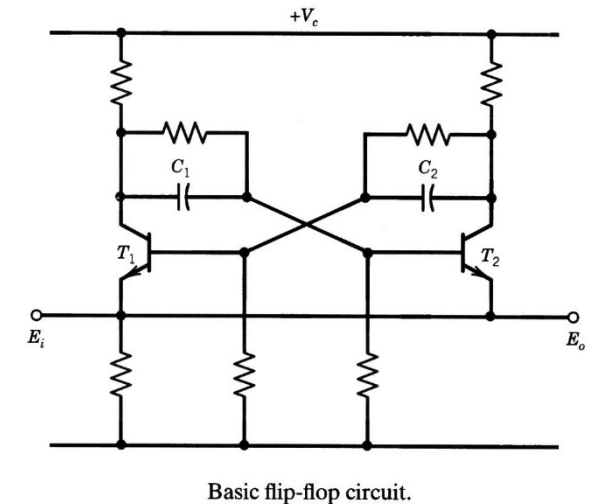
Decimal Digit	Four-Bit Binary Equivalent	Binary-coded Decimal equivalent
0	0000	0000
1	0001	0001
2	0010	0010
3	0011	0011
4	0100	0100
5	0101	0101
6	0110	0110
7	0111	0111
8	1000	1000
9	1001	1001
10	1010	Illegal
11	1011	Illegal
12	1100	Illegal
13	1101	Illegal
14	1110	Illegal
15	1111	Illegal

The fundamental basic element for the *electronic counting* is the astable electronic multivibrator (**FLIP – FLOP**)

The **FF** changes status when it receives a trigger at its input, and “keeps the new status” until a new trigger is received at the input of the device:

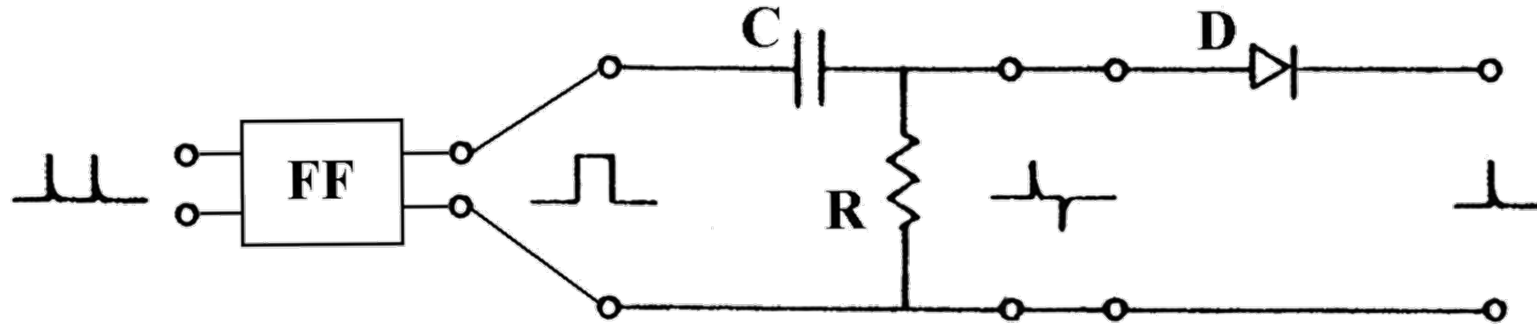
Note on the left table:

4 bits = we count up to $2^4 - 1$



Binary Coded Decimal (BCD) counter / Decade counter

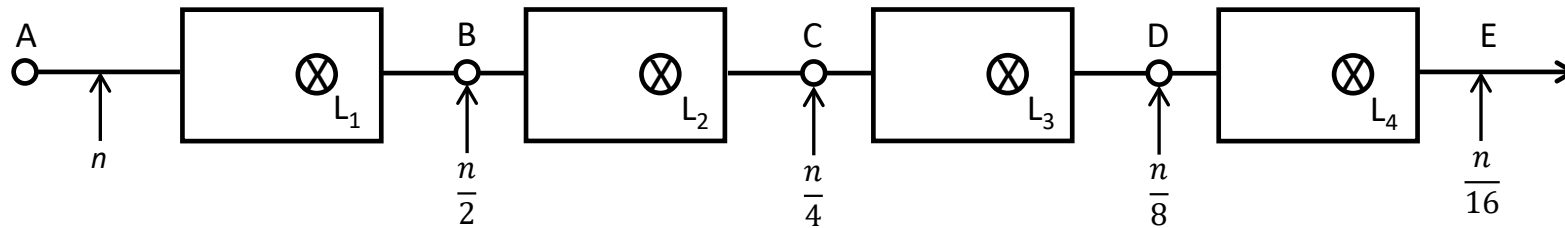
The "elementary circuit" is composed of a **Flip – Flop (FF)** together with a **CR circuit** and a **rectifier diode**



For every two triggers at the circuit input, we have only one trigger at the output !

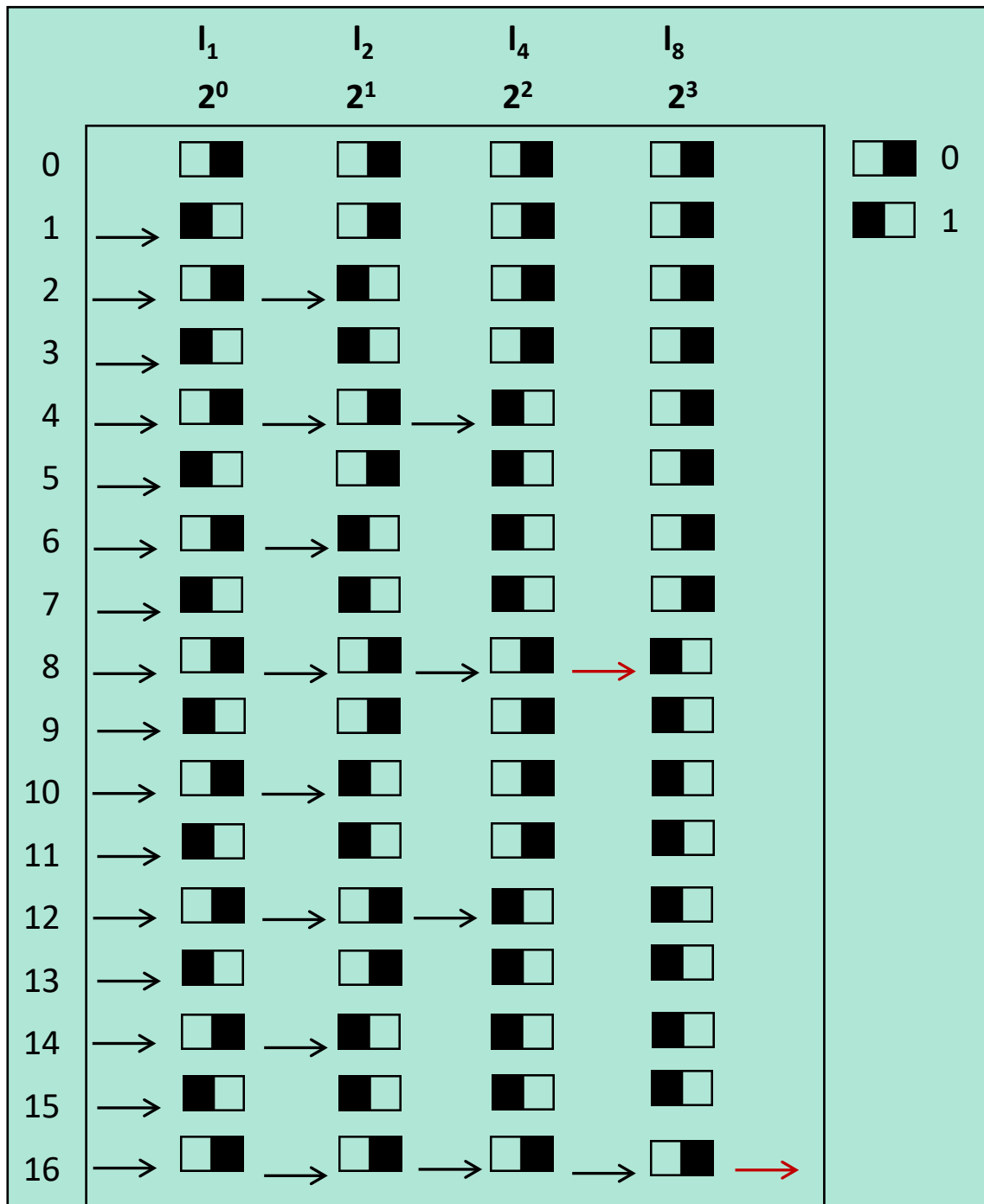
The circuit divides by two the electric triggers received at its input !

If we connect *four of these elementary cells* in series, we have designed the electronic circuit that counts in the BCD code a single digit (from 0 to 9) :



Indicators L tell if the FF is in the *High* (X) or *Low* (O) status

n is the number of triggers received at the input !



To get one trigger at the output we need 16 input triggers.. after that, the counter resets to zero again.

We recognize that the 4 Flip Flop (I_1 I_2 I_4 I_8) are the *elementary (**digital**) memory cells* which change the “combination of their status” depending on how many triggers are inputted to the device.

The four cells count in binary code:

$$(0;1) \cdot 2^0 + (0;1) \cdot 2^1 + (0;1) \cdot 2^2 + (0;1) \cdot 2^3$$

LSB ↑
MSB ↑

LSB = Least Significant Bit

MSB = Most Significant Bit

examples:

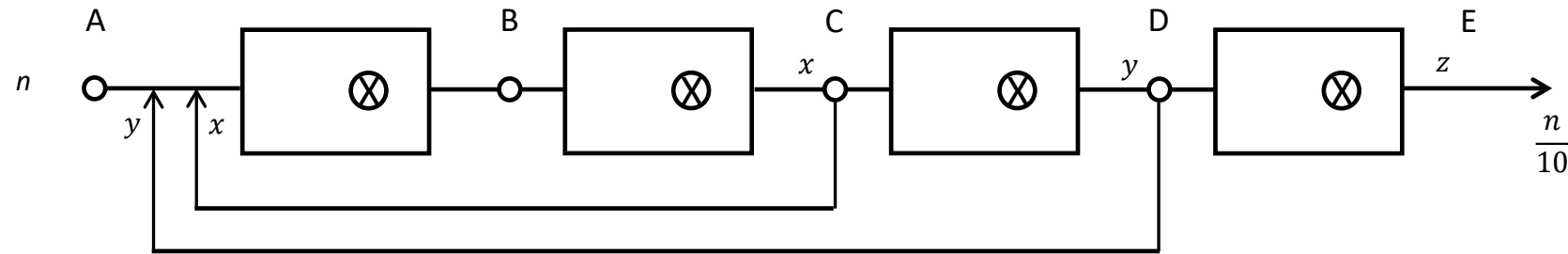
6 = 0 1 1 0

11 = 1 1 0 1

14 = 0 1 1 1

However, to realize the **BCD counter**, we need the counter to count only up to 9: the remaining numbers (10 to 15) must be assigned ***illegal value*** ... and to realize a decimal counter, we need also one trigger to be outputted every ten input triggers !

To obtain this result, we have to modify the electronic circuit, speeding up the trigger output by “sending some extra triggers” at the input with a double feedback:

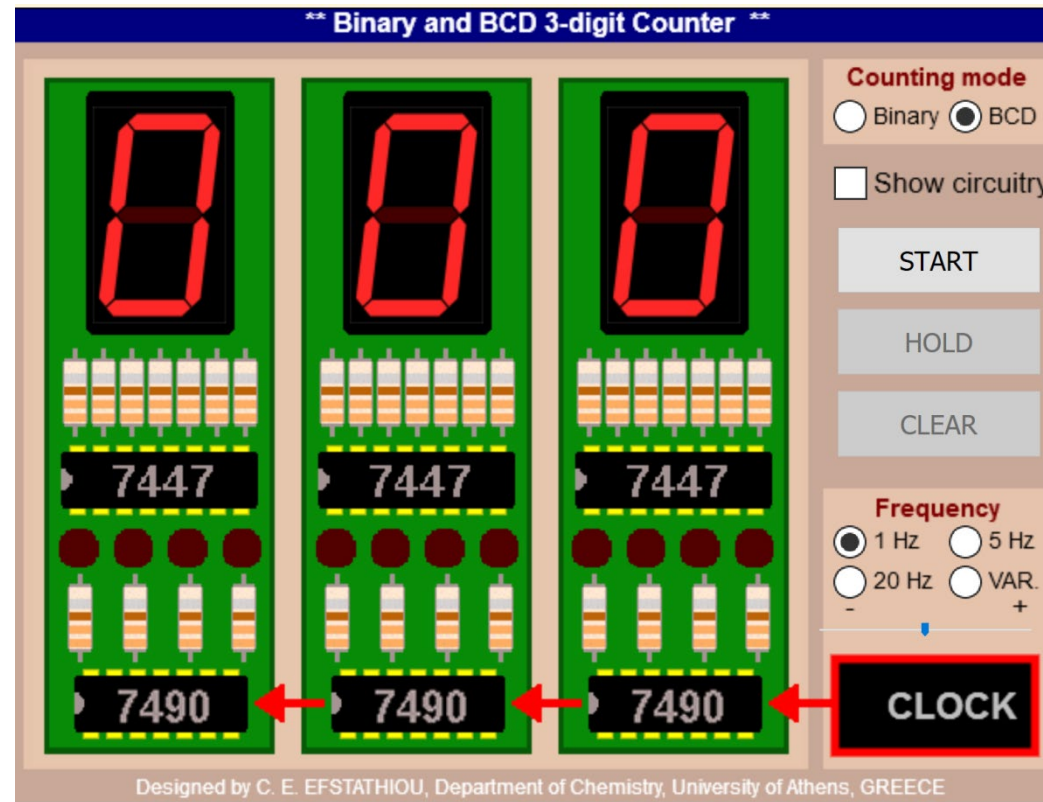


After the “double feedback” we have at the input A: $n+x+y$ triggers and at the feedback point C we have no more $n/4$ triggers, but $\frac{n+x+y}{4} = x$

Because it is also $y = x/2$ and $z = y/2$

we can write: $\frac{n+2y+y}{4} = 2y$ and $n+3y = 8y$ $n = 5y$ or $y = n/5$: $z = \frac{n}{10}$ and we reached our result !

BCD counters with feedback can be “connected in series” so to count decimal numbers but, to be consistent with the *way we read numbers* the circuits must be rotated 180° and the triggers must be inputted from the right side !



Time and Frequency Measurement:

Electronic chronometer

If we connect to the *BCD counter*

- an electronic gate,
- a quartz clock,
- an event input amplifier with a gate control

we can measure with *high resolution* the time between two events:

- The clock is an **electronic oscillator** with a “fairly high” frequency (100 MHz) and is always on.
- The gate control opens and closes the gate depending on the input signal level.
- The triggers produced by the clock pass through the gate and are counted (n) by the BCD counter only during the period of time (t) for which the gate is open:

$$t = \frac{n}{f_{CLK}} = \frac{107153}{10^8 \text{ Hz}} = \underline{0.00107153s}$$

