DIGITAL TECHNICS I

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1. LECTURE:
INTRODUCTION TO DIGITAL TECHNICS

1st year BSc course 1st (Autumn) term 2018/2019

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1. LECTURE

1. General introduction to the course

2. Introduction to digital technics, fundamentals of logic networks (with examples)

3. Classification of logic networks: combinational and sequential logic circuits (with examples)

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GENERAL INTRODUCTION

1. Course administration (E-learning/Moodle System, coursework, home assignments, test, exams, etc.)

2. The Digital technics course

3. 1st term course contents

GENERAL INTRODUCTION: AIMS OF THE COURSE

This course will give an overview of the basic concepts and applications of digital technics, from Boolean algebra to microprocessors.

The aim is to acquaint the future electrical engineers with the fundamentals of digital technics, with the digital circuits, and with their characteristics and applications.

In the course of three-semester lectures, classroom-tutorials and laboratory exercises the future electrical engineer should acquire solid knowledge and sufficient proficiency in the functioning, design and applications of digital systems.

AIMS OF THE COURSE

The central role of digital circuits in all our professional and personal lives makes it imperative that every electrical and electronics engineer acquire good knowledge of relevant basic concepts and ability to work with digital circuits.

The course contents are designed to enable the students to design digital circuits of medium level of complexity taking the functional and hardware aspects in an integrated manner within the context of commercial and manufacturing constraints. However, no compromises are made with regard to theoretical aspects of the subject.

A SHORT INTRODUCTION TO DIGITAL CIRCUITS AND NETWORKS

Digital electronics can be found in many applications in the form of microprocessors, microcontrollers, PCs, and an uncountable number of other systems. The design of digital circuits has progressed from resistor-transistor logic (RTL) and diode-transistor logic (DTL) to transistor-transistor logic (TTL) and emitter-coupled logic (ECL) to complementary metal-oxide-semiconductor (CMOS) logic circuits.

The density and number of transistors in microprocessors has increased from 2300 in the 1971 4-bit 4004 micro-processor to 25 million in the more recent IA-64 chip and it is projected to reach over one billion transistors by 2010.

A SHORT INTRODUCTION TO DIGITAL CIRCUITS AND NETWORKS

The change that has enabled the widespread economical use of digital logic has been a dramatic evolution in device technology, which is most spectacularly described by Moore`s law. Logic circuits comprising of several basic electronic devices (typically transistors, resistors, and diodes), were once designed with each device as a separate physical entity.

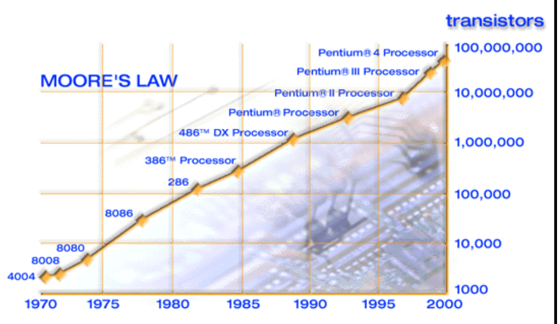
Now, very large-scale integration of devices offers up to several thousand or even millions of equivalent basic devices on the surface of a small piece of silicon wafer, typically rectangular with a maximum dimension of a few tens of millimeters per side.

MOORE'S LAW

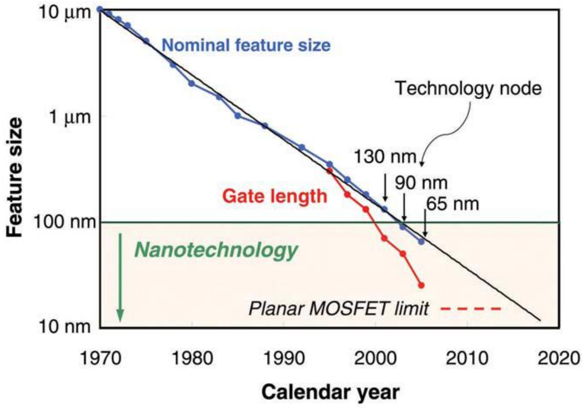
Gordon Moore (co-founder of Intel) predicted in 1965, just four years after the first planar integrated circuit was discovered, that the number of transistors per integrated circuit would double every 18 months.
He forecast that this trend would continue through 1975.

Moore's Law has been maintained for far longer, it has become a universal law of the entire semi-conductor industry. It still holds true as we enter the second decade of new century.

Moore's law is about human ingenuity not physics.



MOORE'S LAW



The INTEL's gurus:

A. Groove, R. Noyce
G. Moore INTEL,1970

Logic technology node and transistor gate length versus calendar year. Note:

mainstream Si technology is nanotechnology.

THE HUNGARIAN CONNECTION

Andy Grove (1936-2015) alias Gróf András

EETimes 3/2016:
Andy Grove a Hungarian immigrant who survived Nazi occupation (and the arrow-cross Hungarian Nazi terror…) and vent on to be instrumental in the formation of Intel Corp. And its rise to become the biggest semiconductor company in the world, died Monday (March 21) at he age of 79.

Though not credited as a co-founder, Grove was present for Intel1s early history, beginning in 1968.

Company's president 1979 to 1997,
CEO from 1987 to 1998,
Chairman of board of directors from 1997 to 2005.

Grove was an enormously influential figure in the semiconductor industry and beyond. At Intel, he presided over the company's transformation from a supplier of memory chips into the world's biggest microprocessor vendor.

THE HUNGARIAN CONNECTION

During Grove's tenure as CEO Intel's market capitalization increased from $4billion to $197billion. During that time Intel's annual revenue increased from $1,9 billion to more than $26 billion (about 7000 billion HUF, roughly 25 % of Hungary's GDP).

Grove immigrated to the U.S. in 1957 after surviving both the Nazi occupation and Soviet repression in Hungary. He studied chemical engineering at the City College of New York and completed his Ph.D at the University of California-Berkeley in 1993.

Grove was hired to Fairchild Semiconductor by Gordon Moore as a researcher in 1963. When Moore and Robert Noyce left Fairchild to found Intel in 1968, Grove was their first hire.

THE HUNGARIAN CONNECTION

„*Andy approached corporate strategy and leadership in ways that continue to influence prominent thinkers and companies around the world*", said Intel Chairman Andy Bryant. „ *He combined the analytic approach of a scientist with an ability to engage others in a honest and deep conversation, which sustained Intel's success over a period that saw the rise of the personal computer, the Internet and Silicon Valley*."

A SHORT INTRODUCTION TO DIGITAL CIRCUITS AND SYSTEMS

The dramatic reduction in size has been accompanied by a number of effects. The power consumption and cost per logic device have been greatly reduced. The cheap digital watch or the basic electronic calculators that can run for over a year on tiny battery, or the recent laptop computers having an affordable price, exemplify these effects.

DIGITAL TECHNICS AND LOGIC NETWORKS

1.1. INTRODUCTION TO DIGITAL TECHNICS

- Fundamental concepts
- Logic variables

1.2. LOGIC NETWORKS AND THEIR MODELS

- Combinational logic circuits
- Asynchronous sequential logic circuits
- Synchronous sequential logic circuits

INTRODUCTION: FUNDAMENAL CONCEPTS

Fundamental concepts: signal, analog, digital

Analog and digital signal

Analog and digital circuit

BASICS OF ELECTRONICS: ANALOG AND DIGITAL

ANALOG CIRCUIT

Input and output quantities are continuous
Large noise susceptibility
Appropriate for handling and processing analog signals

DIGITAL CIRCIUT

Input and output quantities can have only discrete
It's immune to noise in a certain extent
Appropriate for handling and processing digital signals
More reliable operation

SIGNAL

The signal can be defined as a value or change in the value of a physical quantity (state) which is suitable to represent, transmit or store information.

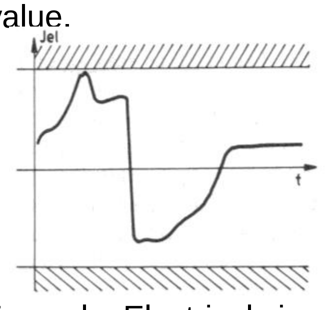
In practice the signal is mostly

electrical quantity especially voltage

But it can also be current, field strength, etc.

ANALOG SIGNAL

Signal suitable to transmit information, the characteristic parameter of which can take any value, the set of values is continuous.
The analog signal represent the information directly with its value.

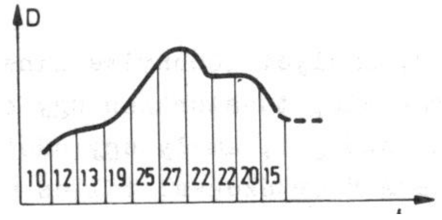


The time evolution of the analog signal can be represented by a continuous function. It changes continuously in time and it can cover fully a given range.

Example: Electrical signal (voltage) transformed by microphone (electroacoustic transducer) from voice (acoustic vibrations).
Its characteristics: frequency range, signal-to-noise ratio, distortion, etc.

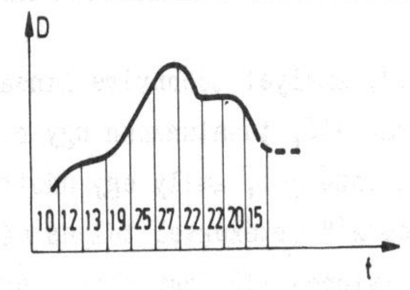
DIGITAL SIGNAL

Signal containing the information in discrete symbols (e.g. numbers in coded form). It ha only discrete or quantized vales, these can be appropriately represented by integer numbers.
One of the most common version of digital signal is the binary signal, which has a set of values comprising of two elements e.g. **0** and **1**.



The digital signal represents the information divided into elementary parts in a numeric form using appropriate encoding. Sampling is performed at given times, and the numbers are attached to it. The digital signal therefore represents coded information.

DIGITAL SIGNAL: EXAMPLE



- Sample Binary coded signal
- 10 0 1 0 1 0
- 12 0 1 1 0 0
- 13 0 1 1 1 0
- 19 1 0 0 1 1
- 25 1 1 0 0 1
- 27 1 1 0 1 1
- 22 1 0 1 1 0
- 22 1 0 1 1 0
- 20 1 1 0 0 0
- 15 0 1 1 1 1
- ....

LOGIC VARIABLES: SET OF VALUES, NOTATIONS

Logic variables are used to describe the occurrence of events.
It can have two values i.e. TRUE or FALSE, depending on whether the given event takes place or not.

If the event takes place, then
the value of the logic variable is TRUE.
If the event does not take place, then
the value of the logic variable is FALSE.

Set of values, notations		
	TRUE (T)	FALSE (F)
	YES	NO
	1	0
	HIGH (H)	LOW (L)

LOGIC VARIABLES: SET OF VALUES

TRUE/FALSE or YES/NO refers to the occurrence of the event, they meaning corresponds to the everyday meaning of the words in question.

Here 1 and 0 are not digits, they do not have any numeric value. They meaning is symbolic:

TRUE ↔ 1 and FALSE ↔ 0.

The meaning of HIGH/LOW is connected with the usual electrical representation of logic vales, they correspond to high(er) and low(er) potentials (voltage levels) e.g. (nominally) +5 V and 0 V respectively.

Modular logic device manufacturers' data sheets mostly use the H and L notations in describing their prouducts.

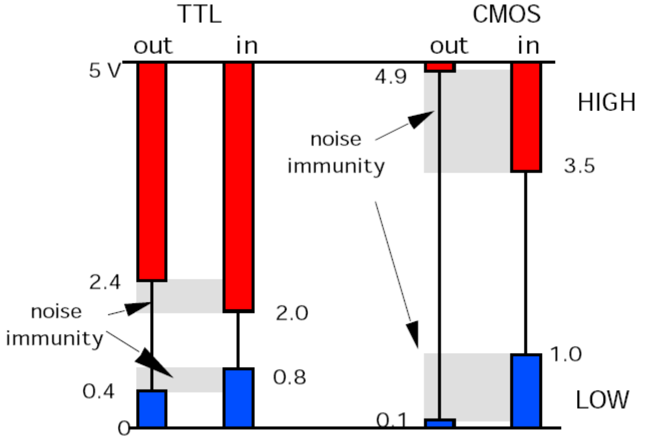
LOGIC VARIABLES IN THE PRACTICE

In the two most common logic circuit family i.e. the MOS technology based CMOS (Complementary Metal Oxide Semiconductor), and the bipolar technology based TTL (Transistor Transistor Logic), the LOW logic level is nominally 0 Volt, the HIGH logic level is a few volt determined by the actual (positive) supply voltage. Specifically

CMOS
$U(1) = U_{supply}$ = +3 ... +15 V (older types)
$U(1) = U_{supply}$ = +2 ... +6 V (newer types)
$U(1) = U_{supply}$ = +1 ... +1.2 V (VLSI IC)
$U(0)$ = 0 V

TTL
$U(1)$ = kb. +3,5 V, U_{supply} = +5 V
$U(0)$ = 0 V

LOGIC LEVELS: TTL AND CMOS

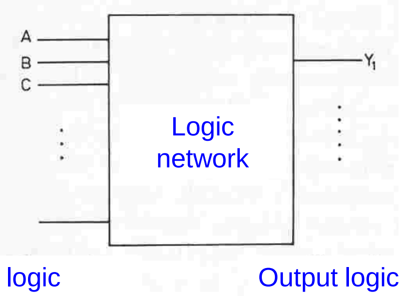


CMOS and TTL logic levels for output and input.
(For 5 V supply)

LOGIC NETWORKS AND THEIR MODELS

1. General model of logic networks
2. Combinational logic networks
3. Asynchronous sequential logic networks
4. Synchronous sequential logic networks

GENERAL MODEL OF LOGIC NETWORKS



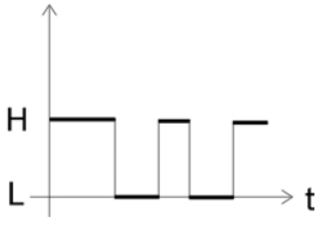
Input logic variables

Output logic variables (signals)

The logic network (logic circuit) processes the actual values of the input variables (A,B,C, ...) and produces accordingly the output logic signals (Y_1, Y_2, ...).

LOGIC CIRCUIT (NETWORK)

Logic networks are implemented with digital circuits, and in reverse, digital circuits can be describes and modeled with logic networks.
Digital circuits: only two values (range of values) of the signal (e.g. voltage) measured at any point of the circuit is distinguished. To these the two logic states are rendered.



For the analysis and synthesis of logic network the logic (Boolean) algebra is used.

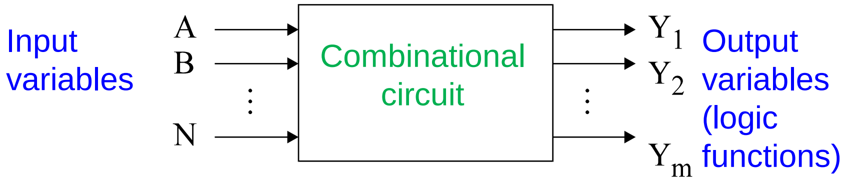
LOGIC NETWORKS

Digital/logic circuits/networks can be classified into two groups:

1. Combinational logic networks
Results of an operation depend *only* on the present inputs to the operation
Uses: perform arithmetic, control data movement, compare values for decision making

2. Sequential logic networks
Results depend on both the inputs to the operation *and* the result of the previous operation
Uses: counter, controllers, etc.

COMBINATIONAL LOGIC NETWORK



The combinational logic network is the simplest logic network. The logic operations on the input variables are performed ”instantaneously” and the result will be available on the output at the same time, (except for the time delay due to the internal operation of the circuits). The output variables can be represented as logic functions of the input variables.

$$Y_i = F_i (A, B, ..., N) \quad i = 1, 2, ... M$$

COMBINATIONAL CIRCUITS: GENERALIZED MODEL AND PROPERTIES

- The independent variables of a Boole function sometimes denoted by the capital letters of an English ABC.
- The Latin word for letter is Literal, for a logic expression of „n” variables frequently called an expression of „n literals”.
- In the followings we apply that name too.

COMBINATIONAL CIRCUITS: GENERALIZED MODEL AND PROPERTIES

- The Combinational Circuit is mapping an input (signal) combination to an output (signal) combination. This is why it's called Combinational Circuit. (CC)
- The very same input combination always implies the very same output combination (when the circuit is in its stationary state).

  E.G. In case a ROM the device answers the very same output when the given particular input address is applied.

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STATIC MODEL OF COMBINATIONAL CIRCUITS

The so called static model (1)

A static model represents the state sequence of a circuit, i.e. its event history and never describes its transients.

The time as variable never occurs in the functions of the states of the circuit.

For that it's not necessary applying differential equations as in case of analogous circuits.

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COMBINATIONAL CIRCUITS: GENERAL PROPERTIES

- The combinational circuit maps an input (signal) combination to an output (signal) combination.
- A combinational circuit is a circuit with no ”memory”.
- The same input combination always implies the very same output combination (except transients).
- The reverse is not true. For a given output combination different input combinations can belong.

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COMBINATIONAL LOGIC EXAMPLE: ELEVATOR/LIFT CONTROL

Logic task:
A lift should start to move ONLY IF its door is closed AND one of the floor push buttons is activated.

In the problem there are four different conditions (door open or closed, one of the floor push buttons activated or not activated) to each of which one of the two possible consequences (the lift starts to move, or it remains in rest).

COMBINATIONAL CIRCUIT EXAMPLE: ELEVATOR/LIFT CONTROL

CONDITIONS		RESULT
1. Door	**2. Floor selecting button**	**Lift**
open	none is activated	does not move
open	one is activated	does not move
closed	none is activated	does not move
closed	one is activated	moves

LIFT CONTROL: LOGIC SCHEME

The two conditions: A and B, the result Y, the logic truth table of the problem is

A	B	Y
FALSE	FALSE	FALSE
FALSE	TRUE	FALSE
TRUE	FALSE	FALSE
TRUE	TRUE	TRUE

Symbolically A *AND* B = Y

This results in a logic AND operation.

ANOTHER EXAMPLE: GO TO LUNCH?

A simple decision about whether to go to lunch can illustrate principles of propositional logic.
Let's say that two conditions must be met:
(1) you're hungry and (2) you have money, i.e., you are solvent.
If both are true at the same time then you can go to lunch.
This is the logical AND operation:

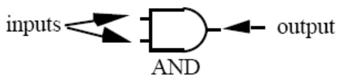
(hungry) AND (solvent) $\Rightarrow$ go to lunch

ELECTRONIC LOGIC

An electronic device can be constructed to make these kind of decisions. Voltage levels can be used to represent the logical true or false states, e.g., +5V for true and 0V for false. An AND operation could be done with a circuit with three terminals. Two terminals are for input and one for output. A voltmeter between the output and ground would measure 5V if both inputs were connected to 5V. If either input were at 0V, the output would drop to zero. The "user interface" of such a device would entail connecting each input to a switch so that the inputs could be switched between 0 and 5V at whim. The output could be connected to light a lamp when it is 5V. This interface could be called "user friendly" if the switches were labeled with words like "*Hungry*", "*Full*", "*Solvent*" and "*Broke*" and the output lamp were labeled, "*Go to Lunch*."

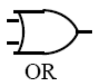
ELECTRONIC LOGIC

Without worrying about the details of how to build this circuit, it can be represented by a symbol showing the inputs and output. A little truth table beside it shows its function.



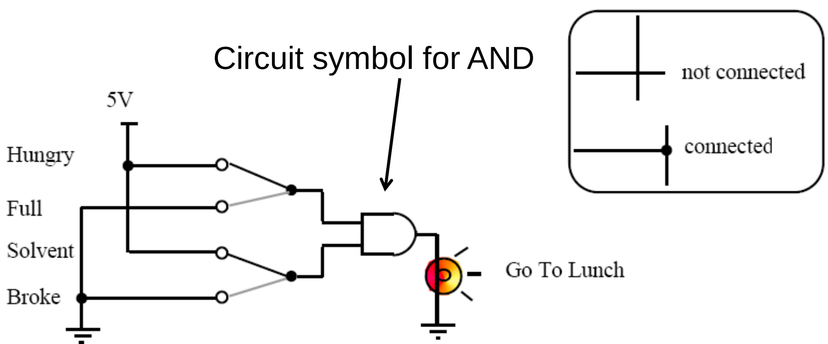
input 1	input 2	output
0V	0V	0V
0V	5V	0V
5V	0V	0V
5V	5V	5V

An OR gate can be diagrammed as follows:



input 1	input 2	output
0V	0V	0V
0V	5V	5V
5V	0V	5V
5V	5V	5V

GO TO LUNCH? ELECTRONIC LOGIC!



Simple circuit to help to decide whether to go to lunch or not.

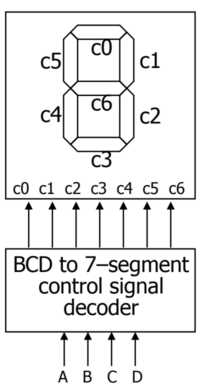
COMBINATIONAL CIRCUIT EXAMPLES

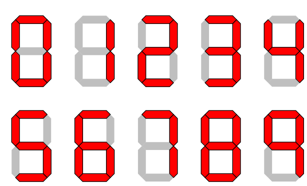
- BCD – seven segment display
- Various encoders and decoders
- Binary arithmetic circuits (half-adder, full-adder, etc.)
- Implementation of simple or complex logic functions
- Comparators
- Etc.

DEMO EXAMPLE: BCD TO 7-SEGMENT DISPLAY CONTROLLER

Input: 4-bit BCD digit (A, B, C, D), i.e. a 4-bit code.
Output: control signals for the display (7 outputs C0 – C6), i.e. a 7-bit code that allows for the decimal equivalent to be displayed.

Block diagram





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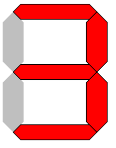
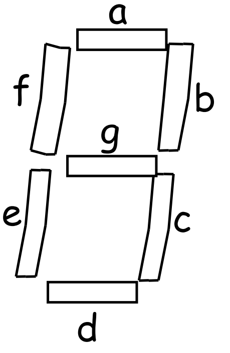
COMBINATIONAL NETWORK BCD-TO-SEVEN-SEGMENT CONVERTER

- Seven-segment display:
  - 7 LEDs (light emitting diodes), each one controlled by an input
  - 1 means "on", 0 means "off"
  - Display digit "3"?
    - Set a, b, c, d, g to 1
    - Set e, f to 0





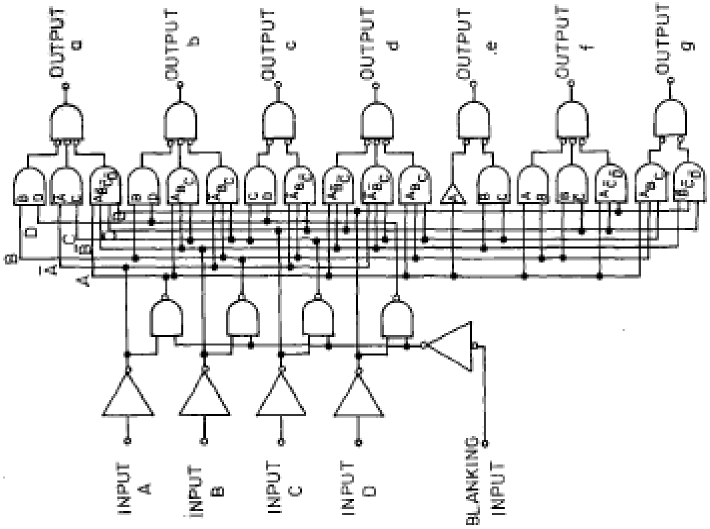
TRUTH TABLE

Combinational logic circuit behavior can be specified by enumerating the functional relationship between input values and output values. For each input pattern of 1's and 0's applied to the CL block, there exists a single output pattern. This input/output relationship is commonly enumerated in a tabular form, called a truth-table.

Exercise: construct the truth table of the BCD-to-seven segment display logic network!
(4 columns for the input variables, 7 columns for the output variables. 10 ”valid” rows, 6 rows ”free” (what to do with them?))
Exercise (for ambitious students): Draw also the logic diagram of a possible version of the BCD-to-seven-segment decoder!

BCD-TO-SEVEN-SEGMENT DISPLAY DECODER

Just for fun…



BCD-TO-7-SEGMENT DISPLAY DECODER

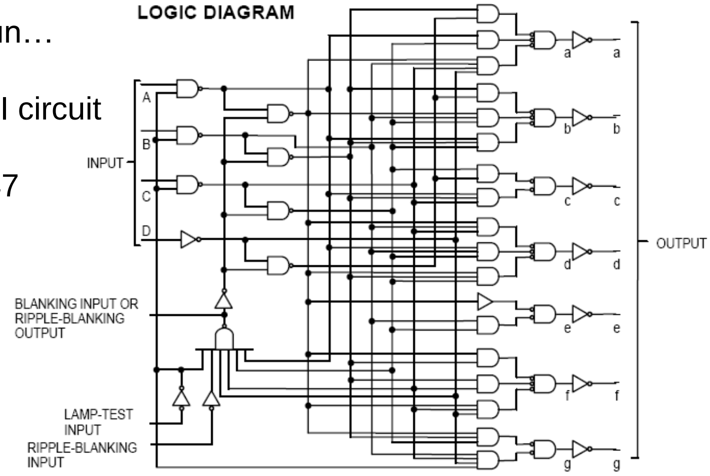
Just for fun…

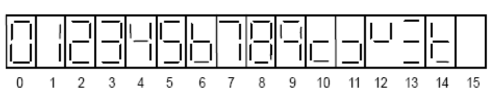
a real MSI circuit

54/74LS47

44 gates

LOGIC DIAGRAM





NUMERICAL DESIGNATIONS — RESULTANT DISPLAYS

SEQUENTIAL LOGIC NETWORKS

The outputs sequential logic network depend not only on the actual input signal combination, but on the actual state of the network established previously. In this way the outputs depend also on the previous input signals.

Sequential logic network.

Input variables: primary variables.
Output variables fed back: secondary variables.

EXAMPLE: LIFT CONTROL AGAIN

Logic problem:
The lift should start to move toward the 3rd floor, if its door is closed, and the floor control push button of the 3rd floor is activated.

In which direction (upward or downward) will the lift start to move?

EXAMPLE: LIFT CONTROL

In this problem – in a somewhat hidden form – three possible results are present:

- the lift remains in rest,
- the lift begins to move toward the 3rd floor UPWARD,
- the lift begins to move toward the 3rd floor DOWNWARD.

Based on the wording of the problem it cannot be decided which result will ensue.

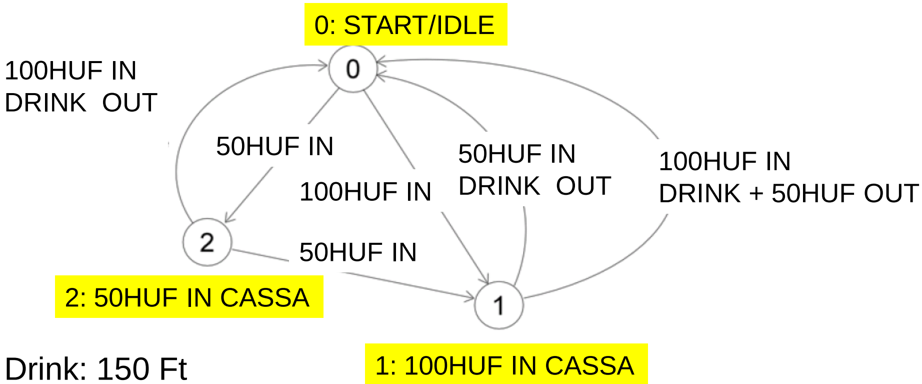
The logic network should have additional or secondary conditions/informations specifying the actual position (which floor?) of the lift.

EXAMPLE: VENDING MACHINE

E.g. a bottled drink vending machine should ”remember” how many and what kind of coins have already been inserted into it. The ”response” of the machine depends not only on the coin last inserted, but also on how many and what kind of coins it accepted already in the given service cycle.

In fact its response depends on the whole sequence of previous events.

EXAMPLE: DESCRIPTION OF STATES OF A DRINK VENING MACHINE



Drink: 150 Ft
Coin: 50 or 100 Ft

Number of states: 3 (START/IDLE, 50HUF IN CASSA, 100HUF IN CASSA)

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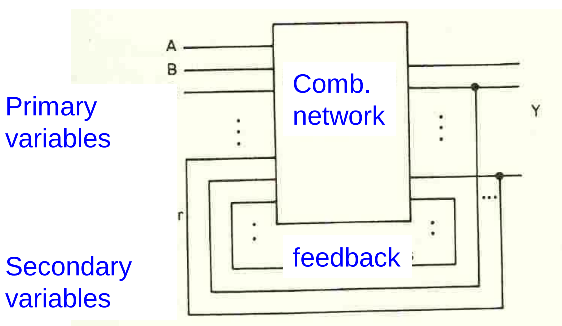
SEQUENTIAL LOGIC NETWORKS



The outputs sequential logic network depend not only on the actual input signal combination, but on the actual state of the network established previously. In this way the outputs depend also on the previous input signals.
This is achieved by feedback: the output signals are feed back to the input.

PROPERTIES OF SEQUENTIAL NETWORKS

Due to the secondary variables (feedback) the sequential circuits, when excited by the same set of input signals can generate different output signals depending on what are the actual value s of the secondary signals.

These (the secondary signals) in turn depend on the sequence of previous signals arriving on the input the consequence of which that the secondary signals change their values during the operation of the system.

The name sequential logic circuit comes from this property.

The sequential circuits, in contrast to the combinational circuits have ”memory”.

ASYNCHRONOUS AND SYNCHRONOUS SEQUENTIAL NETWORKS

Sequential circuits can be classified into two groups:

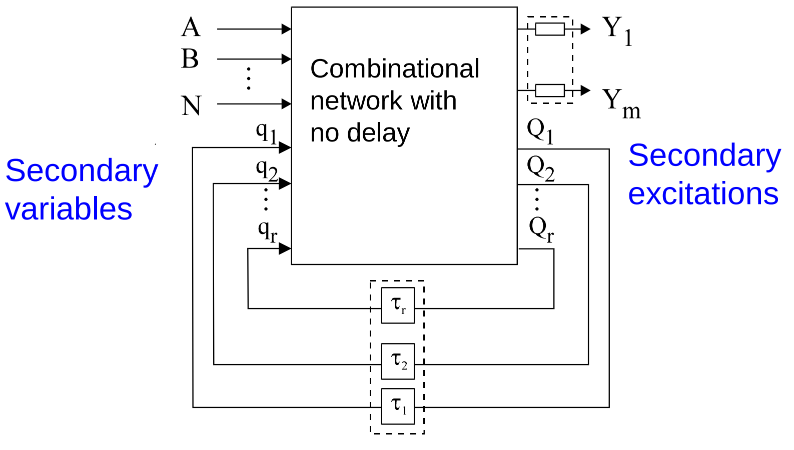
1. Asynchronous sequential circuits (no clock signal),
2. Synchronous sequential circuits (operating with synchronizing/clock signal).

ASYNCHRONOUS SEQUENTAL CIRCUITS

In the asynchronous sequential circuits the inherent time delay in the feedback loop will ensure the „memory" property necessary to generate the secondary variables.

In this case the logic state transitions occur at different times, i.e. asynchronously.

ASYNCHRONOUS SEQUENTIAL CIRCUIT



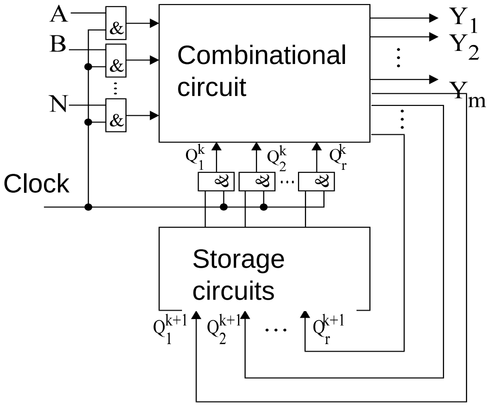
The output signals are fed back to the input (secondary variables). Asynchronous operation. The key of the proper operation are the time delays in the feedback circuit.

SYNCHRONOUS SEQUENTIAL CIRCUITS

The operation is synchronized , a separate signal is used: CLOCK PULSE, CP.

All changes occur in predetermined time (practically a short time interval), determined by the arrival of the clock signal.

SYNCHRONOUS SEQUENTIAL CIRCUIT



The output state variables are written into the storage circuits with the arrival of the clock signal. The stored signals will serve as a „memory". They will affect the input at the arrival of the next clock signal.

OPERATION OF SYNCHRONOUS SEQUENTIAL CIRCUITS

The signals feed back from the output to the input (secondary variables) do not affect the operation instantaneously, but they are written in and stored in the storage elements when the clock signal arrives. The values of these stored variables will affect the input only when the next clock signal arrives.

COMBINATIONAL VS SEQUENTIAL LOGIC CIRCUITS IN REAL LIFE? DISCUSS!

Which of the following contain circuits that are likely to be combinational and which contain sequential circuits?

1. A washing machine that sequences through the soak, wash, and spin cycles for preset periods of time.

2. A circuit that divides two 2-bit numbers to yield a quotient and a remainder.

3. A machine that takes a dollar bill and gives three quarters, two dimes, and a nickel in change, one at a time through a single coin change slot.

COMBINATIONAL VS SEQUENTIAL LOGIC CIRCUITS IN REAL LIFE

4. A digital alarm clock that generates an alarm when a preset time has been reached.

5. A circuit that takes as input two decimal numbers in the range from 0 to 9, outputs a 0 if they are different, and a 1 if they are identical.

6. A circuit that turns on or off a hall light based on the configuration of two input switches. If both switches are in the same position, the light is off. If they are in different positions the light is on.

COMBINATIONAL VS SEQUENTIAL LOGIC CIRCUITS IN REAL LIFE

7. A circuit that takes a sequence of bits, one bit at a time, and outputs a 0 or 1 after each bit that indicates if the number of is in the sequence seen so far is even or odd, respectively.

8. A circuit with two binary inputs and four binary outputs that works as follows. The binary input indicates which of the four outputs should be driven to a 1 with the other outputs set to 0.

REVISION QUESTIONS

1. Describe and discuss the fundamental properties of combinational logic circuits.

2. Describe and discuss the fundamental properties of sequential logic circuits.

EXERCISES

1. Seven switch operate a lamp in the following way. If switches 1, 3, 5, and 7 are closed and switch 2 is open, or if switches 2, 4, and 6 are closed and switch 3 is open, or if all seven switches are closed, the lamp will light.
Show, using NOT, AND, and OR elements, how the switches must be connected.

2. Construct the truth table of the BCD-to-seven segment display logic network! (4 columns for the input variables, 7 columns for the output variables. 10 ”valid” rows, 6 rows ”free” (what to do with them?))
(For ambitious students): Draw also the logic diagram of a possible version of the BCD-to-seven-segment decoder!

END

OF THE FIRST LECTURE

BRAIN TEASERS (LOGIC PROBLEMS) (1)

John has decided to go to the movies if Alice will go with him and if he can use the family car. However, Alice has decided to go to the beach if it is not raining and if the temperature is above 80 ^{o}F. John's father has made plans to use the car to visit friends if it rains or if the temperature is above 80 ^{o}F.
Under what conditions will John go to the movies?

Construct a special-purpose "computer" using inverters, AND, and OR gates, switches, battery, and a light bulb to help to solve the problem. The bulb should light if John goes the movies.

BRAIN TEASERS (LOGIC PROBLEMS) (2)

Buses leave the terminal every hour on the hour unless there are fewer than 10 passengers or if the driver is late. If there are fewer than 10 passengers, the bus will wait 10 minutes or until the number of passengers increases to 10. If the bus leaves on time, it can travel at 55 mph. If the bus leaves late, or if it rains, it can travel at only 35 mph.

Under what conditions can the bus travel at 55 mph?

PRACTICAL LOGIC PROBLEM (3)

Seven switch operate a lamp in the following way. If switches 1, 3, 5, and 7 are closed and switch 2 is open, or if switches 2, 4, and 6 are closed and switch 3 is open, or if all seven switches are closed, the lamp will light.

Show, using NOT, AND, and OR elements, how the switches must be connected.