Module 3

Digital Logic Families

Motivation:

In Digital Designs, the primary aim is to create an Integrated Circuit (IC). A Circuit configuration or arrangement of the circuit elements in a special manner will result in a particular Logic Family. Electrical Characteristics of the IC will be identical. In other words, the different parameters like Noise Margin, Fan In, Fan Out etc. will be identical. Different ICs belonging to the same logic families will be compatible with each other.

Syllabus:

Lecture no	Content	Duration (Hr)	Self-Study (Hrs)
1	Introduction: Terminologies like Propagation Delay, Power Consumption with respect to TTL and CMOS Logic	1	1
2	Fan in and Fan out, current and voltage parameters with respect to TTL and CMOS Logic	1	1
3	Noise margin with respect to TTL and CMOS Logic and their comparison	1	2

Learning Objective:

- Learners shall be able to recall and explain the different terminologies related to TTL and CMOS Logic.
- Learners shall be able to compare TTL and CMOS digital logic families.

Key Definitions:

CMOS: Stands for "Complementary Metal Oxide Semiconductor." It is a technology used to produce integrated circuits. CMOS circuits are found in several types of electronic components, including microprocessors, batteries, and digital camera image sensors.

TTL: Transistor–transistor logic (TTL) is a logic family built from bipolar junction transistors. Its name signifies that transistors perform both the logic function (the first "transistor") and the

amplifying function (the second "transistor"), as opposed to resistor–transistor logic (RTL) or diode–transistor logic (DTL).

Propagation delay: The propagation delay, or gate delay, is the length of time starting from when the input to a logic gate becomes stable and valid, to the time that the output of that logic gate is stable and valid.

Fan-in: It is the number of inputs of an electronic logic gate.

Fan-out: It is a measure of the ability of a logic gate output, implemented electronically, to drive a number of inputs of other logic gates of the same type.

Current Parameter: Current is the rate at which electric charge flows past a point in a circuit. In other words, current is the rate of flow of electric charge.

Voltage Parameter: Voltage, also called electromotive force, is the potential difference in charge between two points in an electrical field. In other words, voltage is the "energy per unit charge".

Noise Margin: The noise margin is the amount by which the signal exceeds the threshold for a proper '0' or '1'. For example, a digital circuit might be designed to swing between 0.0 and 1.2 volts, with anything below 0.2 volts considered a '0', and anything above 1.0 volts considered a '1'. Then the noise margin for a '0' would be the amount that a signal is below 0.2 volts, and the noise margin for a '1' would be the amount by which a signal exceeds 1.0 volt. In this case noise margins are measured as an absolute voltage, not a ratio.

Course Content:

Lecture 1

3.1 Introduction- Logic Families:

In Digital Designs, the primary aim is to create an Integrated Circuit (IC). The digital ICs are categorized as,

1. Small scale integration SSI <12 no of gates
2. Medium scale integration MSI 12 to 99 no of gates
3. Large scale integration LSI 100 to 9999 no of gates
4. Very large scale integration VLSI 10,000 or more

Digital IC can be further categorized into bipolar or unipolar IC.Bipolar ICs are devices whose active components are current controlled while unipolar ICs are devices whose active components are voltage controlled.

Logic Families indicate the type of logic circuit used in the IC. The main types of logic families are:

- TTL(Transistor Transistor Logic)
- CMOS (Complementary MOS)
- ECL (Emitter Coupled Logic)

Characteristics of Logic Families

The main characteristics of Logic families include:

- Voltage and current parameters
- Propagation delay
- Fan-in
- Fan-out
- Noise Immunity
- Power Dissipation

Input /Output voltage level:

The following currents and voltages are specified which are very useful in the design of digital systems.

High-level input voltage, VIH: This is the minimum input voltage which is recognized by the gate as logic 1.

Low-level input voltage, VIL: This is the maximum input voltage which is recognized by the gate as logic 0.

High-level output voltage, VOH: This is the minimum voltage available at the output corresponding to logic 1.

Low-level output voltage, VOL: This is the maximum voltage available at the output corresponding to logic 0.

High-level input current, IIH: This is the minimum current which must be supplied by a driving source corresponding to 1 level voltage.

Low-level input current, IIL: This is the minimum current which must be supplied by a driving source corresponding to 0 level voltage.

High-level output current, IOH: This is the maximum current which the gate can sink in 1 level.

Low-level output current, IOL: This is the maximum current which the gate can sink in 0 level.

High-level supply current, ICC (1): This is the supply current when the output of the gate is at logic 1.

Low-level supply current, ICC (0): This is the supply current when the output of the gate is at logic (0).

Propagation Delay: The time required for the output of a digital circuit to change states after a change at one or more of its inputs. The speed of a digital circuit is specified in terms of the propagation delay time. The delay times are measured between the 50 percent voltage levels of input and output waveforms. There are two delay times, *tp*HL: when the output goes from the HIGH state to the LOW state and *tp*LH, corresponding to the output making a transition from the LOW state to the HIGH state. The propagation delay time of the logic gate is taken as the average of these two delay times.

Power dissipation: When a circuit switches from one state to the other, power dissipates. It represents the amount of power needed by the device. It is measured in mW. It is usually the product of supply voltage and the amount of average current drawn when the output is high or low.

Let's check the take away from this lecture

1) Assume that a particular IC has a supply voltage (Vcc) equal to +5 V and ICCH = 10 mA and ICCL = 23 mA. What is the power dissipation for the chip?

a) 50 mW

b) 82.5 mW

c) 115 mW

d) 165 mW

2) What should be the value of input voltage for an efficient operation of a logic circuit by avoiding the conditions of invalid voltage levels?

a) Lower than VIL (max)

b) Higher than VIH (min)

c) Both a and b

d) None of the above

3) If a high logic output drives a logic circuit input, which among the below specified reasons will be responsible in causing a voltage drop into an invalid state?

a) Positive noise spike greater than VNL

b) Positive noise spike less than VNL

c) Negative noise spike greater than VNH

d) Negative noise spike less than VNH

Exercise
Q.1 Discuss the voltage and current parameters.
Q.2 List the characteristics of logic families.
Q.3 Define propagation delay.

Learning from this lecture: Learners will be able to understand the characteristics of digital logical families like voltage & current parameters, propagation delay, power dissipation.

Lecture 2

Fan-in: It determines the number of inputs the logic gate can handle. It means the number of input signals that can be connected to a gate without causing it to operate outside its intended operating range. expressed in terms of standard inputs or units loads (ULs).

Fan-out: Determines the number of circuits that a gate can drive. It means the maximum number of inputs that can be driven by a logic gate. A fan-out of 10 means that 10 unit loads can be driven by the gate while still maintaining the output voltage within specifications for logic levels 0 and 1.

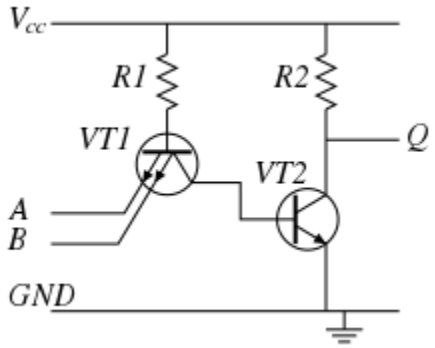
Noise Immunity: Maximum noise that a circuit can withstand without affecting the output.

Speed power product:

The product of the gate speed or propagation delay of an electronic circuit and its power dissipati on.

TTL Logic

In transistor-transistor logic (TTL), logic gates and other digital circuits are made using bipolar junction transistors (BJT) and resistors. The term transistor-transistor is because both logic function and amplification is done by transistor. Using TTL logic families, many logic gates can be fabricated in a single integrated circuit. For logic gate built using TTL logic families, input are given to the emitters of the input transistor. In TTL logic family, analog value from 0 V to 0.8 V is logic 0 and 2 V to 5 V is logic 1. Advantages of the TTL logic families include high switching speed (125 MHz), less noise and more current (3 mA) driving capability.



Two input NAND gate using TTL

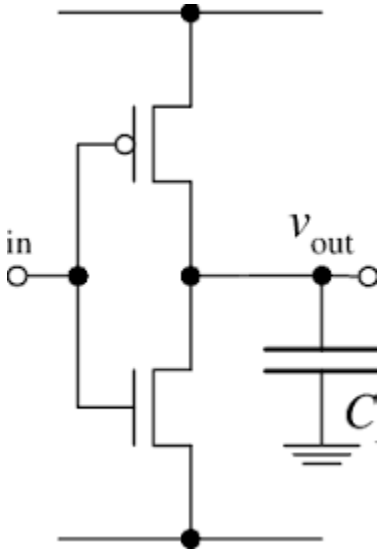
Figure above shows TTL NAND gate. There are two transistor stages in the circuit, a multi-emitter input transistor and output transistor. Function of a multi-emitter transistor is same as that of a two parallel transistor with common base and collector terminals.

Operation of TTL NAND Gate

When the two emitters of the input *transistors* are connected to high voltage, then emitter-base junction of the transistor is reverse biased that means, transistor is in reverse active mode. In reverse active mode, less magnitude current flows in the opposite direction. This current reaches base of the output transistor, allowing it to conduct and pulling down the output voltage to zero. When any one of the input terminal is low, the current through other branch flows out through this terminal. Now no current reaches the base terminal of the output transistor, so output remains at high state.

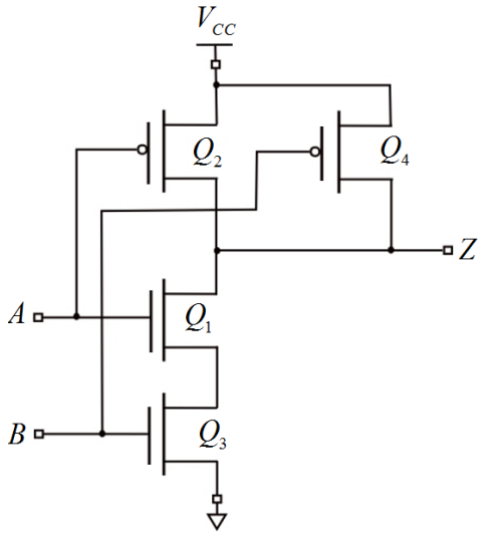
CMOS logic

CMOS (Complementary Metal Oxide Semiconductor) is another classification of ICs that uses Field Effect Transistors (FET) in the design.Because of high noise immunity and low static power dissipation, now CMOS logic families is most preferred in large scale integrated circuits. CMOS (Complementary Metal Oxide Semiconductor) has complementary and symmetrical NMOS (N-type MOS) and PMOS (P-type MOS) transistors. Figure shown below is a **CMOS inverter.**



Depending on the input value, only one transistor of the CMOS inverter will be ON at a time. So in both states, there is no direct connection between power supply and ground, thereby reducing static power loss of a transistor.

Two input CMOS NAND gate



When both inputs of a **CMOS NAND gate** are at high, then transistors T1, T2 will be ON and transistors T3, T4 will be OFF. Now there is a direct connection between output and ground through transistor T3 and T4. Output is pulled down to zero.

When any of the input is low, either transistor T3 or T4 will be off. This breaks the connection between output terminal and ground. At the same time, one of the PMOS transistors is ON, so there is connection between output and power supply. Now output is pulled up to logic high.

Let's check the take away from this lecture

1) As a general rule, the lower the value of the speed–power product, the better the device because of its:

a) long propagation delay and high power consumption

b) long propagation delay and low power consumption

2) What is the range of invalid TTL output voltage?

a) 0.0–0.4 V

b) 0.4–2.4 V

c) 2.4–5.0 V

d) 0.0–5.0 V

3) The basic function of TTL gate is which of the following functions?

a) AND

b) OR

c) NOR

d) NAND

Exercise
Q.1 What is fan-in and fan-out?
Q.2 Explain the operation of TTL logic.
Q.3 How is the speed power product of a logic family determined?

Learning from this lecture: Learners will be able to understand the characteristics of digital logical families like fan-in, fan-out, noise immunity and the operation of TTL and CMOS logic.

3.2 Comparison of TTL and CMOS

TTL

- Dissipates low power: The power dissipation is dependent on the power supply voltage, frequency, output load, and input rise time. At 1 MHz and 50 pF load, the power dissipation is typically 10 nW per gate.
- Short propagation delays: Depending on the power supply, the propagation delays are usually around 25 nS to 50 nS.
- Rise and fall times are controlled: The rise and falls are usually ramps instead of step functions, and they are 20 - 40% longer than the propagation delays.
- Noise immunity approaches 50% or 45% of the full logic swing.
- Levels of the logic signal will be essentially equal to the power supplied since the input impedance is so high.
- Voltage levels range from 0 to VDD where VDD is the supply voltage. A low level is anywhere between 0 and 1/3 VDD while a high level is between 2/3 VDD and VDD.

CMOS

- CMOS components are typically more expensive than TTL equivalents. However, CMOS technology is usually less expensive on a system level due to CMOS chips being smaller and requiring less regulation.
- CMOS circuits do not draw as much power as TTL circuits while at rest. However, CMOS power consumption increases faster with higher clock speeds than TTL does. Lower current draw requires less power supply distribution, therefore causing a simpler and cheaper design.
- Due to longer rise and fall times, the transmission of digital signals becomes simpler and less expensive with CMOS chips.
- CMOS components are more susceptible to damage from electrostatic discharge than TTL components.

Parameter	CMOS	TTL
Basic gate	NAND/NOR	NAND
Fan-out	>50	10
Power per gate (mW)	1 @ 1 MHz	1 - 22
Noise immunity	Excellent	Very good
t_{PD} (ns)	1 - 200	1.5 – 33

Let's check the take away from this lecture

1) What is the standard TTL noise margin?

a) 5.0 V

b) 0.0 V

c) 0.8 V

d) 0.4 V

2) Which of the following is the propagation delay of TTL circuits?

a) 1 s

b) 1 ms

c) 1 ns

d) 1 ps

3) Which of the following logic families dissipates minimum power?

a) CMOS

b) ECL

c) TTL

d) DTL

Exercise
Q.1 What is the recommended fan-out for TTL gate?
Q.2 List the advantages of CMOS logic.
Q.3 Compare CMOS and TTL logic with respect to power dissipation and propagation delay?

Learning from this lecture: Learners will be able to compare TTL and CMOS digital logic families.

Conclusion

The study of Digital Logic Families helps to know the characteristics of the logic families. By learning the operation of TTL and CMOS logic the student will be able to compare the two logic families with respect to the different characteristics.

Short Answer Questions:

1. What is propagation delay?

Ans) The propagation delay, or gate delay, is the length of time starting from when the input to a logic gate becomes stable and valid, to the time that the output of that logic gate is stable and valid.

2. What is power dissipation?

Ans) When a circuit switches from one state to the other, power dissipates. It represents the amount of power needed by the device. It is measured in mW. It is usually the product of supply voltage and the amount of average current drawn when the output is high or low.

3. List the characteristics of logic families?

Ans) The main characteristics of Logic families include:

- Voltage and current parameters
- Propagation delay
- Fan-in
- Fan-out
- Noise Immunity
- Power Dissipation

4. Define speed power product.

Ans) The product of the gate speed or propagation delay of an electronic circuit and its power dissipation.

5. What is noise margin?

Ans) The noise margin is the amount by which the signal exceeds the threshold for a proper '0' or '1'. For example, a digital circuit might be designed to swing between 0.0 and 1.2 volts, with anything below 0.2 volts considered a '0', and anything above 1.0 volts considered a '1'. Then the noise margin for a '0' would be the amount that a signal is below 0.2 volts, and the noise margin for a '1' would be the amount by which a signal exceeds 1.0 volt. In this case noise margins are measured as an absolute voltage, not a ratio.

Long Answer Questions:

1. Explain the operation of TTL logic. (Refer the section 'TTL Logic' in 3.1)
2. Explain the operation of CMOS logic. (Refer the section 'CMOS Logic' in 3.1)
3. Compare CMOS and TTL logic. (Refer 3.2)

Set of Questions for FA/IA/ESE

Q. 1) What is propagation delay?

Q. 2) What is power dissipation?

Q. 3) Define voltage and current parameters.

Q.4) What is noise margin?

Q. 5) What is fan-in and fan-out?

Q. 6) Define speed power product.

Q. 7) Write short note on TTL logic.

Q. 8) Write short note on CMOS logic.

Q. 9) Compare TTL and CMOS logic with respect to different characteristics of logic families.

References:

1) Modern Digital Electronics By R. P. Jain.
2) Digital Logic and Computer Design By M. Morris Mano.
3) Digital Principles and Applications By Donald p Leach, Albert Paul Malvino

Practice for Module-01

Q.1) a) Explain the operation of TTL logic. (5 marks)

b) Explain the operation of CMOS logic. (5 marks)

Q.2) Compare TTL and CMOS logic (10 marks)

Self-assessment

Q.1) State the term 'Digital Logic Families'? List the characteristics of logic families.

Q. 2) Explain the operation of TTL and CMOS logic.

Q. 3) Compare TTL and CMOS logic with respect to different characteristics.

Self-evaluation

Name of Student		
Class		
Roll No.		
Subject		
Module No.		
S.No		Tick Your choice
1.	Do you understand the different characteristics of digital logic families?	○ Yes ○ No
2.	Do you understand the operation of TTL logic?	○ Yes ○ No
3.	Do you understand the operation of CMOS logic?	○ Yes ○ No
4.	Do you understand module 3 ?	○ Yes, Completely. ○ Partialy. ○ No, Not at all.