Grade 12 A/L ICT · Lesson 4

4.3 Designing Digital Circuits: From Everyday Needs to Logic Gates

Syllabus 4.3. Now you **design** small circuits yourself. You pick a real situation (a door alarm, a majority vote, a car seatbelt light), write its **truth table** (up to three inputs), turn the table into a **Boolean expression**, simplify it, and finally **draw the gate circuit**. This is how engineers start every digital design.

1. The design steps

Four clear steps take you from a need to a working circuit:



Need → truth table → expression → circuit

1. Identify the need
Name the inputs and the one output in everyday words.

2. Truth table
List every input mix (2^n rows) and the required output.

3. Expression
Write SOP (or POS), then simplify with laws or a K-map.

4. Draw the circuit
Replace each · with AND, each + with OR, each ′ with NOT.

2. Example A – Door alarm at night

A house alarm should sound when the **door is open (D = 1)** AND it is **night (N = 1)**. By day, or when the door is shut, the alarm stays off.

🧱 **Worked example: Write the truth table and the Boolean expression for the door alarm.**
DN: 00→0, 01→0, 10→0, 11→1. So F = **D · N**. The circuit is a single **AND** gate.

D (door)	N (night)	Alarm F
0	0	0
0	1	0
1	0	0

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1	1	1

3. Example B – Majority of three votes

Three people A, B, C vote yes (1) or no (0). The decision F is yes when **at least two** vote yes – the **majority** function.

> 🧱 **Worked example: Write F for the majority of A, B, C and list when F = 1.**
> F = A·B + B·C + A·C. F = 1 for ABC = 011, 101, 110, 111 (the rows with two or three 1s).

A	B	C	F
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

> 💡 The majority circuit uses **three AND gates** (one per pair) and **one OR gate** that joins their outputs. It is also the carry logic inside a full adder (4.4).

4. Example C – Seatbelt warning light

A car warning light turns on when the **engine is on (E = 1)** AND the **seatbelt is not fastened (S = 0)**. So F = E · S′.

> 🧱 **Worked example: Draw the truth table for F = E · S′ and name the gates you need.**
> ES: 00→0, 01→0, 10→1, 11→0. Gates: one **NOT** on S, then one **AND** with E.

5. Turning an expression into a circuit

Reading an expression left to right: every ′ becomes a NOT bubble (or a NOT gate), every · becomes an AND gate, every **+** becomes an OR gate. Draw inputs on the left, output on the right. Share NOT gates when the same inverted signal is used twice.

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🧱 **Worked example: For F = A·B + A′·C, list the gates required after simplifying is not needed.**
One NOT (for A′), two AND gates (A·B and A′·C), one OR gate joining them – **4 gates** total.

💡 Always simplify before you draw. F = A·B + A·B′ looks like two ANDs and an OR (3 gates), but it is just A (0 extra gates beyond a wire).

🚀 **Beyond the syllabus (2026 update)** *Not required for the exam – read for interest.* Real products combine these tiny designs into HDL code (Verilog / VHDL). In 2026, students and makers also use low-cost FPGA boards (e.g. Lattice iCE40, Xilinx / AMD Spartan) to download a truth table and watch the LEDs follow the circuit you designed on paper.

Key Words

Digital circuit design – Turning a real need into a truth table, expression and gate circuit.

Input variable – A binary signal that feeds a circuit (door, night, vote, ...).

Output function – The single binary result the circuit must produce.

Majority function – Output is 1 when at least two of three inputs are 1. F = AB+BC+AC.

Alarm circuit – Example: F = D · N (door open AND night).

Gate-level circuit – A drawing that shows each AND, OR and NOT gate.

Simplification before drawing – Reduce the expression so the circuit uses fewer gates.

Three-input design – Syllabus limit: truth tables with at most three inputs (8 rows).

Seatbelt warning – F = E · S′ – engine on and belt not fastened.

Shared inverter – One NOT gate reused when the same inverted signal is needed twice.

Application – A real-life situation that a logic circuit can control.

Boolean to gates – · → AND, + → OR, ′ → NOT.

Sample Q&A

1. List the four steps of digital circuit design.

Answer: Need → truth table → Boolean expression (simplified) → draw gates.

2. What is the Boolean expression for a door-open-at-night alarm?

Answer: F = D · N.

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3. Write the majority function of three inputs.

> **Answer:** F = A·B + B·C + A·C.

4. How many rows does a 3-input design truth table have?

> **Answer:** 8 rows.

5. Why simplify before drawing the circuit?

> **Answer:** A simpler expression needs fewer gates, so the circuit is cheaper and smaller.

6. For F = E · S′, which gates do you need?

> **Answer:** One NOT on S and one AND with E.

MCQ

1. The first step in designing a digital circuit is

A. write POS only
B. identify the need and name inputs/output
C. buy an FPGA
D. draw random gates
E. skip the truth table

2. Door alarm F = D · N uses which gate?

A. XOR
B. NOR
C. AND
D. NOT
E. OR

3. Majority of A,B,C equals

A. A + B + C
B. A′B′C′
C. A ⊕ B ⊕ C
D. AB + BC + AC
E. A · B · C

4. A 3-input truth table has

A. 4 rows
B. 8 rows
C. 6 rows
D. 3 rows
E. 9 rows

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5. F = E · S′ needs

A. XOR only
B. OR only
C. NOR only
D. NAND only
E. NOT and AND

6. · in a Boolean expression becomes which gate?

A. OR
B. NOT
C. NOR
D. XOR
E. AND

7. + in a Boolean expression becomes which gate?

A. OR
B. NOT
C. XOR
D. AND
E. NAND

8. For the alarm, F is 1 only when

A. always
B. door shut
C. door open and night
D. never
E. daytime

9. The majority circuit is also used as

A. carry logic of a full adder
B. a clock
C. an antenna
D. a NOT gate
E. a memory cell

10. Simplifying F = A·B + A·B′ before drawing saves

A. the truth table
B. gates (it becomes just A)
C. nothing
D. inputs
E. De Morgan

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11. Syllabus designs are limited to how many inputs?

A. three
B. five
C. ten
D. eight
E. one

12. Shared inverters are used when

A. you have spare OR gates
B. there is no truth table
C. POS is forbidden
D. F = 1 always
E. the same inverted signal is needed more than once

13. Which term means: “Turning a real need into a truth table, expression and gate circuit”?

A. Output function
B. Application
C. Three-input design
D. Digital circuit design
E. Gate-level circuit

14. Which term means: “A binary signal that feeds a circuit (door, night, vote, …)”?

A. Seatbelt warning
B. Majority function
C. Boolean to gates
D. Input variable
E. Simplification before drawing

15. Which term means: “The single binary result the circuit must produce”?

A. Three-input design
B. Shared inverter
C. Output function
D. Digital circuit design
E. Alarm circuit

16. Which term means: “Output is 1 when at least two of three inputs are 1. F = AB+BC+AC”?

A. Majority function
B. Application
C. Gate-level circuit
D. Seatbelt warning
E. Input variable

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17. Which term means: “Example: F = D · N (door open AND night)”?

A. Shared inverter
B. Output function
C. Alarm circuit
D. Boolean to gates
E. Simplification before drawing

18. Which term means: “A drawing that shows each AND, OR and NOT gate”?

A. Majority function
B. Three-input design
C. Application
D. Gate-level circuit
E. Digital circuit design

19. Which term means: “Reduce the expression so the circuit uses fewer gates”?

A. Seatbelt warning
B. Simplification before drawing
C. Alarm circuit
D. Input variable
E. Boolean to gates

20. Which term means: “Syllabus limit: truth tables with at most three inputs (8 rows)”?

A. Digital circuit design
B. Gate-level circuit
C. Shared inverter
D. Output function
E. Three-input design

Structured Questions

1. Describe the four design steps with a short example. *(4 marks)*

> Need (e.g. night door alarm) (1); truth table (1); expression F=D·N (1); draw AND gate (1).

2. Build the truth table and expression for a light that is ON when either switch A or switch B is ON (or both). *(3 marks)*

> AB: 00→0, 01→1, 10→1, 11→1 (1); F = A + B (1); circuit = OR gate (1).

3. For the majority function, state F and say for which of ABC = 101 and 100 the output is 1. *(3 marks)*

> F = AB+BC+AC (1); 101 → 1 (two 1s) (1); 100 → 0 (only one 1) (1).

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4. Design F = E · S′ (seatbelt warning): truth table, expression already given, gates needed. *(2 marks)*

> Table ES: 00→0, 01→0, 10→1, 11→0 (2); gates NOT + AND (1).

5. Explain why you should simplify A·B + A·B′ before drawing, and state the simplified form. *(3 marks)*

> Unsimplified needs 2 AND + 1 OR (1); simplified is A – just a wire (1); saves gates/cost (1).

Summary

- Design flow: need → truth table → simplify expression → draw gates.
- Door alarm: F = D · N (one AND).
- Majority: F = AB + BC + AC (also full-adder carry).
- Seatbelt warning: F = E · S′ (NOT then AND).
- Syllabus designs use at most three inputs (8-row truth tables).

MCQ answer key – 4.3

1. **B** – Start from the real-world need.
2. **C** – AND of door and night.
3. **D** – At least two inputs are 1.
4. **B** – $2^3 = 8$.
5. **E** – Invert S, then AND with E.
6. **E** – · denotes AND.
7. **A** – + denotes OR.
8. **C** – Both D and N must be 1.
9. **A** – Cout = majority(A,B,Cin).
10. **B** – A·B + A·B′ = A.
11. **A** – Up to three inputs.
12. **E** – Reuse one NOT.
13. **D** – Digital circuit design – Turning a real need into a truth table, expression and gate circuit.
14. **D** – Input variable – A binary signal that feeds a circuit (door, night, vote, …).
15. **C** – Output function – The single binary result the circuit must produce.
16. **A** – Majority function – Output is 1 when at least two of three inputs are 1. F = AB+BC+AC.
17. **C** – Alarm circuit – Example: F = D · N (door open AND night).
18. **D** – Gate-level circuit – A drawing that shows each AND, OR and NOT gate.
19. **B** – Simplification before drawing – Reduce the expression so the circuit uses fewer gates.
20. **E** – Three-input design – Syllabus limit: truth tables with at most three inputs (8 rows).

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