Combinational Circuits Cheat Sheet (Theory Only)

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1. Introduction to Combinational Circuits

Combinational circuits are **digital circuits** where the output depends only on the present inputs, not past inputs (no memory).

Key Features:

- No feedback loops.
- Perform logic operations like addition, subtraction, encoding, decoding, multiplexing, etc.
- Built using logic gates (AND, OR, NOT, XOR, etc.).

Examples:

- Arithmetic Circuits (**Adders, Subtractors**).
- Data Processing Circuits (**Encoders, Decoders, Multiplexers**).

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2. Design Procedure for Combinational Circuits

Steps for designing a combinational circuit:

1st **Define the problem statement** (understand input-output relationship).
2nd **Determine the number of input & output variables**.
3rd **Construct the truth table** (mapping inputs to outputs).
4th **Derive the Boolean expressions** for each output.
5th **Simplify the Boolean expressions** using K-Map or algebraic methods.
6th **Implement the circuit using logic gates**.

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3. Adders (Binary Addition Circuits)

(A) Half Adder

- Adds two **single-bit** binary numbers.
- **Inputs:** A, B.
- **Outputs:**
- **Sum (S) = A B**
- **Carry (C) = A · B**

Truth Table:

A	B	Sum (S)	Carry (C)
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

(B) Full Adder

- Adds three bits (A, B, Carry-in C_in).
- **Outputs:**
- **Sum (S) = A B C_in**
- **Carry-out (C_out) = (A · B) + (B · C_in) + (A · C_in)**

Truth Table:

A	B	C_in	Sum (S)	C_out
0	0	0	0	0

A	B	C_in	Sum (S)	C_out
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

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4. Binary Parallel Adder

A **multi-bit binary adder** made using multiple full adders in parallel.
Example: **4-bit parallel adder** using four full adders.

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5. BCD (Binary-Coded Decimal) Adder

Adds **two BCD digits** (0-9) and outputs a **BCD sum**.
If the sum is ≥ 10 (1010_2), a **correction factor (6 or 0110_2)** is added.

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6. Carry Look-Ahead Adder (CLA Adder)

Overcomes the **slow carry propagation** of ripple adders.
Uses **Carry Generate (G) and Carry Propagate (P) functions**.
Formulas:

- G = A · B (Carry is generated).
- P = A   B (Carry is propagated).
- C_out = G + (P · C_in).

Faster than ripple carry adder for large-bit operations.

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7. Subtractors (Binary Subtraction Circuits)

(A) Half Subtractor

- Subtracts two single-bit binary numbers.
- **Difference (D) = A   B**
- **Borrow (B_out) = A' · B**

Truth Table:

A	B	Difference (D)	Borrow (B_out)
0	0	0	0
0	1	1	1
1	0	1	0
1	1	0	0

(B) Full Subtractor

- Subtracts three bits (A - B - B_in).
- **Difference = A   B   B_in**
- **Borrow = (A' · B) + (B_in · (A   B))**

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8. Decoder

Converts n inputs to 2^n outputs (e.g., 3 → 8).
Example: **3-to-8 decoder** produces **one active output** for each input combination.
Truth Table for 2-to-4 Decoder:

A1	A0	O0	O1	O2	O3
0	0	1	0	0	0
0	1	0	1	0	0
1	0	0	0	1	0
1	1	0	0	0	1

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9. Encoder

Converts 2^n inputs into n outputs (inverse of decoder).
Example: **4-to-2 encoder** maps four inputs to two output bits.
Priority Encoder:

- Used when **multiple inputs** are 1.
- Highest priority input is encoded.

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10. Multiplexer (MUX)

Selects one output from multiple inputs based on selector lines.
n-to-1 MUX has:

- n input lines.
- $\log_2(n)$ selection lines.
- 1 output line.

Example: 4-to-1 MUX

- Inputs: I0, I1, I2, I3
- Select Lines: S1, S0
- Output: $Y = (I0 \cdot S1' \cdot S0') + (I1 \cdot S1' \cdot S0) + (I2 \cdot S1 \cdot S0') + (I3 \cdot S1 \cdot S0)$

Multiplexer Applications:

- **Data Selection**
- **Signal Routing**
- **Arithmetic Logic Units (ALUs)**

Comparison of Combinational Circuits

Circuit	Function	Key Feature
Adder	Adds binary numbers	Used in ALU operations
Subtractor	Subtracts binary numbers	Used in arithmetic circuits
Decoder	Converts binary to multiple outputs	Used in memory addressing
Encoder	Converts multiple inputs to binary	Used in digital communication
Multiplexer (MUX)	Selects one input among many	Used in data selection

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Key Takeaways

Combinational Circuits: No memory, outputs depend only on inputs.
Adders & Subtractors: Perform binary arithmetic.
Multiplexer: Selects a single input based on control signals.
Decoder & Encoder: Convert between binary and multiple inputs.
Carry Look-Ahead Adder: Faster than ripple carry adder.

This **Combinational Circuits Cheat Sheet** covers **adders, subtractors, encoders, decoders, multiplexers, and design procedures**. Let me know if you need further explanations!