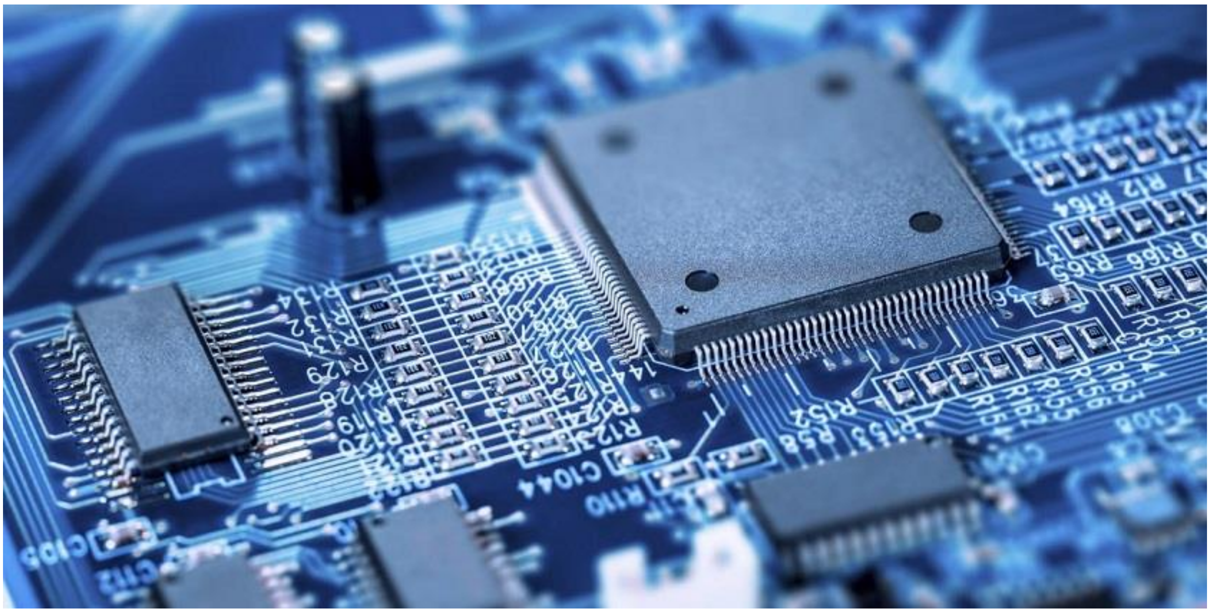
S4 New Curriculum Physics

Theme: Modern Physics

Chapter 7 – Digital electronics



Digital electronics is a branch of electronics that deals with systems and devices that process and control digital signals, which are represented by discrete values, typically binary (0s and 1s), unlike analog electronics that use continuously varying signals.

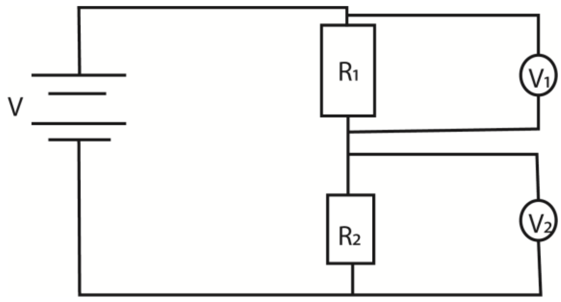
This field forms the foundation of modern electronic devices and systems like computers, smartphones, and communication systems, utilizing logic gates and other components to perform calculations and process information.

Components of digital electronic and their uses

1. Potential divider

A potential divider is any circuit arrangement used to reduce voltage by cartain fraction to suit a certain part of the circuit.

For instance, in the circuit below:



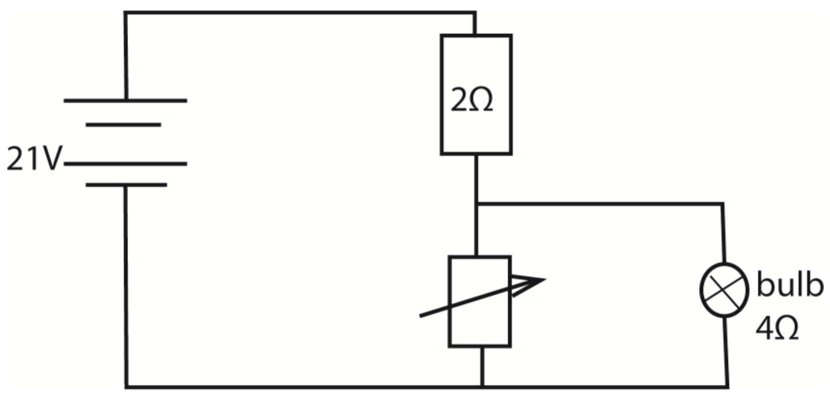
The current through the resistors is the same, therefore the voltage is divided as follows

$V_1 = \frac{R_1}{R_1+R_2}V \text{ and } V_2 = \frac{R_2}{R_1+R_2}V$ or $\frac{V_1}{V_2} = \frac{R_1}{R_2}$

Hence, potential dividers are used to provide specific voltages to certain parts of the circuit in devices from the main voltage. They are used in smartphones, televisions,etc

For example 1.

Find the value of the varible resistor if the bulb is designed to operate at 9V in the diagram below



Solution

Let the resistance of the bulb be R

Resultant resistance of the bulb and the variable resistor = $\frac{4R}{R+4}$

Total resistance in the circuit = $\left(\frac{4R}{R+4} + 3\right)\Omega$

Since the variabe resistor and the bulb are in parallel each must be at 9V

$$9V = \frac{\frac{4R}{R+4}}{\frac{4R}{R+4}+2} x\ 21$$

$$21\left(\frac{4R}{R+4}\right) = 9\left(\frac{4R}{R+4} + 2\right)$$

$$12\left(\frac{4R}{R+4}\right) = 18$$

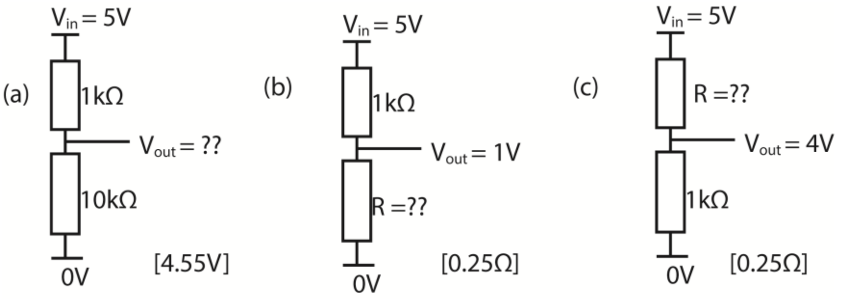
48R =18R + 72

30R = 72

R = 2.4Ω

Trial 1

Compute the missing value in the following circuits



Logic Gates are the fundamental building blocks in digital electronics.

Applications of potential dividers in electronic devices

1. **Volume Controls in Audio Devices:** Turning a volume knob usually adjusts a potential divider circuit, changing the voltage sent to an amplifier and controlling sound output smoothly.
2. **LED Brightness Control:** In some basic circuits, varying the input to an LED through a potential divider can adjust its brightness.
3. **Sensor Readouts:** Many sensors (like temperature or light sensors) change their resistance. Combined with a fixed resistor, they form a divider that outputs a voltage representing the sensor's reading.
4. **Biasing Transistors:** In amplifiers and other circuits, potential dividers set the correct base voltage for transistors, ensuring they operate in the right region for amplification.
5. **Reference Voltages for Comparators:** Comparators compare an input voltage with a reference. That reference is often set using a potential divider to establish precise threshold levels.

6. **Battery Monitoring**: To safely measure high battery voltages with a microcontroller, a potential divider scales the voltage down to within safe limits for the device's analog inputs.

Binary System

In electronics, the binary system is the system that uses **1** to represent a true value/ on/high or conducting state and **0** to represent false value/off/low/cut off state in a circuit.

The binary system forms the fundamental language for digital computers and electronic devices due to its straightforward implementation in electronic circuitry using logic gates. This system is crucial because electronic components like switches and transistors can easily represent these two distinct states (on/off, conducting/cut off) or voltage levels (high/low), making it ideal for processing and storing information in a machine-readable format.

Logic gates

Logic gates *are* electronic switches. They take one or more input signals, **(0s and 1s)**, and process them **to produce a single binary output** based on specific rules of logic. Logic gates can be represented by symbols or algebraic equations called Boolean algebra.

Logic gates are like the decision-makers of the digital world, flipping switches to make sense of 1s and 0s.

Function of logic gates

1. **Perform Logical Decisions:** They take input values (0s and 1s) and decide the output based on logic rules—just like "if this, then that."
2. **Enable Arithmetic Operations:** By combining a bunch of them it is possible to get adders, subtractors, and even complex arithmetic units inside processors.
3. **Store and Transfer Data:** Using flip-flops (built from gates), they can *store bits* of data—essential for memory, registers, and timing.
4. **Control Signal Flow**: In circuits, they help route signals, acting like intelligent traffic cops directing digital signals to the right destinations.
5. **Build Complex Systems** Everything from microcontrollers to CPUs is constructed using layers and layers of logic gates working together.

Types of logic gates

They are three types of basic logic gates

- An **AND gate** only gives a 1 if *both* inputs are 1.
- An **OR gate** gives a 1 if *at least one* input is 1.
- A **NOT gate** flips the input—turns 1 into 0, and 0 into 1.

Boolean algebra, Symbols and Truth tables of of logic ates

Note:

- A truth table represents all possible combinations of inputs in a logic circuit together with their possible outcomes.
- If n is the number of inputs into a logic circuit, the total possible number of combination of inputs is givenby 2**n**.

(i) The AND gate

Boolean algebra: The AND gate isalso known as the multiplication operation and is represented by dot (.) sign in Boolean algebra of digital logic gates. The logic operation A AND B canbe written as A.B = AB. Note that A.B = 1 if and only if both A and B have value .

Circuit symbol of AND gate

Truth table of the AND gate with two inputs

A	B	A.B
1	1	1
1	0	0
0	1	0
0	0	0

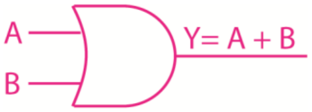
Truth table of the AND gate with three inputs

A	B	C	A.B.C
1	1	1	1
1	1	0	0
1	0	1	0
1	0	0	0
0	1	1	0
0	1	0	0
0	0	1	0
0	0	0	0

(ii) The OR gate

Boolean algebra: The OR gate is also known as the Addition operation and is represented by the plus (+) sign n Boolean Algebra of digital logic gates. The logic operation A OR B is written as A + B = B + A. Note that A +B = 1 if and only if both A and B each has a value of 1

Circuit symbol of OR gate



Truth table of the OR gate with two inputs

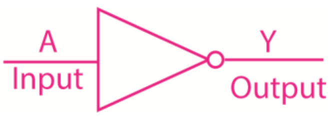
A	B	A+B
1	1	1
1	0	1
0	1	1
0	0	0

Truth table of the OR gate with three inputs

A	B	C	A.B.C
1	1	1	1
1	1	0	1
1	0	1	1
1	0	0	1
0	1	1	1
0	1	0	1
0	0	1	1
0	0	0	0

(iii) A NOT gate

Boolean algebra: The logic operation for NOT A is represented as A' or $\bar{A}$ and the circuit diagram is



Other gates

(iv) NAND gate

The Boolean algebra for a NAND gate expresses its logical function, which is the inverse of an AND gate, meaning it outputs a logical "0" only when all inputs are logical "1". For a two-input NAND gate with inputs A and B, the Boolean expression is Q = $\overline{A.B}$ or (A . B)' or Q = ~(A * B), where the over line or apostrophe denotes the logical negation (NOT) of the AND operation.

Symbol for NAND gate

Truth table of the NAND gate with two inputs

A	B	(A.B)′
1	1	0
1	0	1
0	1	1
0	0	1

(v) NOR gate

The Boolean expression for a NOR gate represents the logical NOT of the OR operation of its inputs, meaning the output is true (1) only when all inputs are false (0), otherwise the output is false (0). For a 2-input NOR gate with inputs A and B, the Boolean expression is commonly written as Q = $\overline{A + B}$ or (A+ B)′ or ~(A+B) where the over line or apostrophe denotes the logical negation (NOT) of the OR operation.

Symbol for NOR gate

Truth table of the NOR gate with two inputs

A	B	(A+B)′
1	1	0
1	0	0
0	1	0
0	0	1

Logic circuits

Logic circuits are the **building blocks of digital electronics**. They process binary signals—just 1s and 0s—to perform specific logical operations like AND, OR, and NOT. They are decision-making tools because depending on the input, they produce a certain output.

There are two main types:

1. **Combinational Logic Circuits** These provide outputs based *only* on the current inputs. Examples: adders, multiplexers, encoders, and decoders.
2. **Sequential Logic Circuits** These depend on both current inputs and past inputs (they have memory). Examples: flip-flops, counters, and registers.

Memory circuits in electronics

Memory circuits are the **storage units** of electronic systems—they hold data either temporarily or permanently, depending on their type. For example

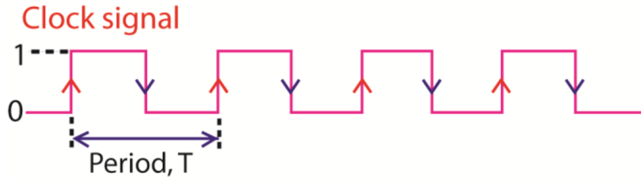
1. **RAM (Random Access Memory)**
    - **Volatile memory**, meaning it loses data when power is off.
    - Used for temporary storage while a device is running (like keeping apps open on your phone).
2. **ROM (Read-Only Memory)**
    - **Non-volatile**, retaining data even without power.
    - Stores permanent instructions for a device (like firmware that boots your computer).
3. **Flash Memory**
    - A kind of non-volatile memory that can be rewritten electronically.
    - Found in USB drives, SSDs, and memory cards.
4. **Registers and Caches**
    - Extremely fast, small memory inside CPUs for quick data access.
    - Help speed up processing by minimizing delays.
5. **Flip-Flops and Latches**
    - Fundamental building blocks of memory circuits in digital logic.
    - Each stores one bit of data and can be combined into larger structures.

Clock signal

In sequential circuits there are many processes going on; the output of one circuit is the input of other(s). For orderly operations, the inputs and outputs have to be timed. This is done using clock signals

Definition

A clock signal is a periodic electric signal that oscillates between high and low states



Clock signals are heartbeats of digital circuits. They synchronize digital circuits, ensuring that data is processed and transferred at the right time.

Functions of the clock

A clock controls **when** data is moved, stored, or processed in devices like microcontrollers, processors, and memory. Each pulse tells the system, "Now is the time to act!"

Components where timing is required in electronic devices

- **Microprocessors** (keeping all tasks in sync)
- **Flip-flops and counters** (updated on clock edges)
- **Communication circuits** (timing data transmission)
- **Digital watches and timers** (literally counting the seconds)

Clock signal characteristics

(i) **Clock Signal:** is a repetitive square wave (alternating HIGH and LOW states) used to control the timing of operations in circuits.

(ii) **Clock source:** It is where clock signal originates. It can be a port of design or a pin of cell inside the design. It is usually generated by crystal oscillator, phase-locked loop (PLLs) or external clock in some systems

(iii) **Clock Pulse:** A single cycle of the clock signal—used to trigger or advance operations in sequential logic like flip-flops or counters.

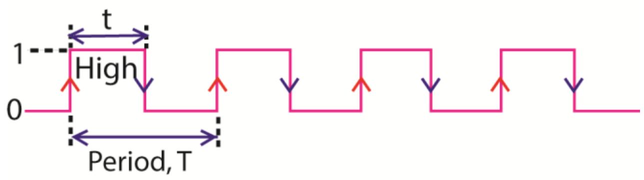
(iv) **Clock Frequency:** The number of clock cycles per second, measured in **Hertz (Hz)**. Higher frequency means faster operations. It determines how often a clock signal switches between high and low states.

(v) **Clock Period:** The time it takes for one full clock cycle. It indicates time after which the clock repeats its behaviors. It's the inverse of the frequency (Period = 1/Frequency).

(vi) **Rising Edge / Falling Edge** Refers to transitions in the clock signal:

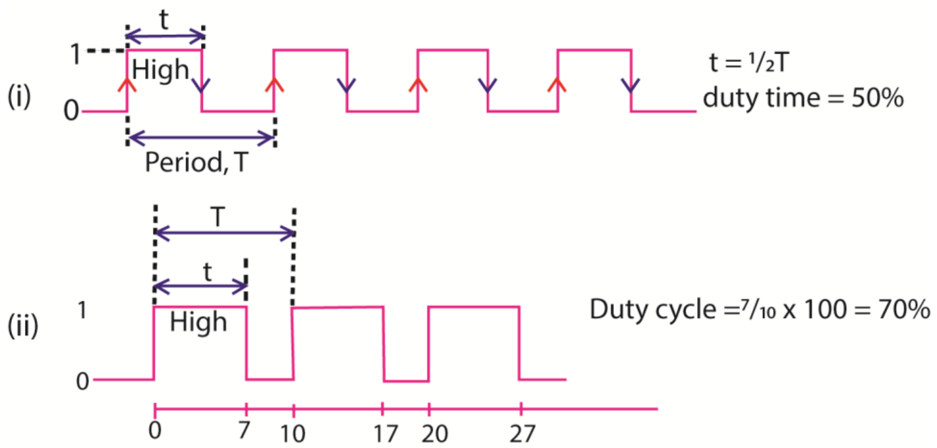
- **Rising edge**: LOW → HIGH
- **Falling edge**: HIGH → LOW Many circuits are edge-triggered, meaning they respond only when a specific edge occurs.

(vii) **Duty Cycle** The percentage of time the clock signal stays HIGH during each cycle.



In the diagram above duty cycle = $\frac{t}{T} x\ 100\%$

Example



(viii) **Asynchronous / Synchronous**

Most complex designs requre more than one clock. When there are multiple cloccks in a desgn, they would need to interact or share a relationship. This relationship can be synchronous or asychronous.

- **Synchronous clock** share a fixed phase relationship, as they are often derived from the same source.
-
- **Asynchronous clocks** do not share a fixed phase relationship.

(ix) **Clock Skew** A small delay difference in clock signals reaching different parts of a circuit. Too much skew can cause timing errors.

(x) **Clock Divider** A circuit that reduces a high-frequency clock signal into a slower one—used when different parts of a system need different speeds.

Vitual clock

Vitual clocks are clocks that don't physically exist in the specific block but represent an external trigger that impacts the timing of the clock.

Types of clock pulse

(1) **Single Pulse (One-Shot Pulse)**

- A solitary high signal generated in response to a trigger.
- Useful for initiating a single action, like flipping a flip-flop once.

(2) **Continuous Pulse (Free-Running Clock)**

- A regular stream of pulses at a fixed frequency—typical in microprocessors and timers.
- Generated by oscillators, crystals, or clock generator ICs.

(3) **Gated Clock**

- A clock pulse that can be turned on/off by an enable signal.
- Helps conserve power or coordinate multiple subsystems.

(4) **Edge-Triggered Pulse**

- Devices respond on either the **rising edge** (LOW to HIGH) or the **falling edge** (HIGH to LOW) of the clock pulse.
- Common in flip-flops and counters.

(5) **Duty-Cycled Clock**

- The pulse has a specific high/low ratio (e.g. 50% duty cycle for even on/off times).
- Affects timing and energy consumption in circuits.

(6) **Variable Frequency Clock**

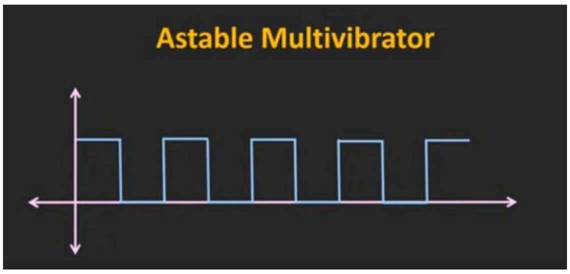
- The frequency of the pulses can change during operation.
- Seen in adaptive systems like dynamic CPU scaling.

Multivibrators circuits

Multivibrator is circuit in electronics used to generate and manipulate signals. It is like the rhythm section in a band—providing beats or holding a state until the next cue.

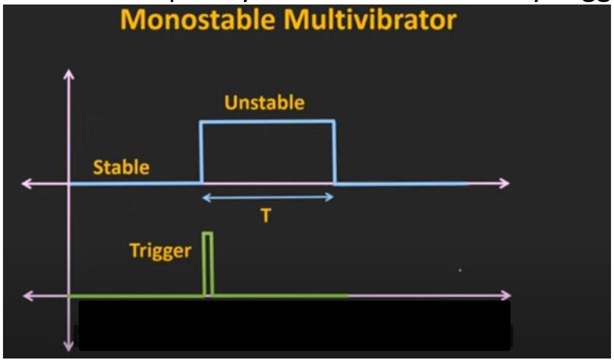
There are three main types, each with a unique personality:

1. **Astable multivibrator** is a free-running multivibrator that has NO stable state but switches continuously between two states; this action produces a train of square pulses at a fixed known frequency. The time for which the output remains in a particular state can be decided by passive components like a resistor and a capacitor. It is like a blinking light that never stops—it's always on the move.



Used for: generating square waves, LED flashers, clock signals.

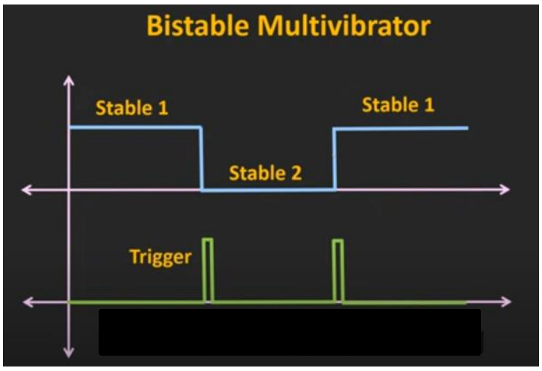
2. **Monostable Multivibrator** is a one short multivibrator that has only ONE stable state and one temporary state. Once externally triggered it returns to its first stable state



Used for: timers, pulse stretching, delay circuits. For instance, a camera flash: press the button (trigger) → bright flash (temporary state) → back to normal.

3. **Bistable Multivibrator**

Bistable multivibrator has two stable states; it toggles between them when triggered.



Used for: memory storage, flip-flops, switch debouncing. This is the basis for storing binary data—just a fancy way of saying ON or OFF.

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Thanks

Dr. Bbosa Science