# Rectification & Power Supplies

**Unit 12 | Phase 2 Electrical Instrumentation**

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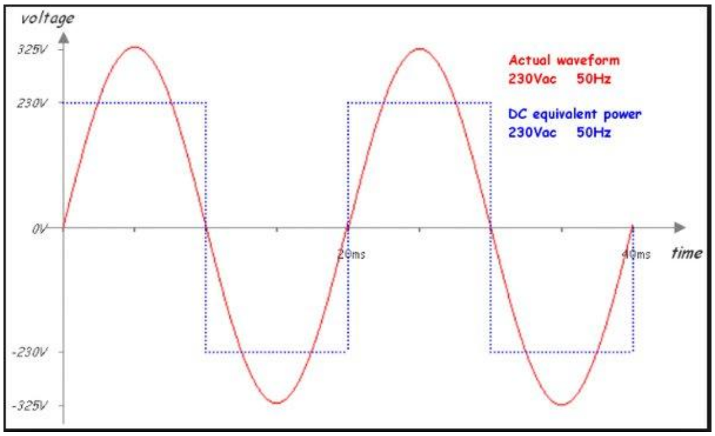
# Module 1: Fundamentals of Electricity (AC vs DC)

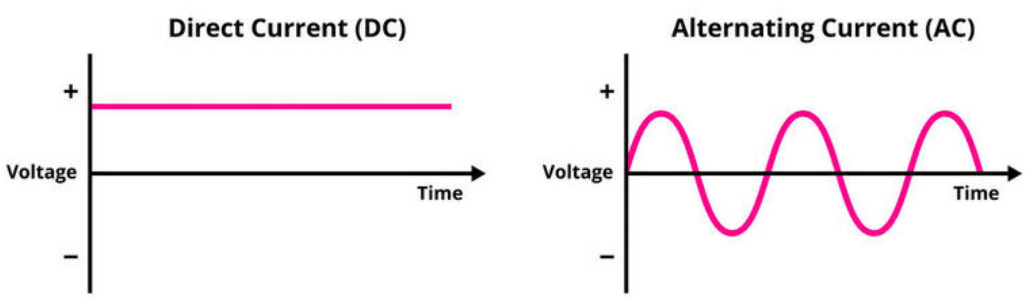
## 1.1 The Nature of Electricity

Before understanding rectification, we must distinguish between the two main types of current used in electrical instrumentation.

- **AC (Alternating Current):**
  - **Source:** The Mains Supply (ESB in Ireland).
  - **Characteristics:** The current changes direction periodically. In Ireland, the frequency is **50Hz**, meaning it changes direction 50 times per second (or 100 direction changes/zero crossings).
  - **Waveform:** Sinusoidal (Sine Wave).
  - **Standard Voltage:** 230V RMS (Single Phase).
  - **Why AC?** It is efficient to transmit over long distances using transformers.




- **DC (Direct Current):**
  - **Source:** Batteries, Solar Panels, and **Power Supplies (Rectifiers)**.
  - **Characteristics:** The current flows in **one direction only**.
  - **Why DC?** Electronic components (microchips, transistors, LEDs, PLCs) require a steady flow of electrons in one direction to operate.



## 1.2 The Goal of this Unit

The primary objective of **Rectification** is to convert an Alternating Current (AC) voltage into a Direct Current (DC) voltage. This is done using a device called a **Rectifier**.

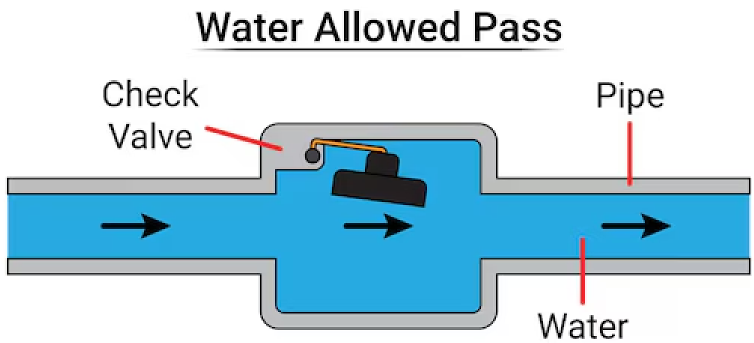
> Student Note:
> * Rectifier: Converts AC → DC.
> * Inverter: Converts DC → AC.
> * Transformer: Changes AC Voltage levels (Step Up/Down)5.

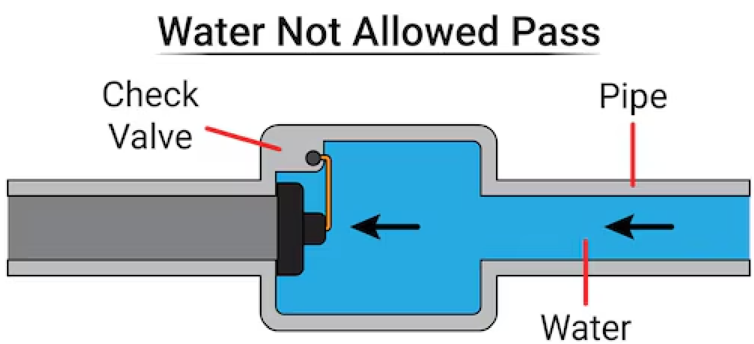
# Module 2: The Semiconductor Diode

## 2.1 The "One-Way Valve"

The core component of any rectifier is the **Diode**.

- **Analogy:** Think of a diode like a check-valve in a water pipe. It allows water (current) to flow freely in one direction but blocks it completely if it tries to flow backward.




## 2.2 Biasing the Diode

To make a diode work, we apply voltage across its two terminals: the **Anode (+)** and the **Cathode (-)**.

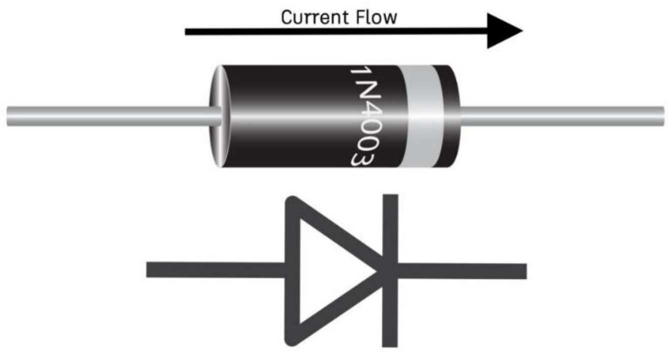
1. **Forward Bias (Switch Closed):**
   - Connect positive voltage to the Anode and negative to the Cathode.
   - **Result:** Current flows. The diode acts like a closed switch.
   - **Voltage Drop:** It "costs" energy to push open the valve. For a Silicon diode, this drop is approx. **0.6V**.

2. **Reverse Bias (Switch Open):**
   - Connect positive voltage to the Cathode and negative to the Anode.

- **Result:** Current is blocked. The diode acts like an open switch (high resistance).
- **Leakage:** A tiny, usually negligible current might flow, but for our purposes, it is zero.

## 2.3 Identifying the Component

- **Symbol:** An arrow pointing against a flat line. The arrow indicates the direction of conventional current flow (Anode → Cathode).
- **Physical:** The cathode is usually marked with a silver or black band on the component body.



# Module 3: Transformers in Power Supplies

## 3.1 Why use a Transformer?

We cannot rectify 230V mains directly for sensitive electronics (which often need 5V, 12V, or 24V). We must first step the voltage down.

## 3.2 Key Principles

- **Mutual Inductance:** Transformers work by inducing voltage from a Primary coil to a Secondary coil via a magnetic field.
- **Isolation:** There is no electrical connection between the input (mains) and output (low voltage). This is a critical safety feature.
- **Frequency:** Transformers only work with AC. If you connect DC to a primary coil, no flux change occurs, and no voltage is induced (and the coil may overheat/burn out).

## 3.3 The Turns Ratio Calculation

The relationship between voltage and turns is linear.

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

- $V_p$ = Primary Voltage
- $V_s$ = Secondary Voltage
- $N_p$ = Primary Turns
- $N_s$ = Secondary Turns

Example:
A transformer has a ratio of 10:1. The primary is 240V. What is the secondary voltage?

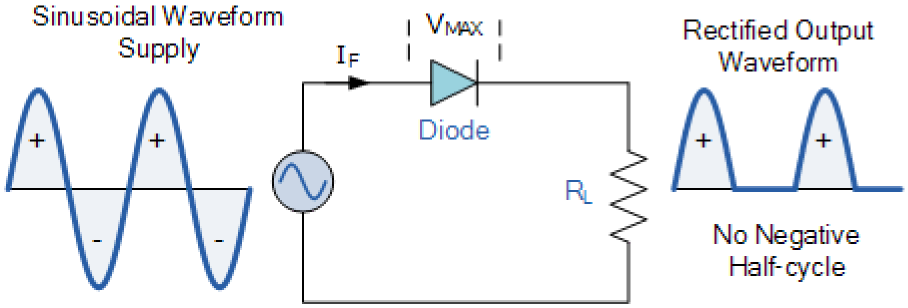
$$V_s = \frac{V_p}{\text{Ratio}} = \frac{240}{10} = 24V$$

# Module 4: Half-Wave Rectification

## 4.1 Construction

The simplest form of rectification.

- **Components:** 1 Diode, 1 Load Resistor.
- **Circuit:** The AC supply is connected in series with a single diode and the load.




## 4.2 Operation

1. **Positive Half-Cycle:** The AC source makes the Anode positive. The diode is **Forward Biased**. Current flows through the load.
2. **Negative Half-Cycle:** The AC source reverses. The Anode becomes negative. The diode is **Reverse Biased**. No current flows.

## 4.3 Output Waveform

The output is a series of positive "pulses" separated by gaps where the negative cycle used to be.

- This is called **Pulsating DC**.
- It is not smooth; it turns on and off 50 times a second.

## 4.4 The Maths: Half-Wave

The average DC value ($V_{avg}$ or $V_{dc}$) is the equivalent steady voltage that would produce the same charge transfer.

- Formula:

$$V_{dc} = \frac{V_{peak}}{\pi} \approx 0.318 \times V_{peak}$$

- **Frequency:**
  - Since we only get one pulse per full AC cycle, the output frequency is the **same** as

    the input frequency.
  - Input: 50Hz → Output: **50Hz**.

### 4.5 Limitations

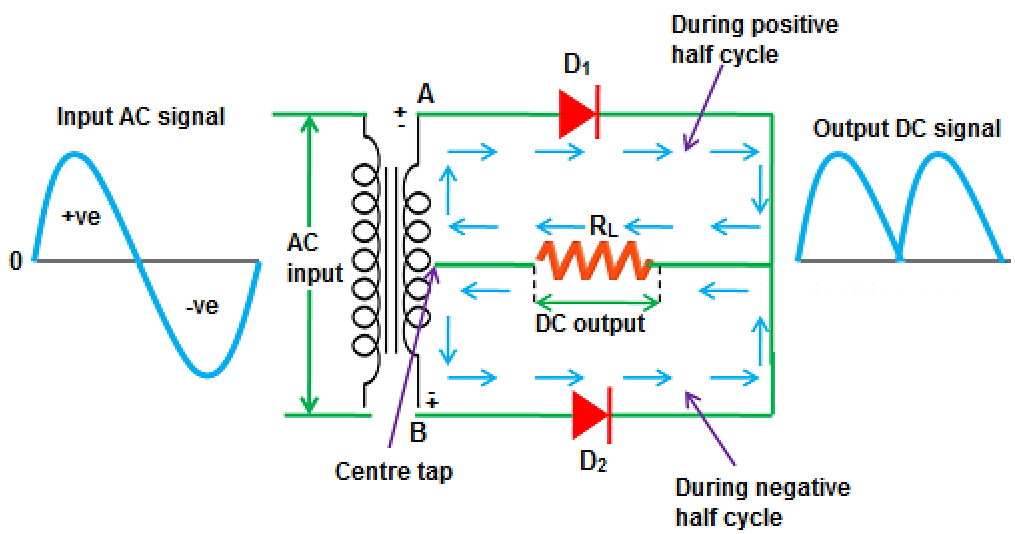
- **Inefficient:** We discard half the available power (the negative cycle).
- **Low Voltage:** The DC output is low (only 31.8% of the peak).
- **Hard to Smooth:** The large "gaps" between pulses require very large capacitors to fill.

## Module 5: Full-Wave Rectification

To improve efficiency, we use **Full-Wave Rectification**. This utilizes *both* the positive and negative halves of the AC cycle to produce output. There are two methods:

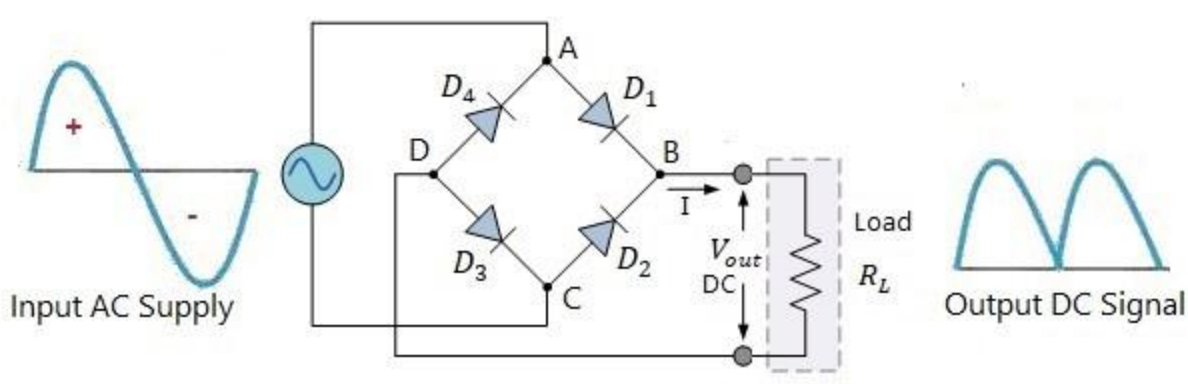
### 5.1 Method A: Centre-Tapped Transformer

- **Components:** 2 Diodes, Centre-Tapped Transformer.
- **Operation:**
  - The transformer splits the AC into two phases, $180^\circ$ out of phase.
  - **Cycle 1:** Top of transformer is positive. Diode 1 conducts.
  - **Cycle 2:** Bottom of transformer becomes positive. Diode 2 conducts.
- **Result:** Current flows through the load in the same direction during both half-cycles.




### 5.2 Method B: The Bridge Rectifier (Industry Standard)

- **Components:** 4 Diodes arranged in a "diamond" bridge configuration.
- **Operation:**
  - **Positive Half-Cycle:** Current flows through **D1 and D3** (Load receives current).
  - **Negative Half-Cycle:** Current flows through **D2 and D4** (Load receives current in the same direction).
- **Waveform:** Identical to the Centre-Tapped version. The output is a continuous chain of pulses with no gaps.




## 5.3 The Maths: Full-Wave

Because we fill the gaps, the average voltage doubles compared to the half-wave.

- Formula:

$$V_{dc} = \frac{2 \times V_{peak}}{\pi} \approx 0.637 \times V_{peak}$$

- **Frequency (Ripple):**
  - We now have two pulses for every one AC input cycle.
  - Input: 50Hz → Output: **100Hz** (Frequency Doubles).

## 5.4 Comparison Table

| **Feature** | **Half-Wave** | **Full-Wave (Bridge)** |
|---|---|---|
| **Diodes** | 1 | 4 |
| **Output Waveform** | Gaps between pulses | Continuous pulses |
| $V_{dc}$ **(Average)** | $0.318 \times V_{peak}$ | $0.637 \times V_{peak}$ |
| **Ripple Frequency** | $1 \times f_{in}$ (50Hz) | $2 \times f_{in}$ (100Hz) |
| **Efficiency** | Low | High |

# Module 6: Smoothing and Filtering

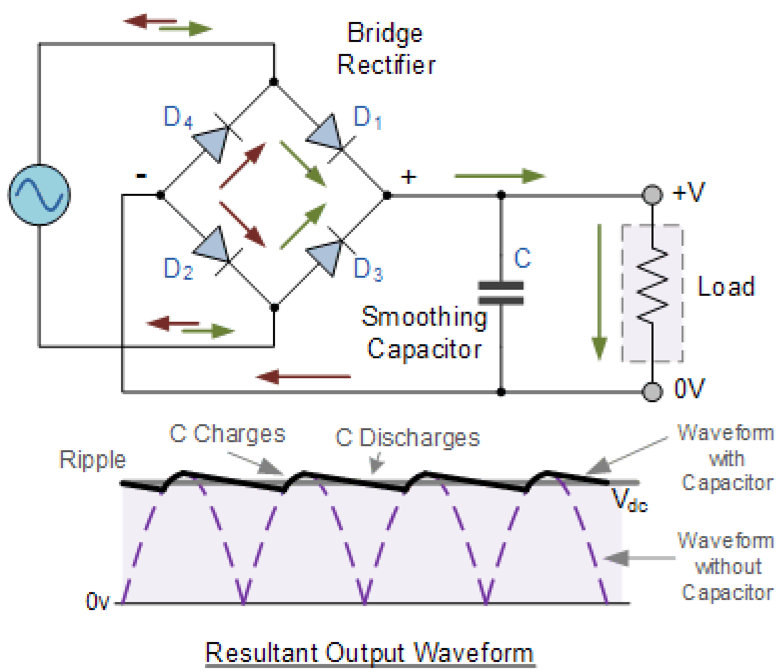
## 6.1 The Problem

The output from a rectifier (Full or Half Wave) is **pulsating DC**. It rises to peak voltage and drops to zero. Electronics (like your phone or a PLC) need **smooth DC** (like a straight line).

## 6.2 The Solution: The Capacitor

We connect a capacitor in **Parallel** with the load resistor.

- **The Reservoir Effect:**
  1. When the voltage from the rectifier rises, it charges the capacitor (fills the bucket).
  2. When the rectifier voltage drops (between pulses), the capacitor discharges its stored energy into the load (bucket trickles out).
  3. This prevents the voltage from dropping to zero.




## 6.3 Ripple Voltage

Even with a capacitor, the voltage isn't perfectly flat. It rises slightly as it charges and drops slightly as it discharges. This variation is called **Ripple Voltage**.

- **Large Capacitor:** Less Ripple (Smoother).
- **Small Capacitor:** More Ripple.
- **Heavy Load (Low Resistance):** Drains capacitor faster → More Ripple.

# Module 7: Voltage Regulation (Zener Diodes)

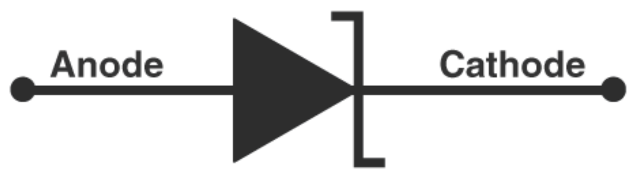
## 7.1 Purpose of Regulation

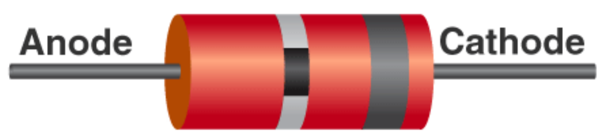
Even with smoothing, the DC voltage can change if:

1. The mains input fluctuates.
2. The load current changes.
   To fix this, we use a Voltage Regulator.

## 7.2 The Zener Diode

A Zener diode is a special diode designed to operate in **Reverse Breakdown** mode.




- **Normal Diode:** Break down and die if reverse voltage is too high.
- **Zener Diode:** Opens a "pressure relief valve" at a specific voltage (e.g., 5.1V, 12V) and holds the voltage there steady.

## 7.3 Circuit Operation

A Zener diode is connected in **Parallel** with the load, but in **Reverse Bias** (Cathode to Positive).

- It is always paired with a **Series Resistor ($R_s$)**.
- **Function:** If voltage tries to rise above the Zener voltage ($V_z$), the Zener conducts more current, pulling the voltage back down. It acts as a **Voltage Stabiliser**.

## 7.4 Calculating the Series Resistor

You may be asked to calculate the resistor needed to protect the Zener.

$$R_s = \frac{V_{supply} - V_{zener}}{I_{total}}$$

# Module 8: Fault Finding & Practical Testing

## 8.1 Tools

- **Digital Multimeter (DMM):** Used to measure $V_{ac}$, $V_{dc}$, and Resistance.
- **Oscilloscope:** The only tool that lets you **see** the shape of the wave (Sine vs Pulse vs Smooth Line) and measure Peak-to-Peak voltage ($V_{pp}$).

## 8.2 Common Measurements (Exam Watch)

- **RMS vs Peak:**
  - Meters usually read **RMS**.
  - Oscilloscopes show **Peak** or **Peak-to-Peak**.
  - Conversion: $V_{peak} = V_{rms} \times \sqrt{2}$ (approx 1.414).
  - Conversion: $V_{rms} = V_{peak} \times 0.707$.

## 8.3 Troubleshooting

1. **No Output Voltage:** Check Fuse → Check Transformer Primary → Check Diodes.
2. **Blown Fuse:** Likely a **Shorted Diode** (Current flows both ways, causing a short circuit).
3. **Output is Low and "Ripply":** Likely an **Open Capacitor** (Smoothing has failed) or **Open Diode** in a bridge (Bridge has turned into a Half-Wave rectifier).

# Module 9: Key Formulas

## 9.1 Essential Formulas

| **Parameter** | **Formula** |
|---|---|
| **Ohm's Law** | $I = \frac{V}{R}$ |
| **RMS Voltage** | $V_{rms} = 0.707 \times V_{peak}$ |
| **Peak Voltage** | $V_{peak} = 1.414 \times V_{rms}$ |
| $\boldsymbol{V_{dc}}$ **(Half-Wave)** | $0.318 \times V_{peak}$ |
| $\boldsymbol{V_{dc}}$ **(Full-Wave)** | $0.637 \times V_{peak}$ |
| **Power** | $P = V \times I$ |
| **Frequency ($f$)** | $f = \frac{1}{T}$ |