Diodes, Transistors and Tubes

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Basic Atomic Structure

• **Everything** in the Universe is made up of Atoms.

• To explain the behavior of atoms, we can visualize atoms as solar systems.

• The center, or **Nucleus**, of the atom is composed of **Protons** and **Neutrons**.

• In **orbit** around the nucleus are one or more **Electrons**.
Atomic Structure

- **Protons** have a **Positive** charge.
- **Neutrons** are electrically **neutral**.
- **Electrons** have a **Negative** charge.
- Protons and Neutrons are about **1800 times heavier** than Electrons.
Valence Electrons

- Electrons are arranged in several discrete orbits, with a maximum number per orbit.
  - 1\textsuperscript{st} 2 electrons
  - 2\textsuperscript{nd} 8 electrons
  - 3\textsuperscript{rd} 18 electrons
  - 4\textsuperscript{th} 32 electrons
  - 5\textsuperscript{th} 50 electrons

- The electrons in the outermost orbit are called the Valence Electrons.
Atomic Bonds

- **Valence electrons** enable atoms to bond with other atoms.
- **Ionic Bond** – attraction based on oppositely charged ions eg: NaCl (salt).
- **Metallic Bond** – electrons are loosely bound and can move freely among the atoms eg: metals.
- **Covalent Bond** – each atom shares its electrons with other atoms, forming an orderly network called a lattice structure.
Germanium Covalent Bond

Note: Only Valence Electrons shown.

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Conductivity of Materials

• **Conductivity** is a measure of a material’s ability to conduct electricity.

• **Good Conductors** have a large number of free electrons.

• **Insulators** have atomic structures where the electrons are tightly bound, and cannot be used to conduct electricity.
Conductors

• **Metals** are good conductors.
• They include:
  – Copper
  – Aluminum
  – Silver
  – Gold
Insulators

- **Insulators** include:
  - Plastics
  - Rubber
  - Dry Wood
  - Porcelain
  - Dry Air
Semiconductors

- **Between** Conductors and Insulators is another category of materials classified as **Semiconductors**.
- They are *neither* good conductors, *nor* good insulators.
- Semiconductors include **Silicon** and **Germanium**.
Doping Semiconductors

• Ordinarily, semiconductors are poor conductors.
• When certain impurities are added however, their conductivity improves.
• The process of adding impurities is called Doping.
• Depending on the dopant, an extra electron, or a Hole (“missing” electron) can be added to the lattice structure.
Germanium with Indium Doping

Note: Only Valence Electrons shown.
P-Type material

- The absence of an electron creates a “hole”.
- The motion of this hole (Majority Carrier) will support the conduction of electricity, as electrons are displaced to fill the hole.
- Because the conduction of electricity is primarily supported by positive holes, substances like this are called P-Type material.
- There are still some free electrons available for conducting electricity (Minority Carrier).
Conduction with Holes
Electrons (Minority Carriers)
Germanium with Arsenic Doping

Note: Only Valence Electrons shown.

Extra Arsenic Electron
N-Type Material

- Because there are “extra” electrons that are not part of the covalent bonds, conduction of electricity is primarily through the movement of these electrons (Majority Carriers).

- Because electrons have a negative charge, these substances are called N-Type.

- There are still some holes available in N-Type material (Minority Carriers).
P-N Junction

- When P-type and N-type material are placed together, electrons and holes near the boundary recombine.
- This creates a region with negatively charged atoms in the P-type material, and positively charged atoms in the N-type material.
- This is called the Depletion Zone, because there is a lack of holes and electrons.
- It is very thin – approximately 0.01 mm thick.
Junction Barrier

P-Type  

Junction

Depletion Zone

N-Type
Junction Barrier

• It is not possible for electrons to migrate from the N-type material into the P-type material because they are repelled by the negatively charged atoms (called Ions) in the Depletion Zone.

• For this reason, the electric field created by the ions is called the Junction Barrier.
Junction Barrier Potential

• This electric field is small:
  ~ 0.3 volts for germanium
  ~ 0.7 volts for silicon

• Once established, no further current flows across the junction.

• For a current to flow, we must overcome the barrier potential.
Reverse-Biased Junction Barrier

Wider Depletion Zone

Original Depletion Zone

P-Type

N-Type

Ammeter
Forward-Biased Junction Barrier

Narrower Depletion Zone

Original Depletion Zone

P-Type

Ammeter

N-Type

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Diodes

• A PN junction allows current to flow in one direction only.
• This forms a diode.
• Used to rectify AC and demodulate AM transmissions among other things.
Diode Symbol

(a) P-N junction representation

Depletion region

(b) Schematic symbol

Anode

Cathode

Stripe marks cathode

(c) Real component appearance

P-type material

N-type material

Positive

Negative

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Valve Equivalent of Diodes

(a) Flow permitted

(b) Flow prohibited
Biasing

(a) Forward Biased

(b) Reverse Biased
Diode Voltages

Silicon Diode and its V-I Characteristics

Conventional Current Flow

Forward Voltage Drop

Reverse Breakdown Voltage

Leakage Current

Quadrant I Positive Rectification

I

V

Anode (A)

Cathode (K)

P
N
Zener Diode

- Acts as a voltage regulator in power supplies.
- Provides a reference voltage for regulator circuits, but can do it by itself if current requirements are low.

![Zener Diode Diagram](https://www.electroSome.com)
Zener Diodes

Cathode (K) or Anode (A)

Reverse Breakdown Voltage

Forward Current

Reverse Bias

“Zener” Breakdown or Avalanche Region e.g. 7.5v

Constant Voltage

Reverse Current

-Iz

+I_F

Forward Bias

+V

0.7v
Zener Diode Voltage Regulation

D.C. input voltage from rectifier and smoothing circuit

Vin ($V_s$) ---+--- $I_S$ | $R_S$

Zener Diode

$V_{out}$ ($V_Z$) ---+--- $I_L$

$R_L$

$I_Z$
Varactor Diode

- Diode’s capacitance changes as applied voltage changes.
- Used as a smaller/cheaper replacement for variable capacitors in radio circuits.
- Also called varicap or tuning diode.
Light Emitting Diode (LED)

• When forward biased, LEDs emit red, yellow or green light depending on composition of the diode.
Light Emitting Diode (LED)
Diodes in Half Wave Rectifiers

![Diagram of a half-wave rectifier circuit with an AC input waveform and a resultant output waveform.]

AC Input Waveform

Resultant Output Waveform

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Half Wave Rectifier with a Capacitor

![Diagram of a half wave rectifier with a capacitor](image-url)
Checking Diodes

(a) Anode to Cathode

(b) Cathode to Anode
Diode Check Function

[Image of a digital multimeter with a reading of 0.548 VΩ and a diagram of a diode with leads connected to it, labeled "Anode" and "Cathode".]
Questions?
Transistors
What do Transistors do?

• Switch current on and off
  – Computer and digital circuits

• Control current in a continuous manner
  – Amplifiers
  – Control circuits
Transistor—
mighty mite of electronics

Increasingly you hear of a new electronic device—the transistor. Because of growing interest, RCA—a pioneer in transistor development for practical use in electronics—answers some basic questions:

Q: What is a transistor?
A: The transistor consists of a particle of the metal germanium imbedded in a plastic shell about the size of a kernel of corn. It controls electrons in solids in much the same way that the electron tube handles electrons in a vacuum. But transistors are not interchangeable with tubes in the sense that a tube can be removed from a radio or television set and a transistor substituted. New circuits as well as new components are needed.

Q: What is germanium?
A: Germanium is a metal midway between gold and platinum in cost, but a penny or two will buy the amount needed for one transistor. Germanium is one of the basic elements found in coal and certain ores. When painstakingly prepared, it has unusual electrical characteristics which enable a transistor to detect, amplify and oscillate as does an electron tube.

Q: What are the advantages of transistors in electronic instruments?
A: They have no heated filament, require no warm-up, and use little power. They are rugged, shock-resistant and unaffected by dampness. They have long life. These qualities offer great opportunities for the miniaturization, simplification, and refinement of many types of electronic equipment.

Q: What is the present status of transistors?
A: There are a number of types, most still in development. RCA has demonstrated to 200 electronics firms—plus Armed Forces representatives—how transistors could be used in many different applications.

Q: How widely will the transistor be used in the future?
A: To indicate the range of future applications, RCA scientists have demonstrated experimental transistorized amplifiers: phonographs, radio receivers (AM, FM, and automobile), tiny transmitters, electronic computers and a number of television circuits. Because of its physical characteristics, the transistors qualify for use in lightweight, portable instruments.

RCA scientists, research men and engineers, aided by increased laboratory facilities, have intensified their work in the field of transistors. The multiplicity of new applications in both military and commercial fields is being studied. Already the transistor gives evidence that it will greatly extend the base of the electronics art into many new fields of science, commerce and industry. Such pioneering assures finer performance from any product or service trademarked RCA and RCA Victor.

RADIO CORPORATION OF AMERICA
World leader in radio—first in television

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Transistor Construction

- Stack 3 slices of doped material together.
- **PNP** Transistor
  - “P in P” for arrow
- **NPN** Transistor
  - Arrow points out
Bipolar Transistors

“P in P”
Current Flow

Fig. 3--CURRENT FLOW in transistors: NPN (a), and PNP (b).
A small current between the base and the Emitter controls a LARGE current between the Emitter and Collector.
The image shows a diagram of a transistor with the following equation:

\[ I_{\text{collector}} = H_{fe} \times I_{\text{base}} \]
Modern Bipolar Transistor

Collector region near base - Lightly doped (high resistivity) N type Silicon

Emitter
Heavily doped N type Silicon

Base (Very thin) P type Silicon

Metal collector contact
Metal Base contact
Metal emitter contact

Collector
Heavily doped (low resistivity) N type Silicon
Field Effect Transistors

- Uses voltage to control the flow of current.
- Very little current flows through the Gate, so it does not affect the preceding circuit.
- Very high impedance.
Field Effect Transistors

- **Source** – Terminal where the charge carriers enter the channel.
- **Drain** – Terminal where charge carriers exit the channel.
- **Gate** – Electrode that controls the conductance of the channel between the Source and Drain.
Types of FETs

- The **JFET** (Junction Field Effect Transistor) uses a reverse biased P-N junction to separate the gate from the body.
- The **MOSFET** (Metal Oxide Semiconductor Field Effect Transistor) utilizes an insulator (typically SiO$_2$) between the gate and the body.
N and P Channel JFET

N-channel JFET

P-channel JFET
MOSFET

Construction of MOSFET
Pinch-Off Voltage

• The reverse bias voltage that cuts off conduction completely.
Gain

- Gain is an increase in the strength of a signal.
- An electronic circuit that accomplishes this is an Amplifier.
- The process is called Amplification.
- We can amplify voltage, current or power.
The Amplifier

\[ P_{\text{input}} \rightarrow \text{Amplifier} \rightarrow P_{\text{output}} \]
Basic Bipolar Transistor Amplifier

[Diagram of a basic bipolar transistor amplifier with labels for signal input, bias, and output waveforms.]

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Basic FET Amplifier
Audio and RF Amplifiers

• Audio Frequency (AF) Amplifiers work in the audio range.
  – 20 Hz to 20 KHz

• Radio Frequency (RF) Amplifiers work in on higher frequencies.
  – Greater than 20 KHz (in general)
Transistor Characteristics

• Breakdown Voltage – Max voltage that may be safely applied to the electrodes.

• Maximum Voltage – Max operating voltages that may safely be applied to the electrodes. Usually less than Breakdown Voltage, and never greater.
Transistor Characteristics

• Maximum Current – Usually refers to the maximum Collector Current, $I_c$
• Maximum Power – Maximum amount of power the device can shed in terms of heat.
• Heat is the big enemy of most semiconductor devices!
Integrated Circuits

• Electronic circuits built on a small plate, usually silicon.
• Contains transistors, resistors, capacitors, diodes, and sometimes inductors.
• Newest “chips” have billions of transistors!
Cross-Sectional View of the Circuit Shown in (a) When Transformed into a Monolithic Form
Advantages of Integrated Circuits

• Scale – Millions, even billions of discrete components on a single chip.
• Cost – MUCH cheaper than individual components!
• Reliability – Manufacturing process is strictly controlled and chips thoroughly tested before leaving the factory.
Vacuum Tubes

• An electronic device that controls electric current through a vacuum in a sealed container.
• Obsolete now, but still used for some specialized applications.
• Often found in power amplifiers ("Linears").
Edison Effect
Vacuum

Anode

Electrons attracted by positive potential on anode

Free electrons

Heated cathode gives off electrons

Filament supply

Current
The Diode

Directly heated

Anode

Filament

Indirectly heated

Anode

Heater

Cathode
The Triode
Using the Triode

SM0VP0

- Anode
- Grid
- Cathode
- Output
- Positive
- Negative
- 200 volts
- 3.5 to 4.5 volts

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Triode Audio Amplifier
Grid Bias

• If we make the grid sufficiently negative, all electrons will be repelled, and none will get through to the Anode.
• This is called cut-off.
• That voltage value is called the cut-off bias.
Comparison – Transistors and Tubes

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<td><strong>Control</strong></td>
<td>Base</td>
<td>Gate</td>
<td>Control Grid</td>
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</table>
The Tetrode
The Pentode

Cloud of electrons

Glass Envelope

Cathode

Control Grid

Screen Grid

Suppressor Grid

Anode

SM0YPO
Inside a miniature tube (this is a pentode)
Questions?