Welcome Back !!

to

Week # 3 of Class

for

EXTRA CLASS Radio License

Chapter 5

Components and Building Blocks

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Chapter 5

Chapter 5 sections

- 5.1 – Semiconductor Devices
  - Materials
  - Junction Diodes, Schottky Barrier Diodes, Zener Diodes, Varactor Diodes
  - Light-Emitting Diodes
  - Bipolar Transistors, Field Effect Transistors, JFET, MOSFET
  - RF Integrated Devices
- 5.2 – Optoelectronics
  - Photoconductivity, Optoelectronics Components, Photovoltaic Cells
- 5.3 Digital Logic
  - Logic Basics
  - Sequential and Synchronous Logic
  - Logic Families

Chapter 5

The discovery of semiconductor material
(1904 -primitive cat's whisker detector, but largely in1947 is when the transistor invented)

- Resulted in many new components
- Miniaturized electronics
- Made entire new communications modes possible

We'll start with some basics of how semiconductors work before jumping into all the modern devices.

Semiconductor Devices 5.1

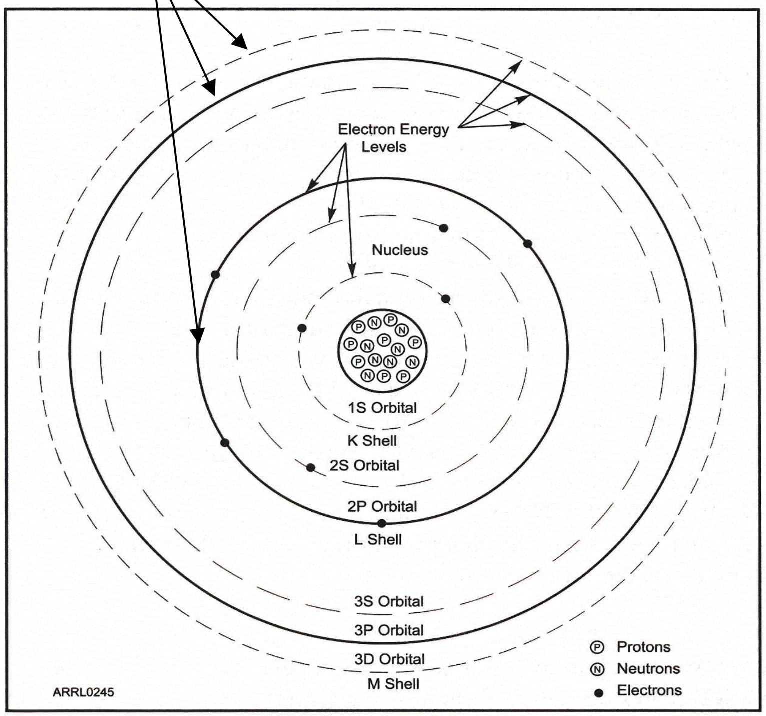
Materials

Pg: 5-1

A little background information to get us started (later on in the License Manual)

Electrons in orbital shells

- Atomic Structure.
  - Nucleus (Protons & Neutrons)
  - Electrons (Orbit in the shell)
    - Orbits the Nucleus (Shells of electrons).
    - Valence shell is the outer most shell.

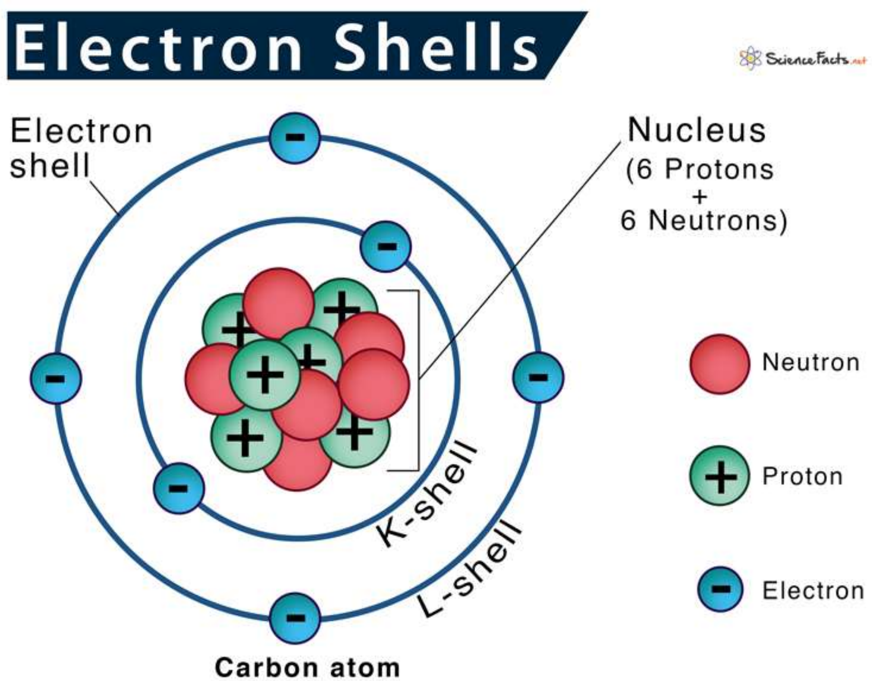


Semiconductor Devices 5.1

Materials

Electrons in outer shell are called ***valence* electrons**.

These electrons participate in forming chemical bonds and determine an element's chemical properties and reactivity. Atoms with a full outer shell, like noble gases, are chemically stable and less reactive, while those with incomplete outer shells will readily gain, lose, or share valence electrons to achieve stability.



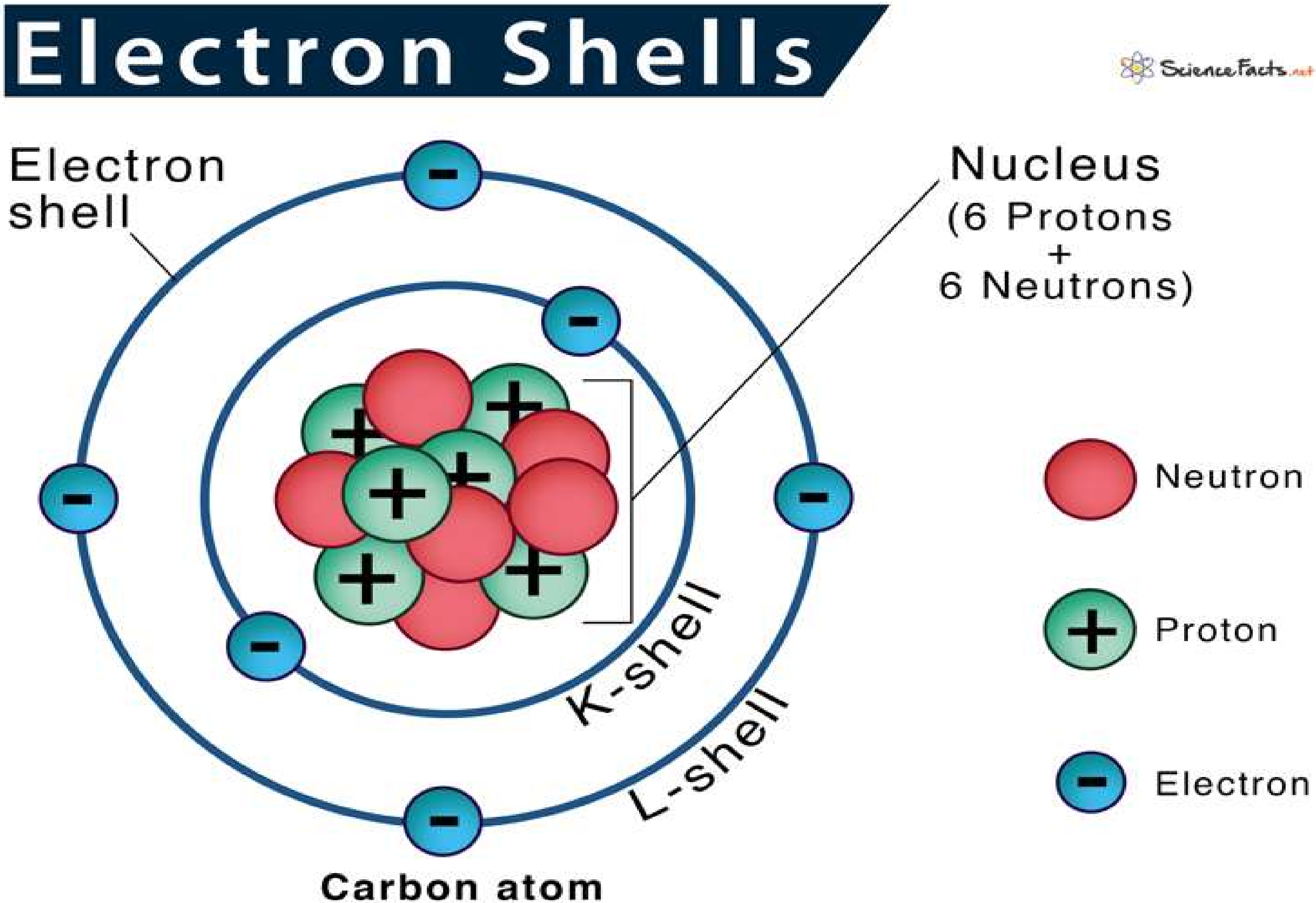
Atoms want to have their outer shell of electrons filled.

Atoms can have 2, 8, 18, 32 or 50 electrons when their valence shell is filled.

Atoms can share valence electrons with other atoms to fill their outer shell.

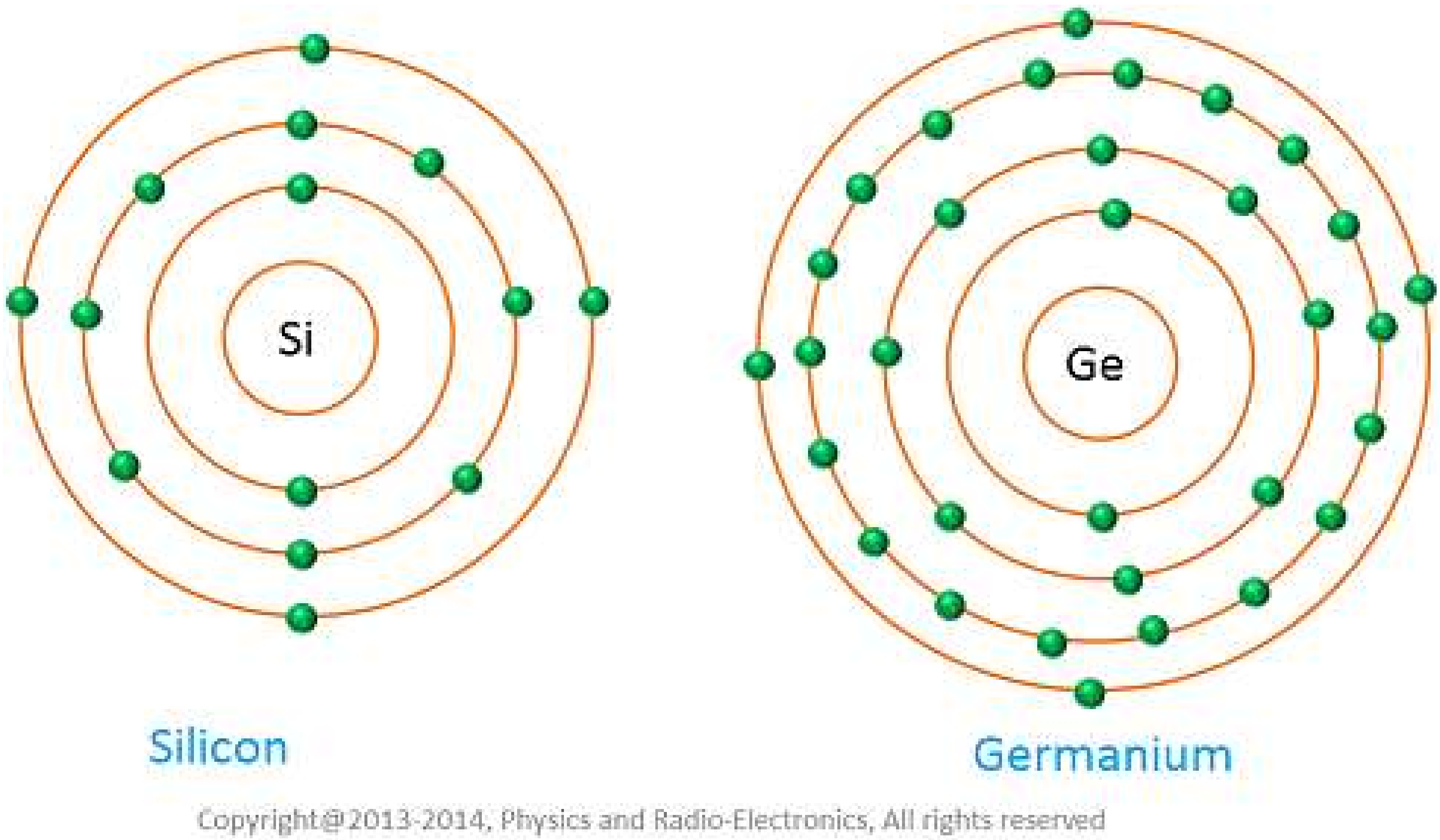
Semiconductor Devices 5.1

Materials



Semiconductor Devices 5.1

Materials



Semiconductor Devices 5.1

Materials

Pg: 5-1

- Atoms that arrange themselves into a regular pattern by sharing electrons form *crystals.*
- Atoms with **fewer** than 4 valence electrons are normally **conductors (metals)**.
- Atoms with **more** than 4 valence electrons are normally **non-conductors.**
- Atoms with **exactly 4** valence electrons are normally ***semi-conductors*** (they are neither good conductors or good insulators).

  - **Silicon** (Has **4** shareable electrons in it's valence band)
  - **Germanium** (Has **4** shareable electrons in it's valence band)
    - They do not make "good" conductors or insulators, so are called *semi-conductors*
  - Under the right conditions, both **can be made to act as conductors or insulators.**

Semiconductor Devices 5.1

Materials

Pg: 5-2

- To control the electrical characteristics of semiconductors, **atoms of <u>another</u> material are added to silicon or germanium crystals through a controlled process**
    - This process is called <u>"doping"</u>
    - This produces a material that is no longer <u>pure</u> silicon or pure germanium.
    - We call the added atoms <u>*impurities*</u>

- Doping with atoms that have **either 3 or 5 valence electrons** causes the crystal to become **<u>more conductive</u>**
  (because there is 1 extra or 1 too few electrons in the valence band)

Semiconductor Devices 5.1

Materials Semiconductor N

Pg: 5-2

- Adding an element with **5** valence electrons (called a donor impurity) creates **N**-type material.
- Silicon starts with 4 valence electrons
  + 5 more Arsenic
  = 9 total valence electrons

  One more than 8 makes an "extra
- free electron "free to move around" in the new valence band.
  - Excess free electrons = **N** material
- Typical donor impurities are:
  - Arsenic
  - Antimony
  - Phosphorus

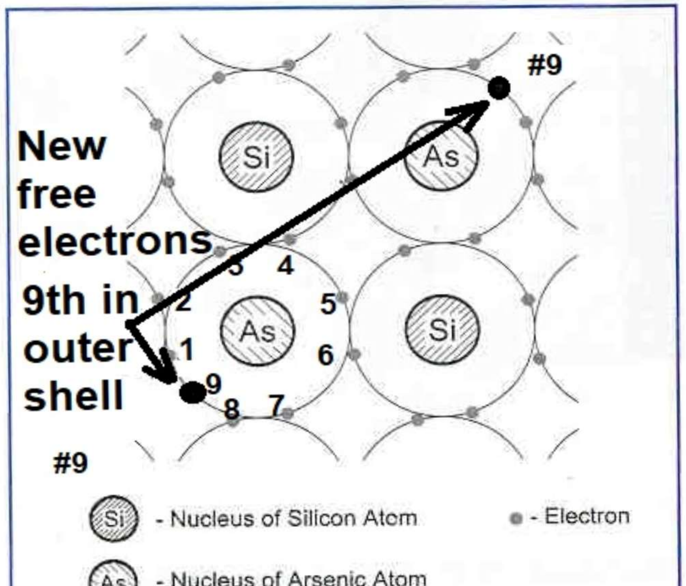


Figure 5.2

Remember: electrons are **N**egative in **N material**

- **Semiconductor materials that contain excess free electrons are N-type.**

Semiconductor Devices 5.1

Materials Semiconductor P

Adding a material with only 3 valence electrons leaves a “HOLE” and is called an *acceptor impurity* creating semiconductor “P” type material.

Silicon starts with 4 valence electrons
+ 3 more Gallium
= 7 total valence electrons
One less than 8 makes a “hole” in the new valence band.

Holes means P material
- Shortage of free electrons leaves holes.

- Typical acceptor impurities:
  - Aluminum
  - Gallium
  - Indium

Remember: **P** punches holes

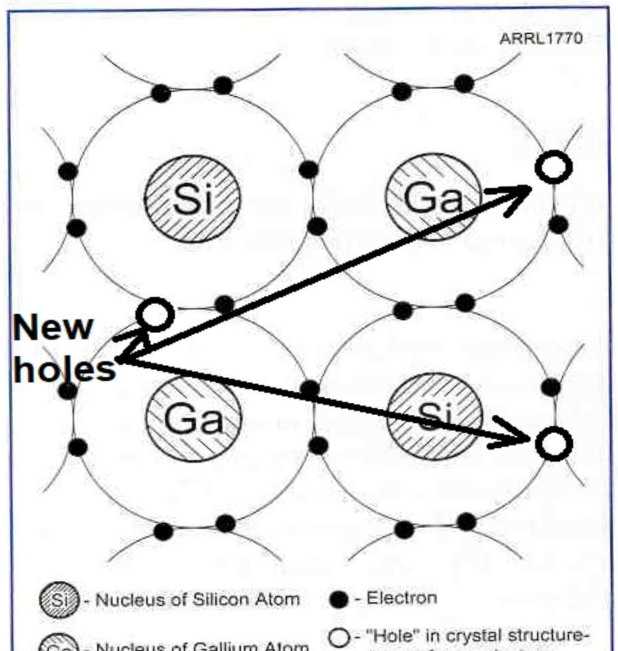


Figure 5.3

- **The name given to an impurity atom that adds holes to a semiconductor crystal structure is called an Acceptor impurity. [E6A04]**

Semiconductor Devices 5.1

Materials – wrap up

Pg: 5-2

Semiconductor material remains neutral after adding atoms – it simply has either excess free electrons, or excess free holes - which external voltages can act upon. Which ever is excess – this is called the "*majority charge carrier*"

- Majority Charge Carriers.
  - N-Type Material = Electron (-)
  - P-Type Material = Hole (+)
- Other semiconductor materials.
  - Gallium-Arsenide (GaAs) for Microwave frequencies.
  - Gallium-Nitride (GaN) – fast switching FETs.

Remember:
N "electrons are **N**egative" in N
P "**p**unch a hole for **P**ositive in P

- The semiconductor material that contains excess holes in the outer shell of electrons is: P-Type semiconductor material.
- **The majority charge carriers in N-type semiconductor material are Free electrons. [E6A02]**

Semiconductor Devices 5.1

Junction Diodes

Pg: 5-3

Diodes you will become acquainted with:

- Junction Diodes (PN Junction Diode)

  Primarily P and N type material.
  Power rectifiers

- Specialized diodes - with unique types of junction
- Zener
- Schottky
- PIN
- Varactor
- Point contact & Hot Carrier
- LEDs

Semiconductor Devices 5.1

Junction Diodes

Pg: 5-3

A ***semiconductor diode*** allows current flow in one direction and resists current flow in the other direction

The junction is between P & N types of material.

The end contacts are:

- Anode
- Cathode

PN Junction

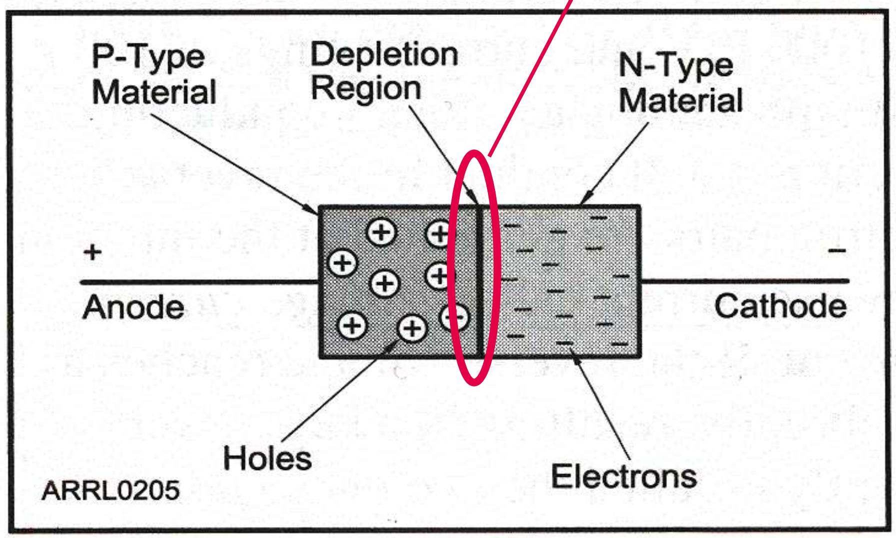


Figure 5-4 — A PN junction consists of P-type and N-type material separated by a thin depletion region in which the majority charge carriers are not present.

Semiconductor Devices 5.1

Junction Diodes

Pg: 5-3

When no voltage is applied, the junction acts as a barrier that prevents carriers from flowing between the layers and no current flows. This barrier to current flow is called the *depletion region*.

A saying: "Opposites Attract"
(also true for electrons)

<ins>If the anode is made positive with respect to the cathode, electrons are attracted towards the anode. Holes are attracted towards the cathode, they both cross the Junction and current flows.</ins>

<ins>**This is called forward *biased*.**</ins>

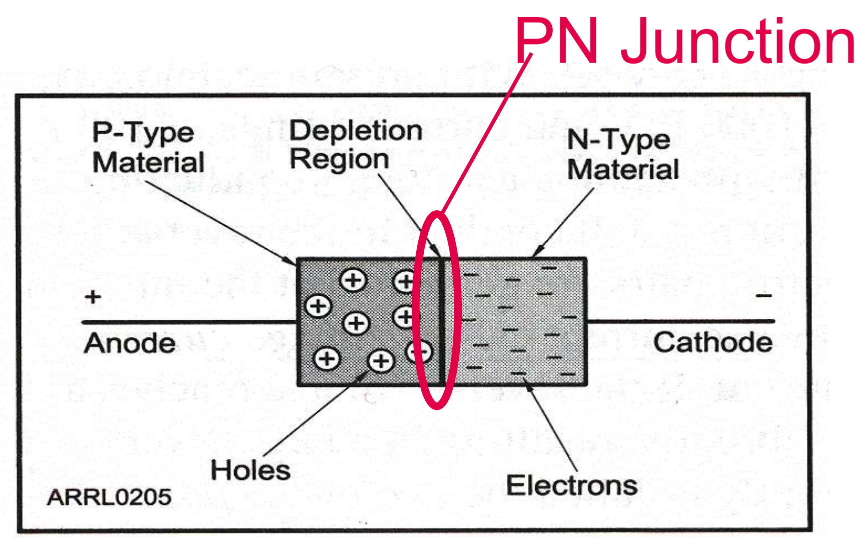


Figure 5-4 — A PN junction consists of P-type and N-type material separated by a thin depletion region in which the majority charge carriers are not present.

If the anode is made negative with respect to the cathode. Electrons and holes are attracted away from the junction enlarging the depletion region.
<ins>**This is called *reverse biased.***</ins>

- **A PN-junction diode does not conduct current when reverse biased because holes in P-type material and electrons in the N-type material are separated by the applied voltage, widening the depletion region. [E6A03]**

Semiconductor Devices 5.1

Junction Diodes

Pg: 5-3

When forward biased:

- <u>Electrons</u> flow from cathode to anode
- Holes flow from anode toward cathode

- Holes move? ...well not really, but that is the effect,and a way one could to think of it. More like “place holders” for electrons.

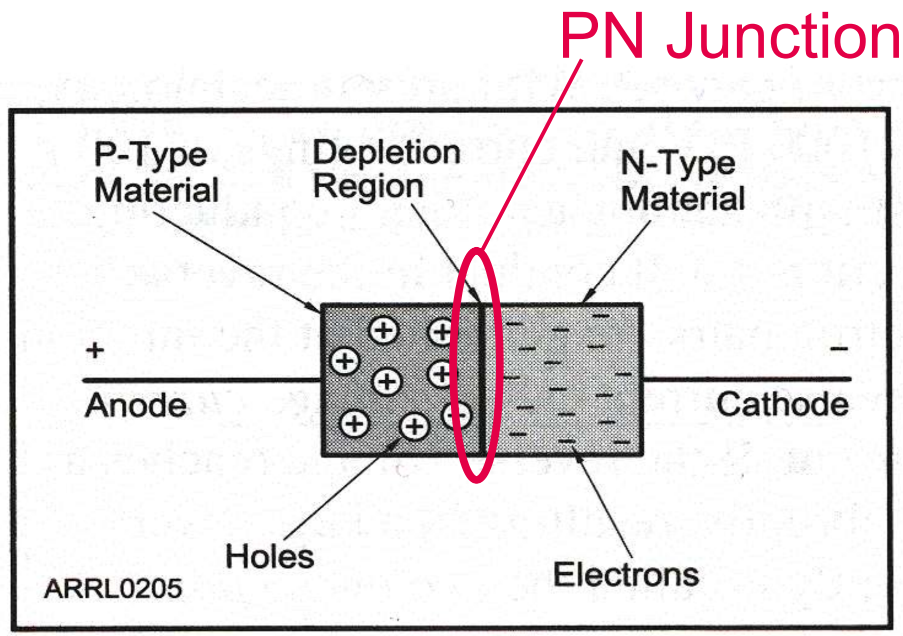
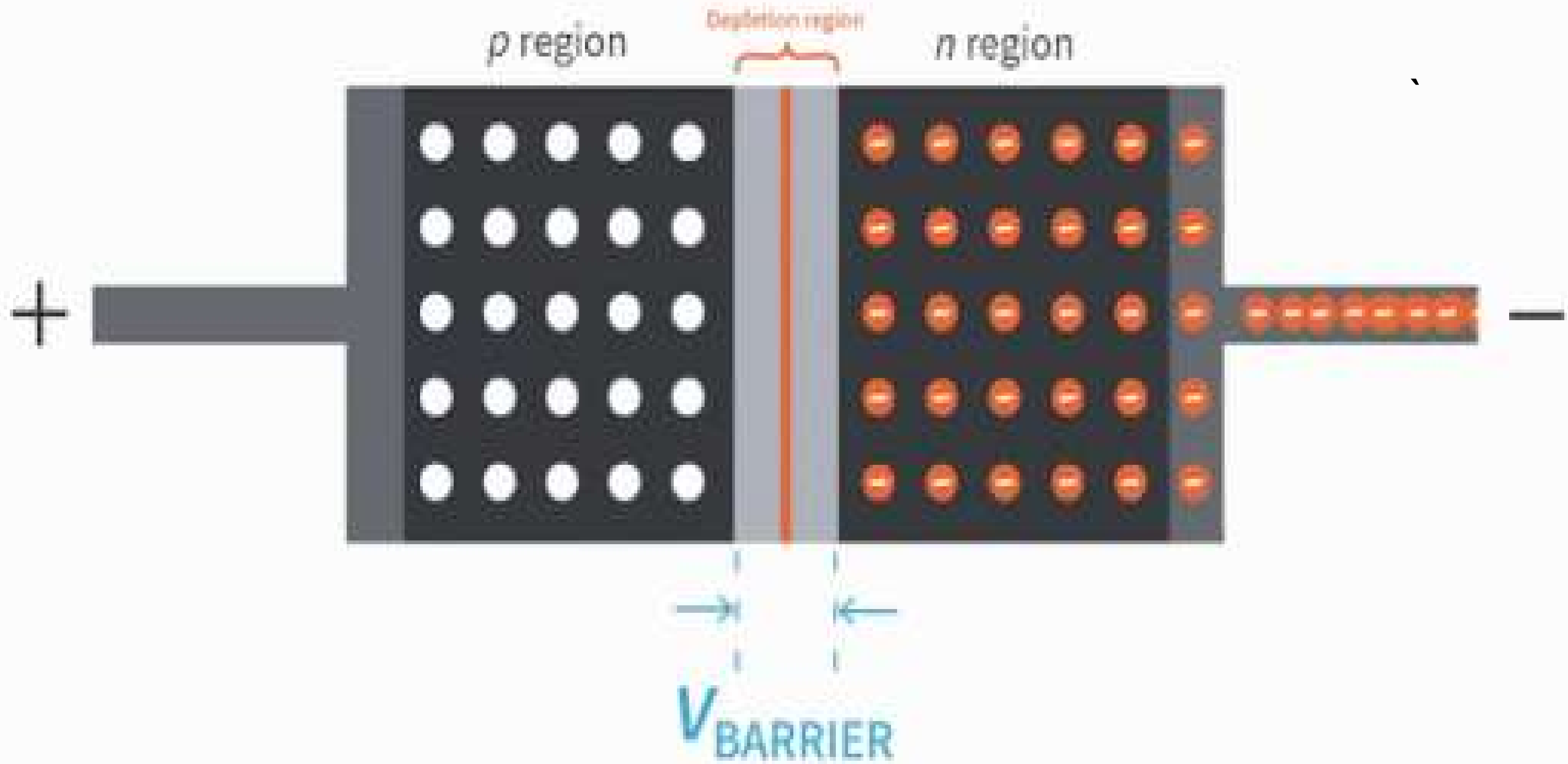


Figure 5-4 — A PN junction consists of P-type and N-type material separated by a thin depletion region in which the majority charge carriers are not present.

Video: Current in a Junction Diode
Representation of forward biased diode with electrons passing from right to left across the depletion region creating a flow of current.

(PDF version of this file will not show the movement – click the link below image to view.)



Link to moving image: https://dwma4bz18k1bd.cloudfront.net/tutorials/Forward-Bias-2.gif

Credit: CircuitBread https://www.circuitbread.com/search?q=How+does+a+diode+work%3F

Semiconductor Devices 5.1

Junction Diodes

What is going on inside of diodes?

How does current flow?

It flows across the junction.

When does current flow?

Negative Electrons are attracted to positive voltage and cross over the junction.

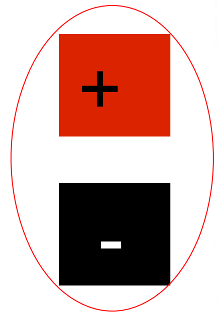
Holes move toward negative voltage.

This is "forward biased"and usually takes 0.6V-0.7V for current to flow.

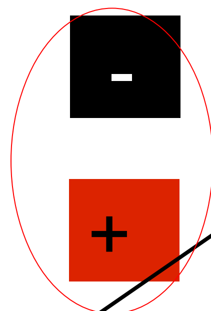
When won't it flow?

If it is "reverse biased".

When the anode is connected to negative and cathode is connected to positive, the device is said to be *reverse biased* *so* the excess electrons in the N-type material are attracted away from the junction toward the positive battery terminal [opposites attract] .



Note the polarities



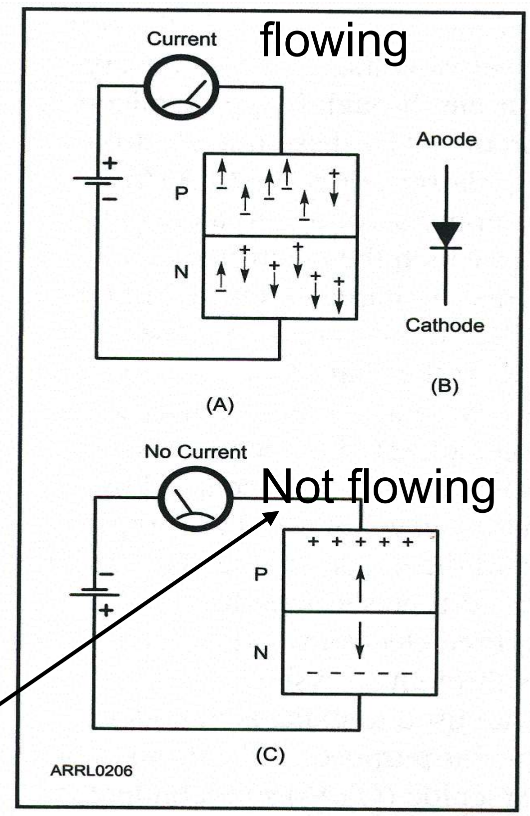


Figure 5-5 — At A, the PN junction is forward biased and conducting. B shows the schematic symbol used to represent a diode, oriented so that its internal structure is the same as in A. Conventional current flows in the direction indicated by the arrowhead in the symbol. At C, the PN junction is reverse biased, so it does not conduct.

Semiconductor Devices 5.1

Junction Diodes

Figure 5-6 shows what typical diodes look like, and their schematic symbol.

There are surface mount packages also.

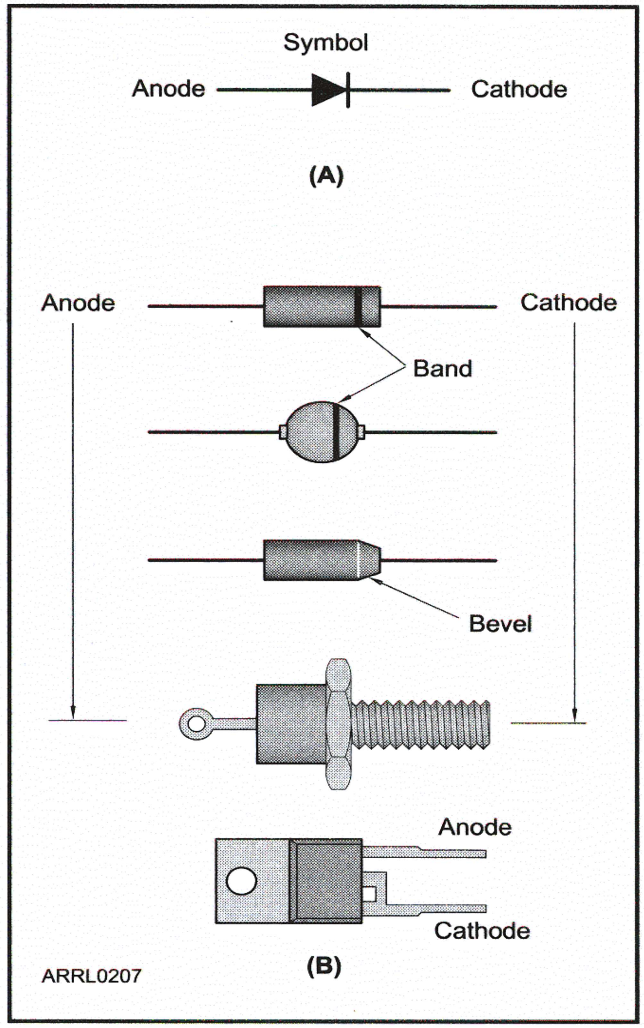


Figure 5-6 — The schematic symbol for a diode is shown at A. Typical diode packages are shown at B.

Semiconductor Devices 5.1

Junction Diode Ratings

Pg: 5-4

Diode Ratings.

- Peak Inverse Voltage (PIV).
  - Avalanche voltage (the reverse voltage level that causes abrupt current rise damaging the diode).
- Maximum Average Forward Current.
  - Is the highest avg current to not exceed the Maximum Allowable Junction Temperature.
- Forward Voltage Drop.
  - Silicon = 0.7 Volts (approx.)
  - Germanium = 0.3 Volts (approx.)

The maximum average forward current is the highest average current that can flow through a diode in the forward direction for it's specified maximum allowable junction temperature.

The failure mechanism when a junction diode fails due to excessive forward current is excessive junction temperature [E6B07]

Excessive reverse voltage can break down the depeletion region of the die.

Semiconductor Devices 5.1

Junction Diode Ratings

Besides the PN Junction, there are other types of *semiconductor diodes*:

- ***Schottky Barrier Diodes***
- ***Point -Contact Diodes***
- ***Hot-Carrier Diodes***
- ***Zener Diodes***
- ***Varactor Diodes***
- ***PIN Diodes***
- ***LED Diodes***

Semiconductor Devices 5.1

The Schottky barrier diode Pg: 5-4

Schottky Barrier Diodes.

- **P-type material replaced with a layer of metal. [E6B08]**
- An important characteristic of a Schottky Barrier Diode compared to an ordinary silicon diode when used as a power supply rectifier it has less forward voltage drop.

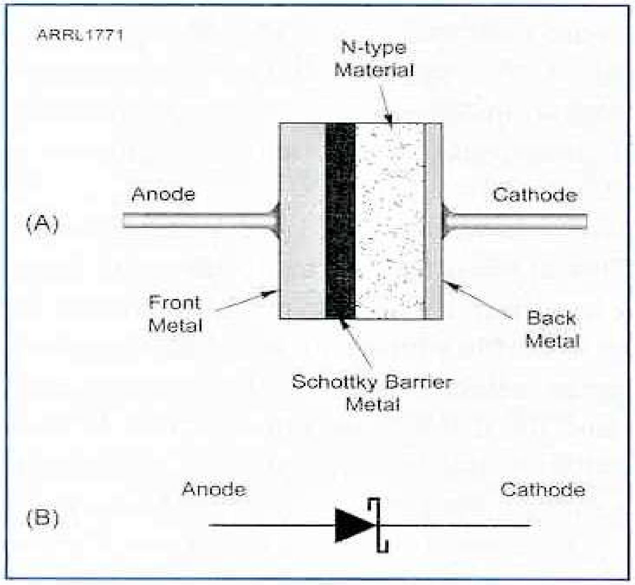


Figure 5.7 — The Schottky barrier diode substitutes a metal layer for the P-type material of a PN-junction. This results in a lower forward voltage drop than for a PN-junction diode. The schematic symbol for a Schottky barrier diode is shown at B.

- **The Schottky barrier diode has similar rectifying properties of an ordinary PN-Junction but with a lower forward voltage than an all semiconductor PN junction. [E6B02]**
- The Schottky diode has a forward voltage is 0.2V to 0.5V compared to 0.6V to 0.7V for a regular silicon PN Junction diode.

Semiconductor Devices 5.1

Diodes

Pg: 5-5

Point-Contact Diodes.

- Very low junction capacitance
- Very low current
- Better for RF detectors at VHF and below than a normal junction diode
- UHF mixers

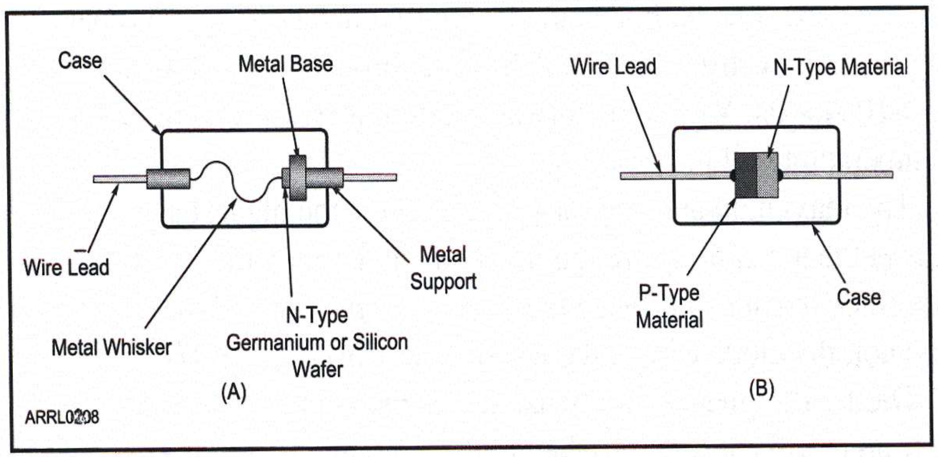


Figure 5-9 — The internal structure of a point-contact diode is shown at A. B shows the internal structure of PN-junction diodes. The schematic symbol for point-contact diodes is the same as junction diodes.

- **Point-contact Schottky diodes are generally used as UHF mixers and as RF detectors at VHF and below. [E6B09]**

Semiconductor Devices 5.1

Diodes

Pg: 5-5

Hot-Carrier Diodes

- Similar to point-contact diode.
- More stable mechanically.
- Lower contact resistance ➔ Higher current capability(“hot”).

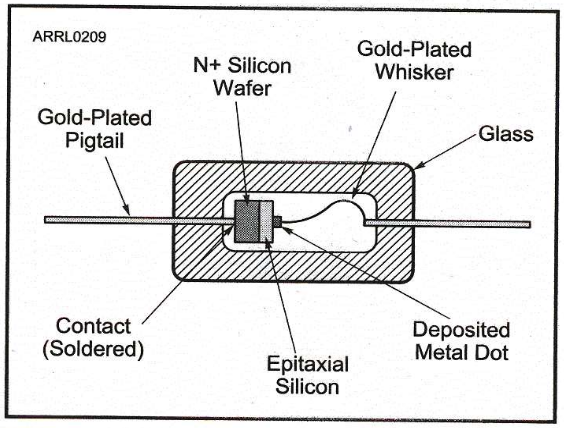
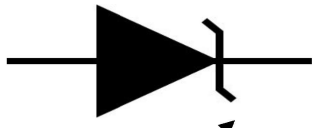


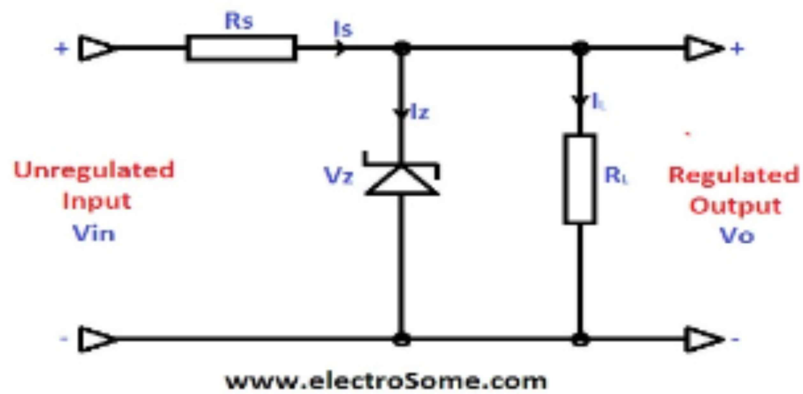
Figure 5-10— This drawing represents the internal structure of a hot-carrier diode. The whisker contact is attached to a metal contact directly on the semiconductor material, improving mechanical and electrical performance over a point-contact diode.

- A common use of hot-carrier diodes are as a VHF / UHF mixer or detector.

Zener Diodes



Sort of looks a bit like a "Z" doesn't it?



- Zener Diodes.
  - Operates with reverse bias.
  - Leakage current rises as reverse voltage rises
  - Operates at it's avalanche voltage
  - Large change in avalanche current results in small change in voltage across the zener.
  - Designed to withstand large avalanche current with proper heat sink.
  - Used as voltage references and voltage regulators
- **Since the current in the avalanche region can change over a wide range while the Voltage stays practically constant, the Zener Diode can be used as a voltage regulator. [E6B01]**

Semiconductor Devices 5.1

Diodes

Pg: 5-5

- Most Transceiver Radios contain numerous zener diodes in their VOLTAGE REGULATORS .
- The circuit below shows how a variety of voltages are obtained starting with 100V.
- ***NOTE – this example is positive voltage referenced, not common in products – ground referenced circuits are more standard.***

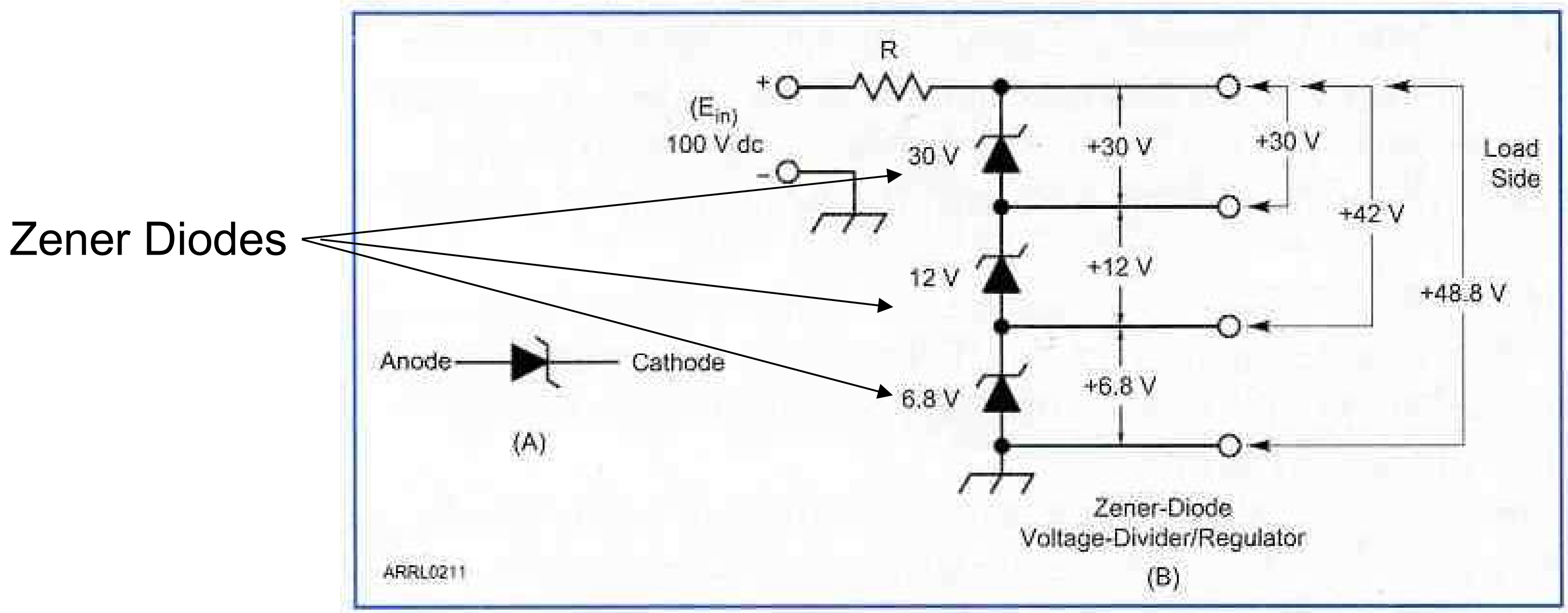


Figure 5.10 — The schematic symbol for a Zener diode is shown at A. B is an example of how Zener diodes are used as voltage regulators.

Semiconductor Devices 5.1

Diodes

Pg: 5-6

Varactor Diodes

- Recall diodes have depletion regions (electrons & holes are backed away from each other until a voltage is applied)
- Separation distance of electrons/holes is similar to separation of capacitor plates.
- Operates with reverse bias.
- Varying the reverse bias changes the separation of carriers outside the depletion region.
- Operates from a few picofarads to >100 pF.
- Variable capacitance and varactor diodes make voltage controlled capacitors.
- **Used for variable-frequency oscillators & for FM modulators and Rx front-end tuning.**

A type of semiconductor device designed for use as a voltage controlled capacitor is the Varactor diode. [E6B04]

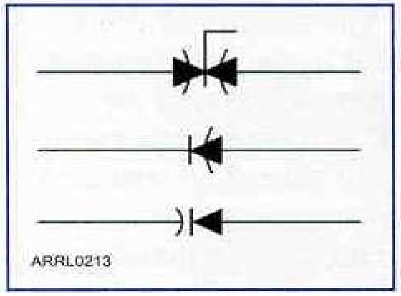


Figure 5.11 — These schematic symbols are commonly used to represent varactor diodes.

Semiconductor Devices 5.1

Diodes

Pg: 5-6 & 7

PIN Diodes

- **P** material **I**ntrinsic material **N** Material
  - The 3rd layer in the middle is undoped (intrinsic) material
  - Forward resistance varies with forward bias voltage.
    - More bias voltage creates lower resistance.
  - Used for RF attenuation & switching.
  - Conduction is carried out by the electrons intrinsic to the normal silicon crystal in the middle **I** Region.
  - The PIN characteristics are determined by the thickness and area of the **I** Region.

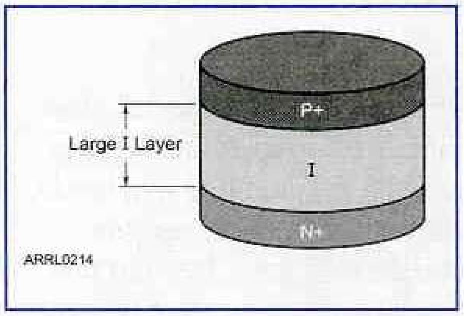


Figure 5.12 — This diagram illustrates the inner structure of a PIN diode. The top and bottom layers are labeled P+ and N+ to indicate very heavy levels of doping impurities are used.

- **PIN Diodes low junction capacitance makes them useful as an <u>RF switch</u> [E6B05]**
- **<u>The attenuation of RF signals by a PIN diode is controlled by changing the forward DC bias current.</u>**

Semiconductor Devices 5.1

PIN Diodes

Pg: 5-7

A Few "For fun" slides

Lets examine how PIN Diodes can be used to switch a radio between 2 different units.

Radio

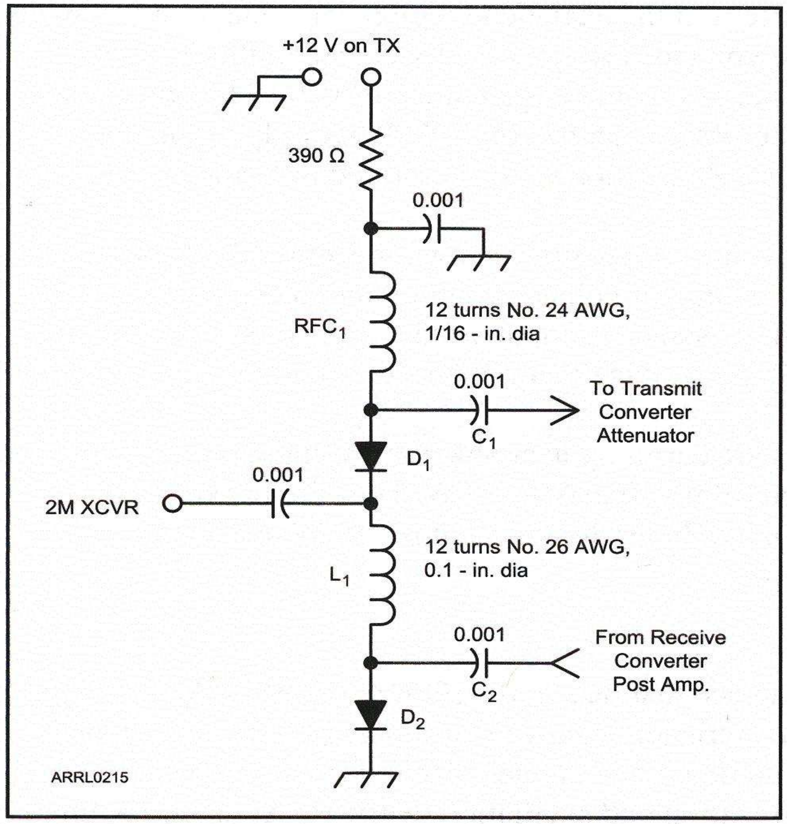


Figure 5-14 — PIN diodes may be used as RF switches. This schematic shows PIN diodes (D1, D2) switching a 2 meter transceiver between a transmit converter and a receive converter. Applying 12 V turns both diodes ON, shorting the receive converter input to ground and connecting the transmit converter to the 2 meter rig. When bias (12 V) is removed, the diodes are both OFF, disconnecting the transmit converter and reconnecting the receive converter.

Unit #1

Unit #2

Semiconductor Devices 5.1

PIN Diodes

Pg: 5-7

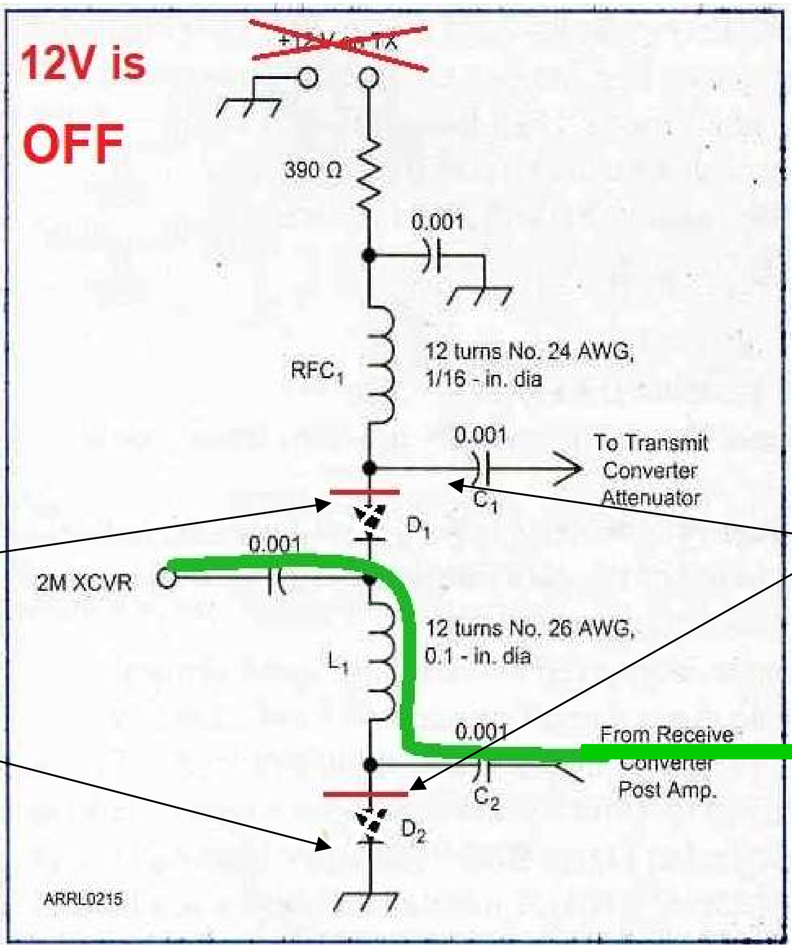
When the 12V DC is
OFF

The PIN Diodes are not biased to conducting.

The Receive Converter Post Amp is connected to the 2M XCVR.

This is because D1 and D2 appear as "open" and not conducting essentially disconnecting that portion of the circuit.

(PIN diodes D1 and D2 are shown grayed out)



Green shows the connected signal path.

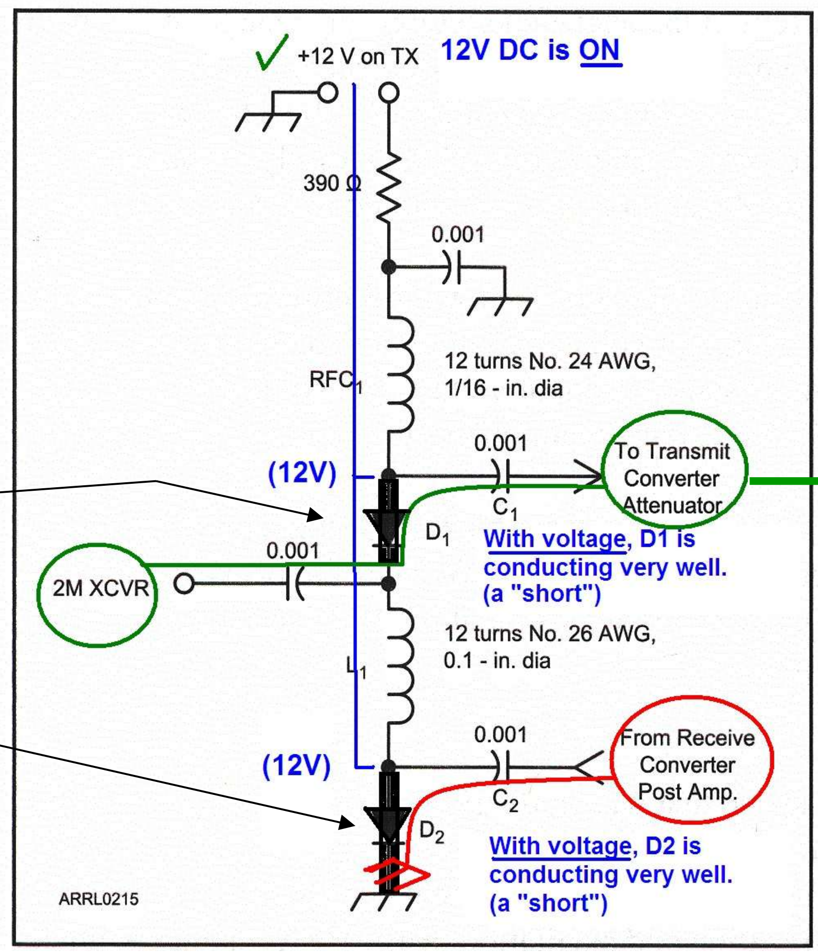
Red shows the open in the circuit created by PIN Diodes.

When 12V DC is ON

PIN diodes D1 and D2 are conducting thus connecting the Transmitter Converter Attenuator to the 2M XCVR.

D1 is completing the path to the 2MTransmit converter,

And D2 is shorting Receive Converter Post Amp to ground.



Green shows the connected signal path.

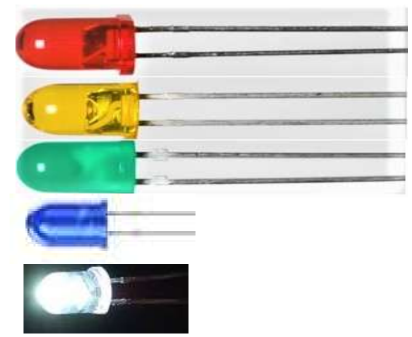
Red shows the shorted to ground path.

Semiconductor Devices 5.1

LEDs

Pg: 5-7 & 8

- **Light-Emitting Diodes (LED)**
  - **LEDs are designed to emit light when they are forward biased so that current passes through their PN Junctions.**
    - Forward voltage drop varies with color.
      - Red : 1.8V ~ 2.4V AlInGaP 626 nm
      - Yellow 1.8V ~ 2.4V AlInGaP 590nm
      - Green: 2.8V ~ 3.8V InGaN 530 nm
      - Blue: 2.8V ~ 2.8V InGaN 470 nm
      - White: Blue LED with Yellow Phosphorous coating



      - 3mm and 5mm LEDs typically operate with 10 mA to 20 mA for full brightness
      - High intensity LEDs for Lighting use more current and are in a variety packages.

  - **The schematic symbol of an LED and typical case style is shown in Fig 5-14**

Semiconductor Devices 5.1

Bipolar Transistors

Pg: 5-8

Bipolar Transistors.

- **3 doped layers.**
  - N-P-N.
  - P-N-P.
- **3 terminals.**
  - Collector.
  - Base.
  - Emitter

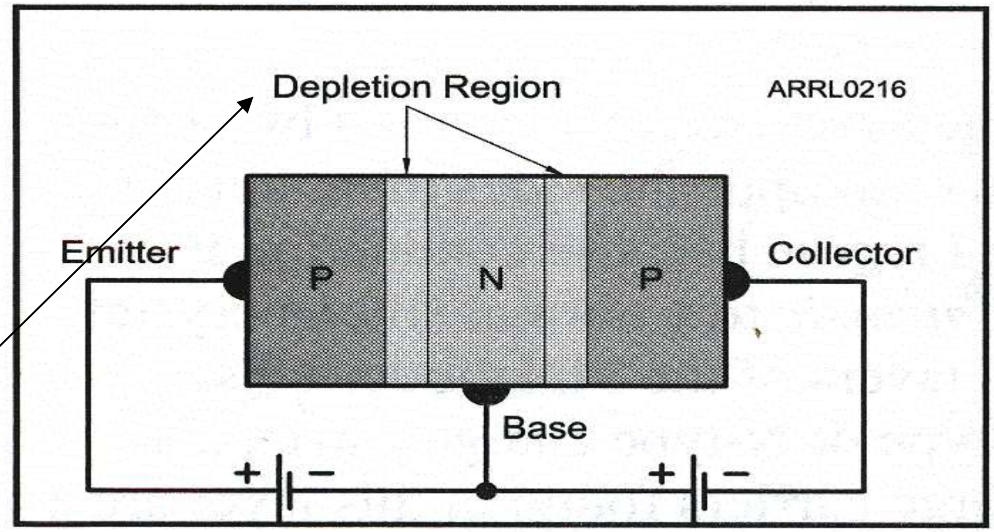


Figure 5-15 — A bipolar junction transistor consists of two layers of N- or P-type material sandwiching a layer of the opposite type of material. This drawing shows the internal structure of a PNP transistor.

- Each of the <u>two junctions</u> has a depletion region.
- **Able to use small currents to control large currents (amplify current)**

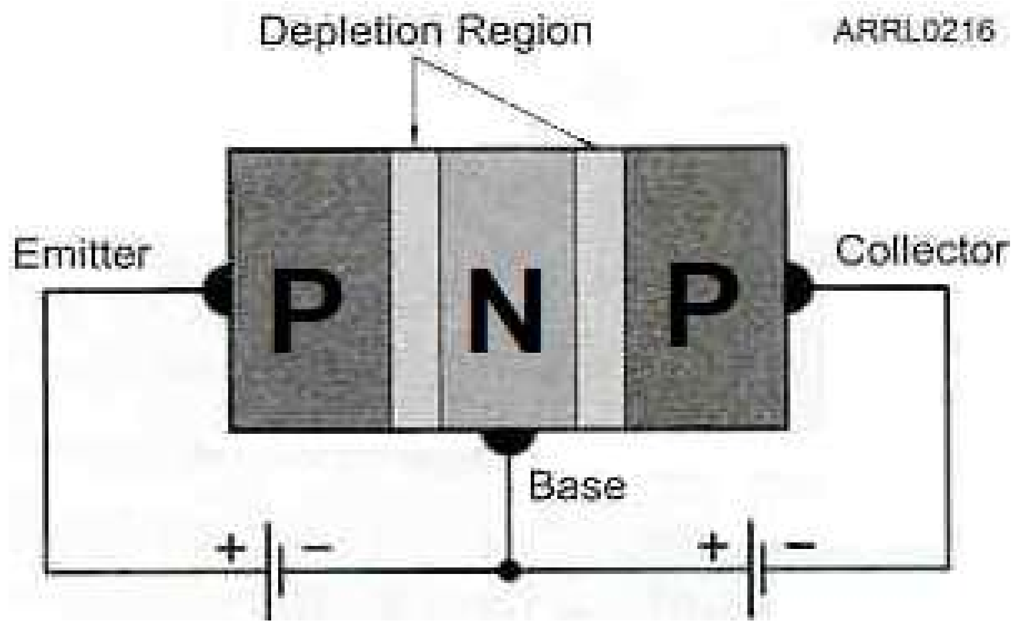
Semiconductor Devices 5.1

Bipolar Transistors

Pg: 5-8

Bipolar Transistors

- Base region is very thin.
- **Low** input impedance.
- **Low** output impedance.



What happens inside a Transistor ?

- Big Picture:
  - If Emitter-Base junction is forward biased and the Collector-base junction is reverse biased
  - Then a small current flowing through base-emitter junction causes a large current to flow from the emitter to the collector.

(details next slide)

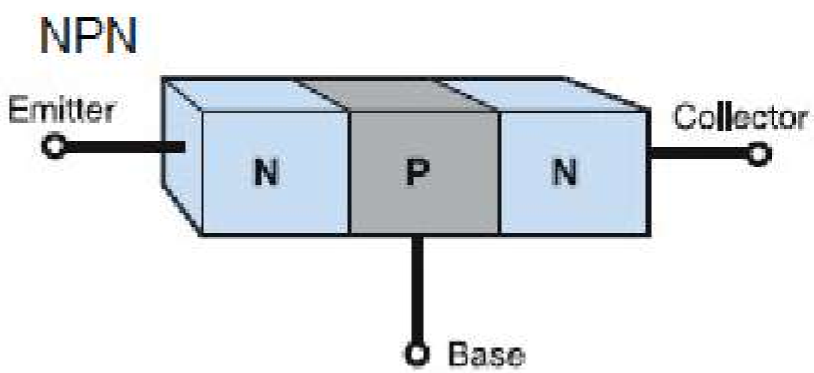
Semiconductor Devices 5.1

Bipolar Transistors

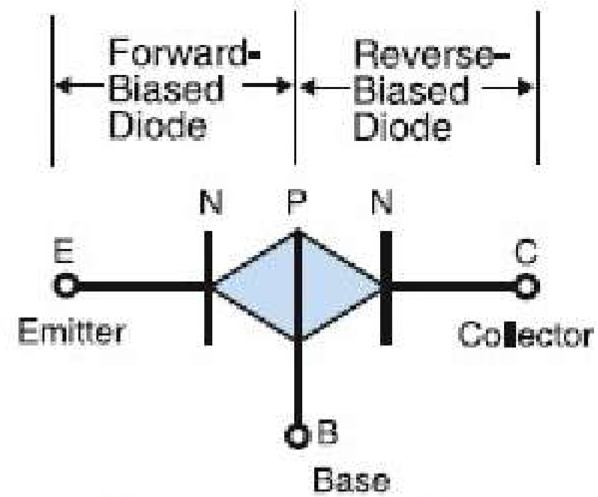
Pg: 5-8

“Junction Diode equivalent”

Example for the NPN



d. Junction Structure



e. Diode Junction Equivalent

Semiconductor Devices 5.1

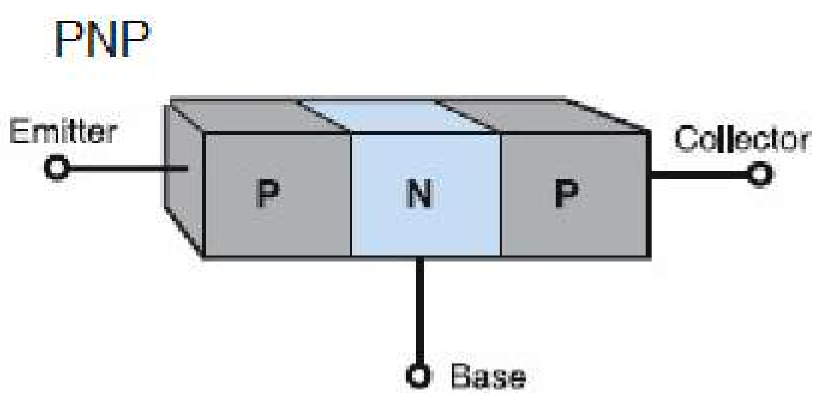
Bipolar Transistors

Pg: 5-8

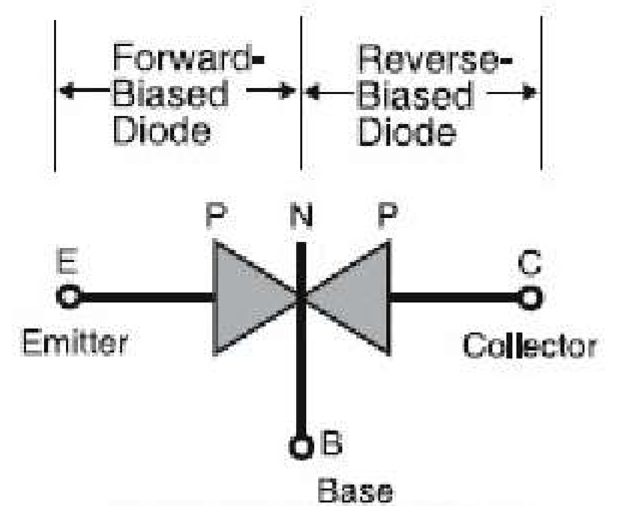
Another way to conceptualize transistors is by using several “Junction Diode equivalents”

Example for the PNP

-



a. Junction Structure

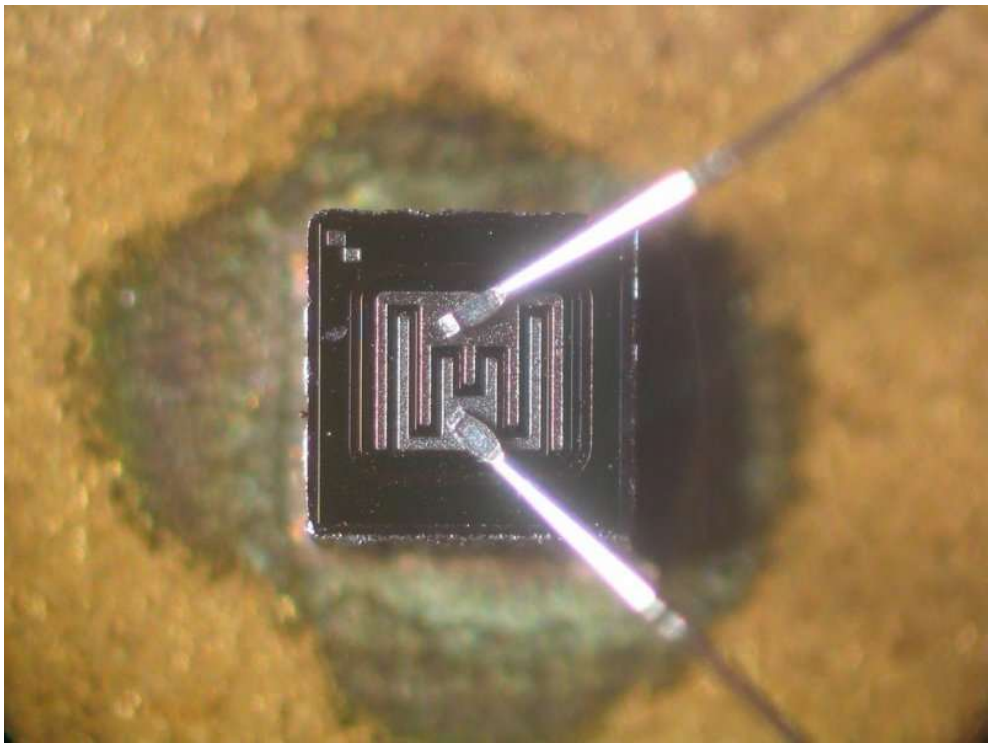


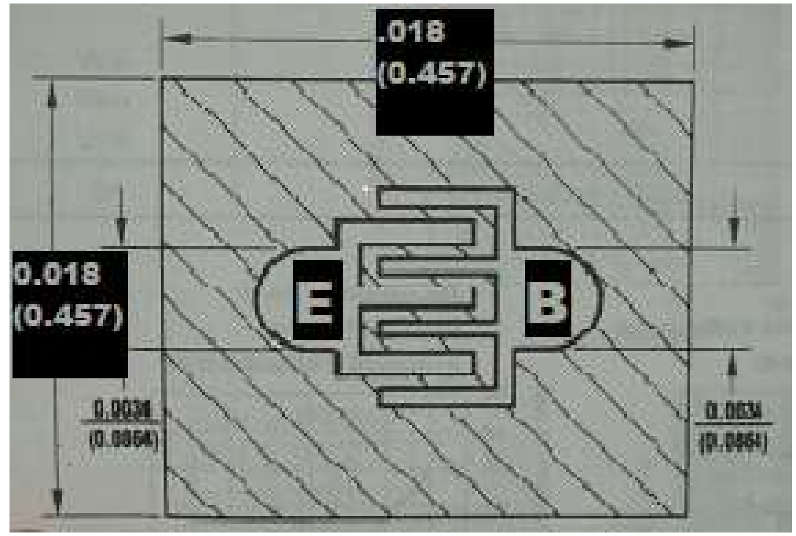
b. Diode Junction "Equivalent"

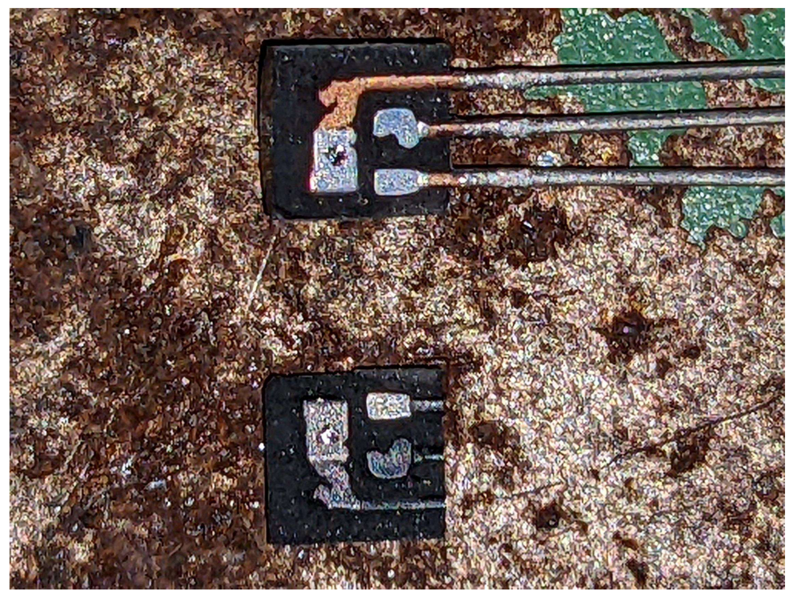
Semiconductor Devices 5.1

Bipolar Transistors

2N3904 – NPN transistor construction.
Emitter – Base – Collector facing flat side.
Collector is the leadframe.



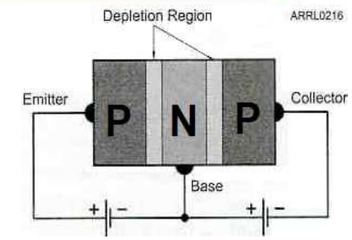




Semiconductor Devices 5.1

Bipolar Transistors

Pg: 5-8



BJT Operation:

- Forward bias voltage across the emitter-base section causes electrons to flow through it from the base to the emitter.
- The excess holes from the emitter -overshoot the thin base- and go into the collector, where they are attracted by the negative supply voltage (creating current flow from the emitter to the collector).
- A BJT(either PNP or NPN) is "biased on" when:

  A forward voltage drop is present across the emitter-base junction and the collector-base junction is reverse biased.

- Whether PNP or NPN it's simply a matter of voltage polarity:
- **For silicon transistors, the emitter to base "on" voltage is 0.6 to 0.7 V from base to emitter for NPN and from emitter to base for PNP. [E6A07]**

Semiconductor Devices 5.1

Bipolar Transistors

Pg: 5-9

Bipolar Transistor characteristics:

– Current gain (β).

– $\beta = I_C/I_B$ Eq. 5.1

Ic = collector current
Ib = Base current

Alpha (α).

– $\alpha = I_C/I_e$ Eq. 5.2

Ic = collector current
Ie = emitter current

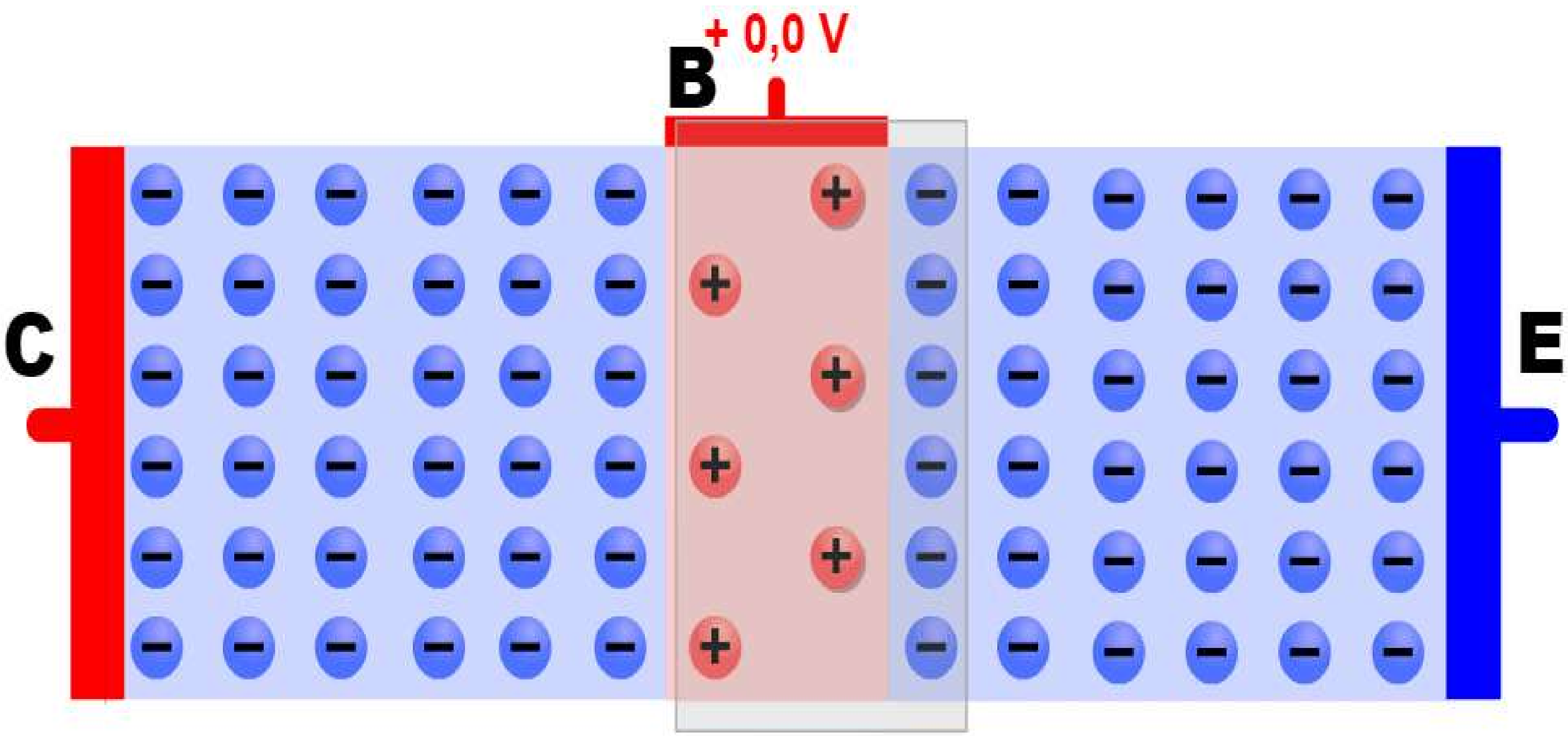
- **The ratio of collector current to base current is called the beta or current gain,** and designated by the Greek symbol β. Common-emitter current gain.
- **Alpha is ratio of collector current to emitter current and designated by the Greek letter α.** This is a key parameter for common-base configurations.

Semiconductor Devices 5.1

Bipolar Transistors

Pg: 5-8

Visualizing the flow of electrons and holes in Bipolar Junction Transistor.
Watch the Base voltage at **B** increase to 0.7 Volts overcoming the barrier region.



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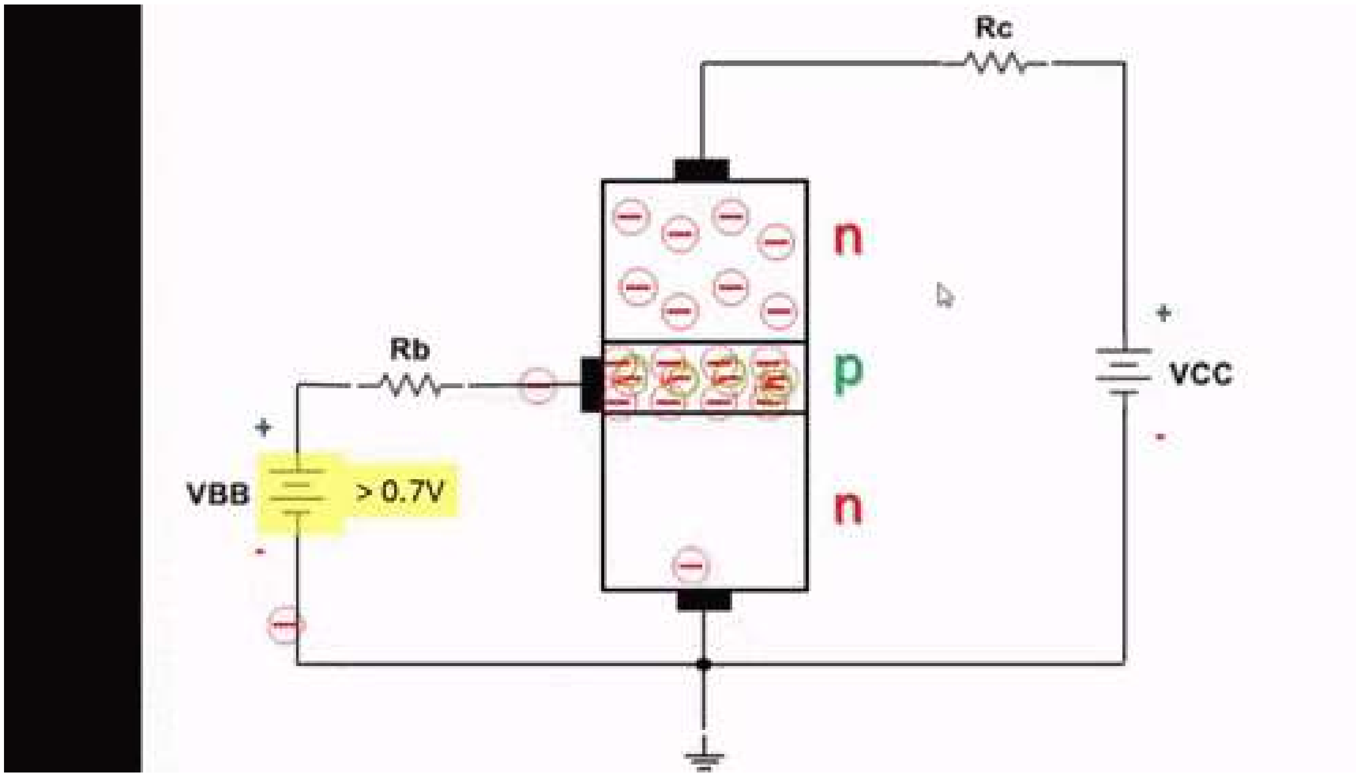
Credit: Webber You @webberyou

Semiconductor Devices 5.1

Bipolar Transistors

Pg: 5-8

Visualizing the flow of electrons and holes in Bipolar Junction Transistor.



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Credit: Best Bjt GIFs | Gfycat

Semiconductor Devices 5.1

Bipolar Transistors

Pg: 5-9

Bipolar Transistors

- Transistor characteristics. Cut-off Frequencies

- Alpha Cut-off Frequency.
  - Frequency at which current gain drops to 0.707 times the value at 1 kHz.
  - Practical upper frequency limit for **common-base amplifier**.
- Beta Cut-off Frequency.
  - Frequency at which current gain drops to 0.707 times the value at 1 kHz.
  - Practical upper frequency limit for **common-emitter amplifier**.

A term that indicates the frequency at which the ground-base current gain of a transistor Has decreased to 0.7 of the gain obtainable at 1 kHz is the Alpha cutoff frequency. [E6A08]

Semiconductor Devices 5.1

Field Effect Transistors

Pg: 5-10

Field-Effect Transistors (FET)

- **Electric field (voltage)** controls the **FET**
- (we just learned that current controls the Bipolar Transistor)

- Two types of FETs:
  - JFET (Junction FET)
  - MOSFET (metal oxide semiconductor)
  - Have high input impedance
  - (we just learned that BJT's are low impedance)

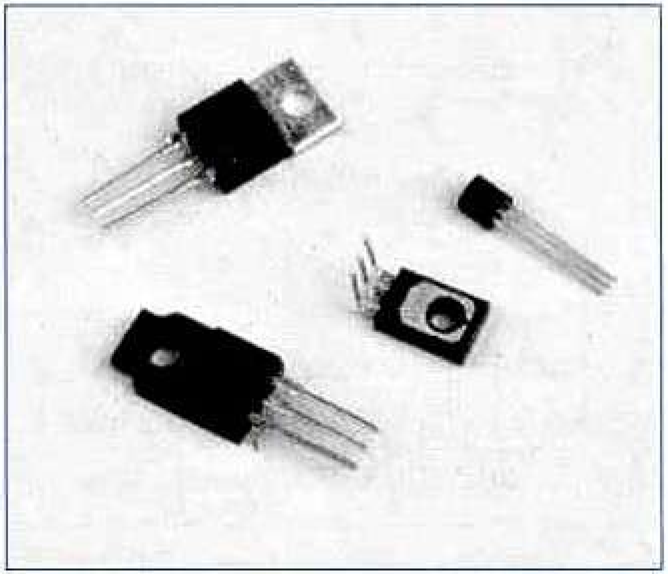


Figure 5.18 — FETs are packaged in cases much like those used for bipolar junction transistors.

Semiconductor Devices 5.1

Field Effect Transistors

Field-Effect Transistors

- Junction Field-Effect Transistor (JFET).
- 3 terminals: Source, Drain and Gate(s)
- A reverse-biased voltage between the gate & source controls the source-drain current.
- Gate terminal is always reverse-biased.
- Very little gate current flow.
- High input impedance.
- Low output impedance.

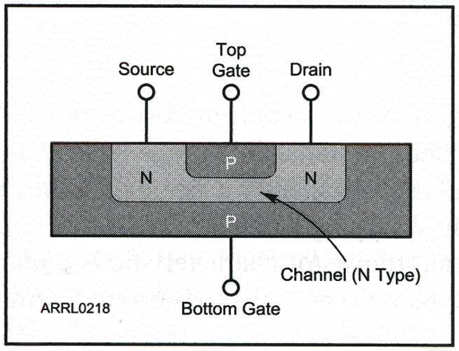


Figure 5-19 — The construction of a junction field-effect transistor (JFET). The top and bottom gate terminals are connected together outside the cross section shown here.

- **The names of the three terminals of field-effect transistor are: Gate, drain, source.**
- **Symbols you should recognize for JFETS are shown in Fig 5-20**
- **A comparison of DC input impedance at the gate of a field-effect transistor compared with input impedance of a bipolar transistor shows An FET has high input impedance; a bipolar transistor has low input impedance. [E6A12]**

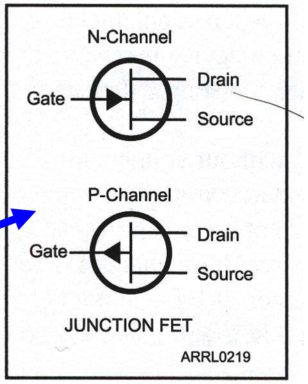


Figure 5-20 — The schematic symbol for an N-channel JFET has an arrow pointing toward the center line that represents the channel. The arrow points away from the channel for a P-channel JFET.

Semiconductor Devices 5.1

Field Effect Transistors

Pg: 5-11

Metal Oxide Semiconductor Field-Effect Transistor (MOSFET)

Gate is insulated by a thin dielectric layer from the source to drain channel.

So very very little gate current flow.

Very high input impedance. ≥10 megohms.

Low output impedance.

Susceptible to damage from static discharge to the thin insulation.

Often have internal zener diodes to protect gate from puncture.

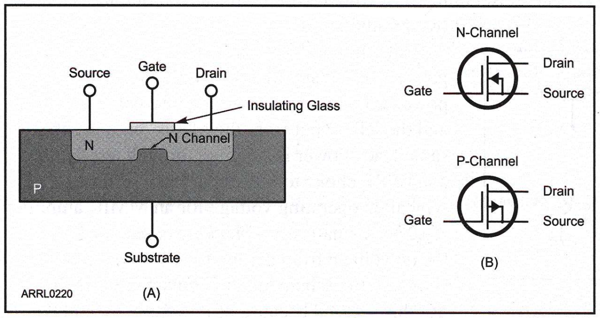
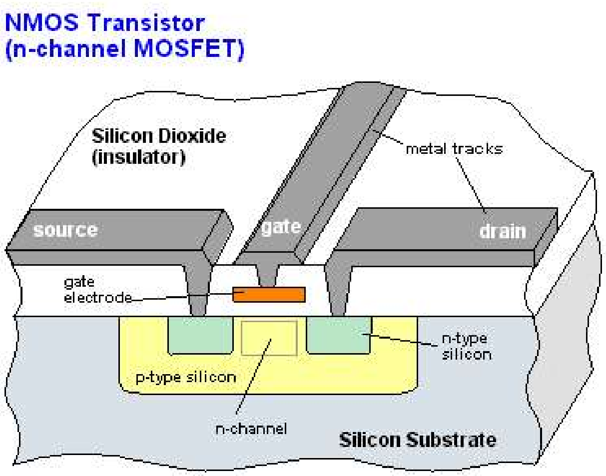
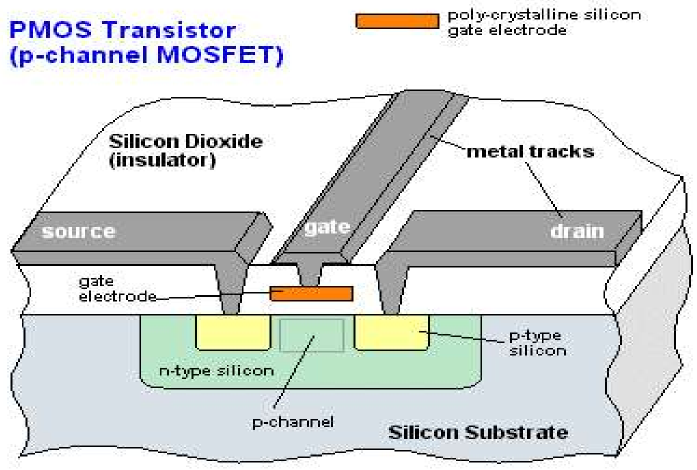


Figure 5-21 — Part A shows the construction of a MOSFET. The schematic symbols (B) for MOSFETs show that the gate terminal is not connected to the channel as in a JFET. As in the JFET symbols, the arrow's direction indicates the type of channel material. These are single-gate MOSFET symbols.





Semiconductor Devices 5.1

Field Effect Transistors

Pg: 5-11

MOSFETS cont.

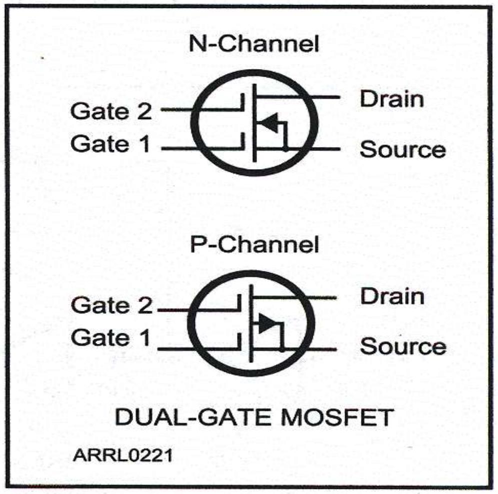


Figure 5-22 — The schematic symbols for N-channel and P-channel dual-gate MOSFETs. Notice that the direction of the arrows again indicates the type of channel material.

Remember:
N: (pointing **IN)**

Remember:
P: (not pointing in)

- **The Schematic Symbols for N-channel and P channel dual-gate MOSFETs are in Fig 5-22. [E6A10 & E6A11]**
- **Most MOSFETS devices have internally connected Zener diodes on the gates to reduce the chance of the gate insulation being punctured by static discharges or excessive voltages. [E6A12]**

Semiconductor Devices 5.1

Field Effect Transistors

Pg: 5-11

- Field Effect Transistors are available with two types of channels.
- **Depletion Mode** less common
  A channel exits, but application of a reverse bias voltage at gate reduces the channel by depleting the charge carriers, so current decreases.

- **Enhancement Mode** (MOSFETS only) more common
  - No channel exits until bias voltage is applied to gate.
  - Channel conducts only with gate to source voltage.
  - The higher the voltage the more current.
    (Not for JFETs, due to their construction without insulated gates, if their gate is forward biased it will conduct like a diode)

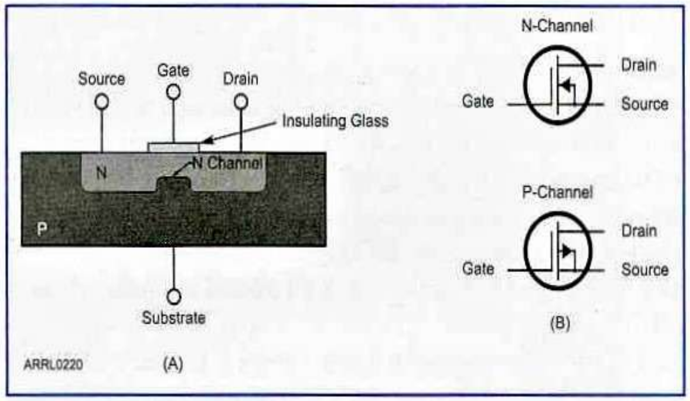
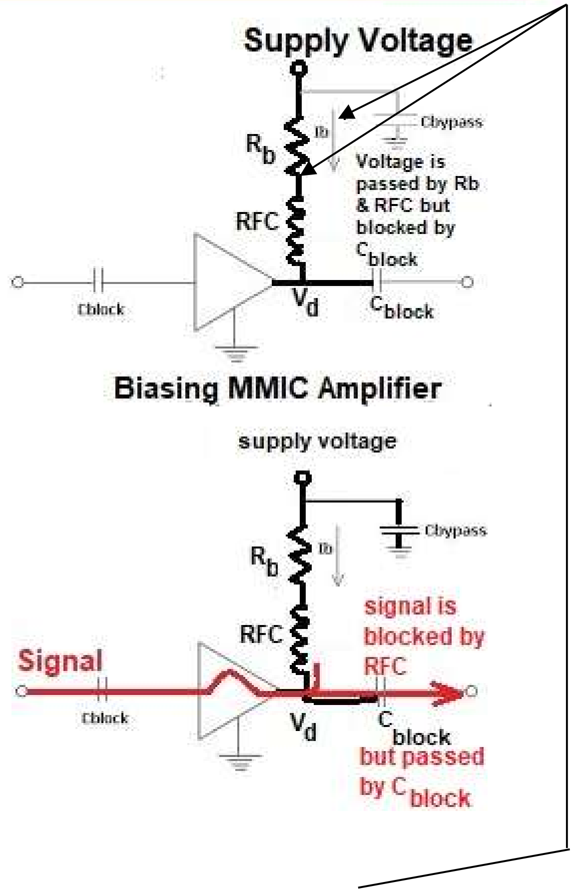


Figure 5.21 — Part A shows the construction of a MOSFET. The schematic symbols (B) for MOSFETs show that the gate terminal is not connected to the channel as in a JFET. As in the JFET symbols, the arrow's direction indicates the type of channel material. These are single-gate MOSFET symbols.

A depletion-mode FET is shown in Fig 5.19 where a channel exists without gate voltage applied. [E6A09]

MMICs:

- Monolithic microwave integrated circuit.
  - Use Gallium arsenide (GaAs), Gallium nitride (GaN) which are faster than silicon and germanium
  - VHF, UHF, microwaves.
  - Typically 50Ω
  - Low Noise Figure
  - Typically 2.0 dB
  - Microstrip Construction
  - Small "pill packages"
  - Used at highest frequencies
  - 4 Leads: Input output and two ground leads
  - No separate power lead ! no separate output lead !
  - Where's the power lead?
    - MMICs don't have a separate power lead
    - DC power, and RF output share the same lead,
    - Powered through a resistor and or an RF choke.



- **Voltage from a power supply normally furnishes the most common type of monolithic microwave integrated circuit through a resistor and / or RF choke connected to the amplifier output lead. [E6E08]**

Semiconductor Devices 5.1

RF Integrated Devices

Pg: 5-13

MMICs:

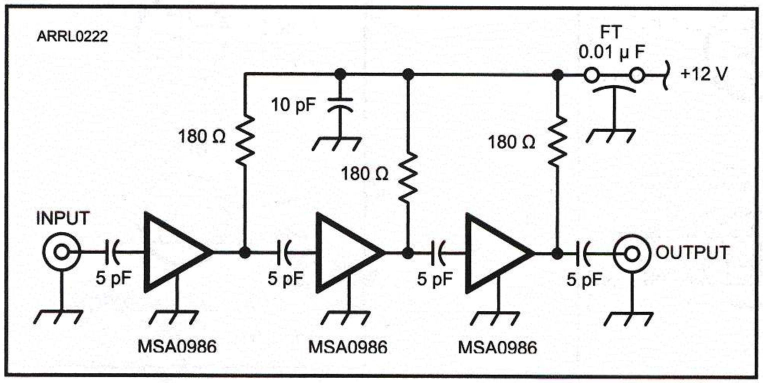


Figure 5-23 — The schematic diagram of the amplifier for UHF and microwave bands shown in Figure 5-24. Three MMIC devices provide a lot of gain without requiring a lot of complex circuitry. Operating power is supplied to the MMICs at their output pins with 5 pF capacitors coupling the RF signal to the next stage while blocking the dc voltage.

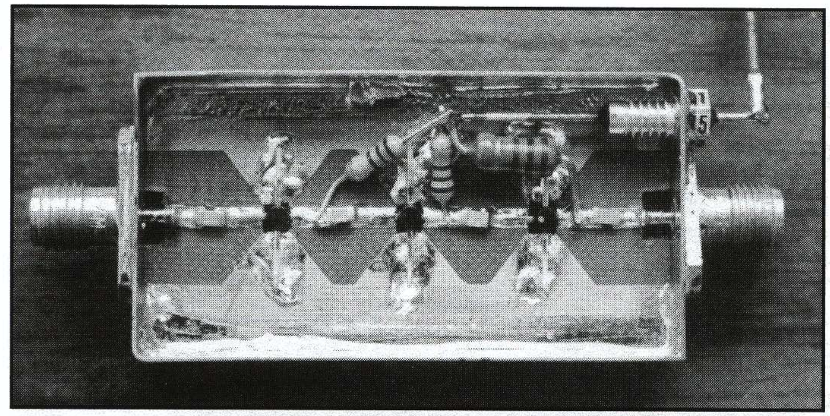


Figure 5-24 — This simple utility amplifier is suitable for low-level amplification on the amateur bands from 903 MHz through 5.7 GHz. The schematic is shown in Figure 5-23. The three MMICs are visible as round, black "pills" in a straight line between the input jack at left and the output jack at right.

- Note that only a few external components are needed for proper operation of MMICs.
- **The MMIC characteristics that make it a popular choice for VHF microwave circuits are controlled gain low noise figure, and constant input and output impedance over the specified frequency range. [E6E06]**
- **Common input and output impedance for MMICs is close to 50Ohms. [E6E04]**
- **MMIC amplifier devices have noise figures in the range of 2.0db or less. [E6E05].**

Semiconductor Devices 5.1

RF Integrated Devices

Pg: 5-13

MMICs:

- Above VHF and UHF, the gain of silicon and germanium devices falls off rapidly because the charge carriers don't move fast enough.
- RF transistors and MMICs made with Gallium Arsinide(GaAs) and Gallium Nitride(GaN)
  - Operate well into the microwave range
  - Are preferred to germanium or silicon who's gain falls off above VHF and UHF.
- **The application in which gallium arsinide is used as a semicondutor material is in microwave circuits. [E6A01]**
- **The higher electron mobility of gallium arsinide is useful for semiconductor devices operating at UHF. [E6E01]**
- **The material that is likely to provide the highest frequency of operation when used in MMICs is Gallium Nitride. [E6E03]**

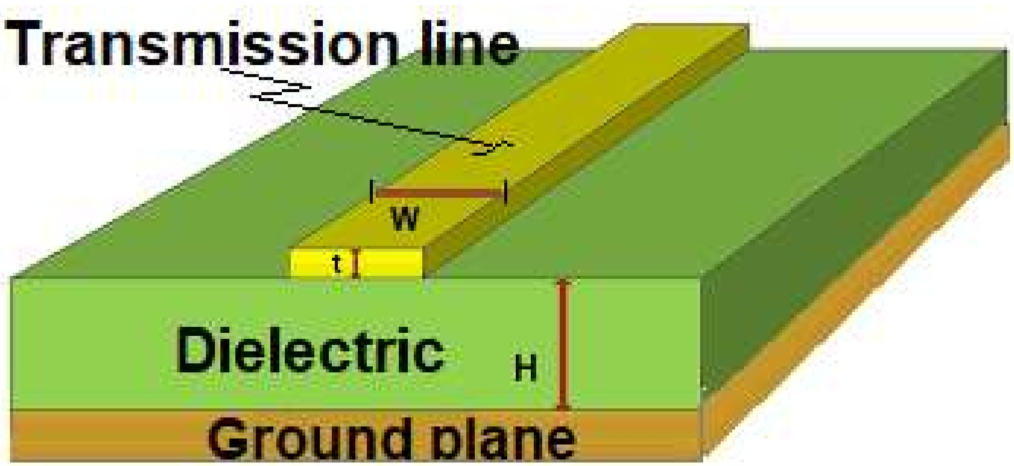
Semiconductor Devices 5.1

RF Integrated Devices

Pg: 5-13

Microstrip:

At microwave frequencies, we use ***microstrip*** construction**.**
Double-sided circuit board material with one side forming a ground plane and precisely sized traces over the the ground plane to form 50 Ohm transmission lines. **[E6E04]**



- **Microstrip is precision printed circuit conductors above a ground plane that provides constant impedance interconnects at microwave frequencies. [E9F05]**
- **Microstrip transmission lines are used to connect MMICs. [E6E07]**

Chapter 5

Pg: 5-14

Chapter 5 sections

- 5.1 – Semiconductor Devices
  - Materials
  - Junction Diodes, Schottky Barrier Diodes, Zener Diodes, Varactor Diodes
  - Light-Emitting Diodes
  - Bipolar Transistors, Field Effect Transistors, JFET, MOSFET
  - RF Integrated Devices
- 5.2 – Optoelectronics
  - Photoconductivity, Optoelectronics Components, Photovoltaic Cells
- 5.3 Digital Logic
  - Logic Basics
  - Sequential and Synchronous Logic
  - Logic Families

Optoelectronics 5.2

Photoconductivity

Pg: 5-15

The diagram of atomic structure again.

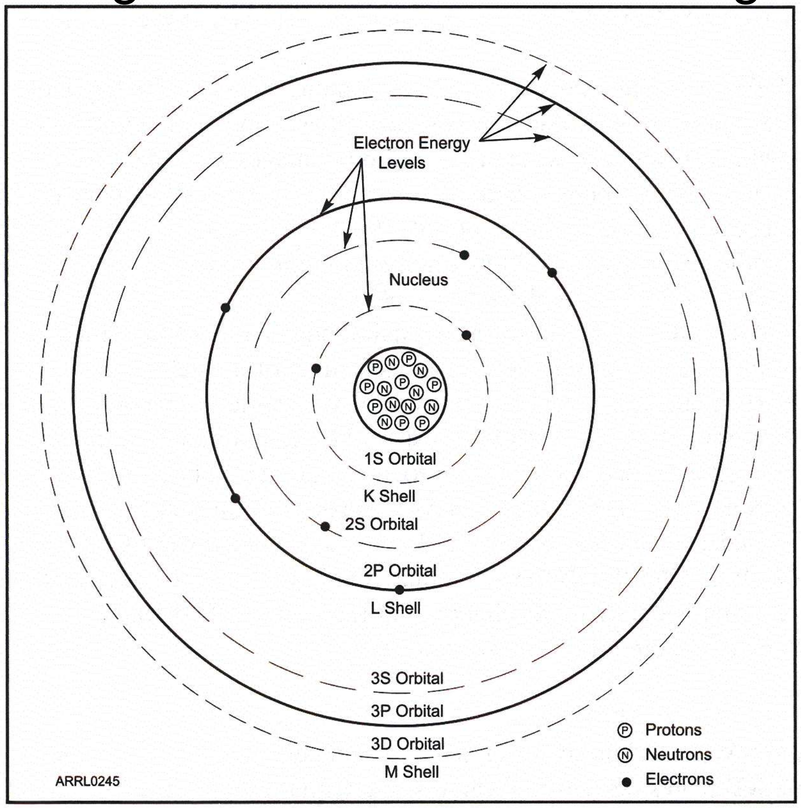


Figure 5.45 — In the structure of an atom, shells of electrons surrounding the nucleus have increasing energy levels with increasing distance from the nucleus. The photoelectric effect is caused by electrons in the outermost shell absorbing a photon of light with sufficient energy to cause them to leave the atom. As free electrons they can flow as current.

- Components that are <u>hybrids of optical and electronic functions</u> are called *optoelectronics.*
- They use semiconductors to perform functions.

- Use optical properties called photoconductivity
- Light interacts with a semiconductor to change its conductivity.

- *Photovoltaic effect:* Light causes current to flow.

Optoelectronics 5.2

Photoconductivity

Pg: 5-16

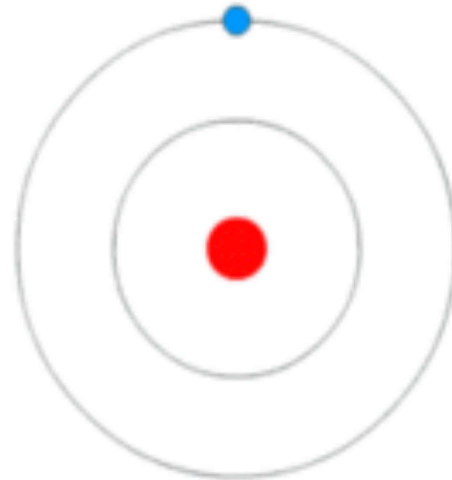
Photoelectric effect.

- **Light striking photosensitive material knocks electrons loose, thereby increasing its conductivity (resistance decreases). [E6F02]**
- Most pronounced for crystalline semiconductors.
  - Cadmium-Sulfide: Visible light.
  - Lead-Sulfide: Infra-red light.
  - All semiconductor junctions exhibit photoelectric effect.

Photoconductive effect.

- The total conductance of a piece of wire may increase and resistance decrease when light shines on the surface.

- **When light shines on a photoconductive material its resistance decreases. [E6F02]**



Emitting a photon & and loosing electron energy
moves to next shell **in.**

Absorbing a photon and gaining electron energy
moves to next shell **out.**

- **The photovoltaic effect of light is to electrical energy. [E6F04]**
- **The materials affected the most by photoconductivity is crystalline semiconductor. [E6F06]**

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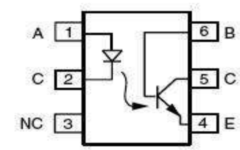
Credit: https://commons.wikimedia.org/wiki/File:Bohr_atom_animation.gif

Optoelectronics 5.2

Optoelectronic Components

Pg: 5-17

Optocoupler or Opto-isolator



- LED & phototransistor in same package
- Very high impedance between light source & phototransistor.
- High degree of isolation between control circuit & power circuit.
- By combining an optocoupler with power transistors, the functions of an electromechanical relay can be implemented by solid state components. Such as a Solid State Relay (SSR: operates faster than mechanical relay).
- The LEDs in most optocouplers are infrared emitters, although some operate in the visible light portion of the electromagnetic spectrum.

- **An optocoupler or optoisolator most common configuration is an LED and phototransistor. [E6F03]**
- **Opto-isolators are often used in conjunction with solid state circuits when switching 120VAC because Opto-isolators provide a very high degree of electrical isolation between a control circuit and the circuit being switched. [E6F08].**
- **A solid state relay is a device that uses semiconductors to implement the functions of an electromechanical relay. [E6F07]**

Optoelectronics 5.2

Optoelectronic Components

Pg: 5-17

Optical shaft encoder.

- Used for VFO knobs & other controls in many modern rigs.
- Using 2 emitters and detectors, allows the speed of rotation to be detected.

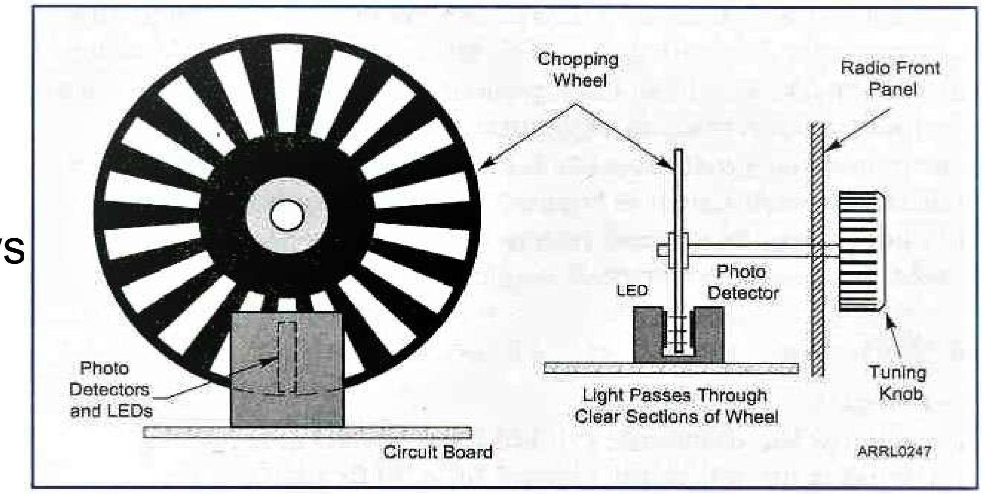


Figure 5.27 — An illustration of the operation of an optical shaft encoder often used on the tuning and control knobs of transceivers.

- The <u>Optical Shaft Encoder</u> is made using an array of emitters, two detectors a microprocessor.

- **An optical shaft encoder detects rotation by interpreting a light source with a patterned wheel. [E6F05]**

Optoelectronics 5.2

Photovoltaic Cells

Pg: 5-18

If sufficient light falls on a P-N junction, free electrons in the N-type material will absorb energy(photons) & flow across the junction into the P-type material.

- Most common material is Silicon.
- Most efficient material is Gallium-Arsenide.
- Fully-illuminated junction of silicon yields about 0.5 VDC.
- Rapidly becoming commercially viable for power generation.

If a circuit is provided between the two sides of the junction the voltage will cause a current to flow. This current represents the conversion of light energy from photons to electrical energy carried by the electrons in the circuit. This is the *photovoltaic effect*.

- **The light energy falling on a photovoltaic cell is absorbed by electrons in the semiconductor material. [E6F01]**
- **The photovoltaic effect is the conversion of light to electrical energy. [E6F04]**

Optoelectronics 5.2

Photovoltaic Cells

Pg: 5-18

Solar Cell
Converting solar energy to electrical current.

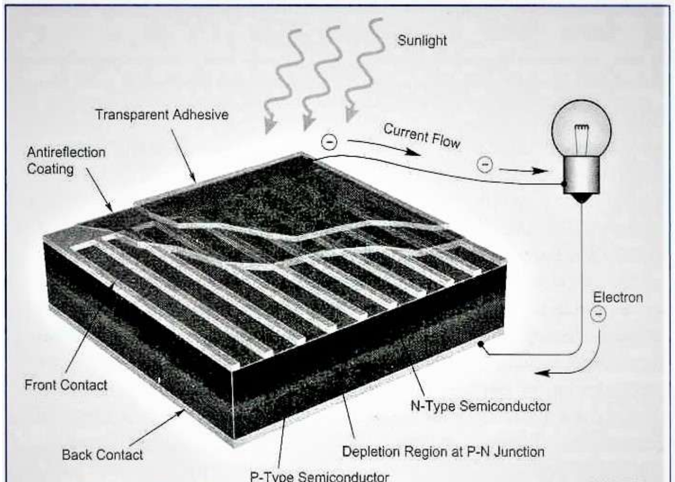


Figure 5.28 — The construction of a photovoltaic cell.

The relative fraction of light energy that is converted to electrical energy is the conversion efficiency of the material.

- **The most common type of photovoltaic cell used for electrical power generation is Silicon. [E6F10]**
- **The approximate open-circuit voltage produced by a fully-illuminated silicon photovoltaic cell is 0.5V [E6F11]**
- **Conversion efficiency is the relative fraction of light energy that is converted to electrical energy in the form of current. [E6F09]**

Chapter 5

Pg: 5-19

Chapter 5 sections

- 5.1 – Semiconductor Devices
  - Materials
  - Junction Diodes, Schottky Barrier Diodes, Zener Diodes, Varactor Diodes
  - Light-Emitting Diodes
  - Bipolar Transistors, Field Effect Transistors, JFET, MOSFET
  - RF Integrated Devices
- 5.2 – Optoelectronics
  - Photoconductivity, Optoelectronics Components, Photovoltaic Cells
- 5.3 - Digital Logic
  - Logic Basics
  - Sequential and Synchronous Logic
  - Logic Families

Digital Logic 5.3

Logic Basics

Logic Basics

- Boolean Algebra.
    - For digital electronics
    - Variables have only 2 values
        - Represented by
            - 0 or 1
            - False or True
            - Off or On
- Output state is determined by the combination of input states.
- Simplest digital devices are switches and relays
- Modern Digital ICs generate, detect or process digital signals
- All digital systems use common mathematical principles called *logic*.
- *Combinational logic* follows binary mathematics called Boolean algebra
- Each combination of inputs results in a specific output or combination of outputs.
- A Truth table shows inputs and outputs (results).

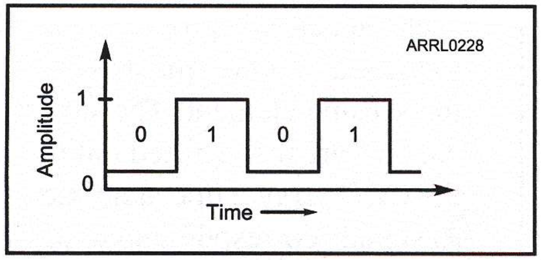


Figure 5.29 — A typical binary signal may have either of two signal levels, shown as 0 when the signal has the amplitude representing a logic value of 0 and 1 when the signal amplitude represents 1. Digital systems use many other combinations of amplitude and timing.

TRUTH TABLE is a list of inputs and corresponding outputs for a digital device. [E7A10]

Logic Basics

- **First : Elements with <u>One</u>-input and <u>One</u>-output**
  - Non-inverting buffer.
  - Inverting buffer or “Not” gate.

One Input → One Output

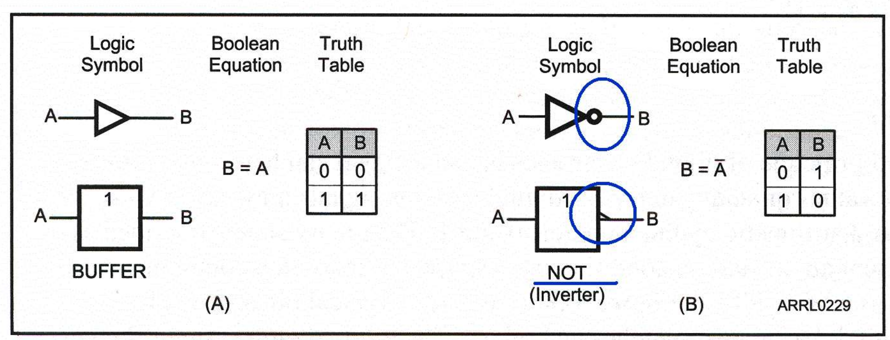
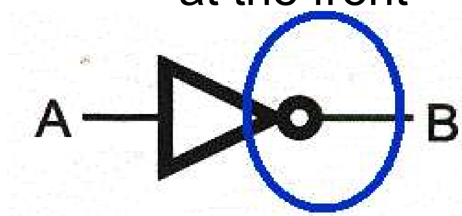


Figure 5.30 — Schematic symbols for a noninverting buffer (A) and inverter or NOT function (B) are shown. The distinctive (triangular) shape is used by ARRL and in most US publications. The square symbol is an alternate. The Boolean equation for the buffer and a truth table for the operation are also given.

The “O” at the front



- **The schematic symbol for the NOT operation (inverter) is: [E6C11]**
- The <u>non-inverting buffer</u> & <u>inverter</u> (<u>NOT gate)</u> are two logic elements that have only ONE input and ONE output.

Digital Logic 5.3

Logic Basics

Pg: 5-21

Logic Basics Two Input – One output device

- **AND gate**.
  - Output true(1) only if ALL inputs are:

    True (1's)

In The Truth Table:

C = A * B

Both A & B must be 1's for C to be 1

The AND symbol is shown in Fig 5-31

2 Inputs → 1 Output

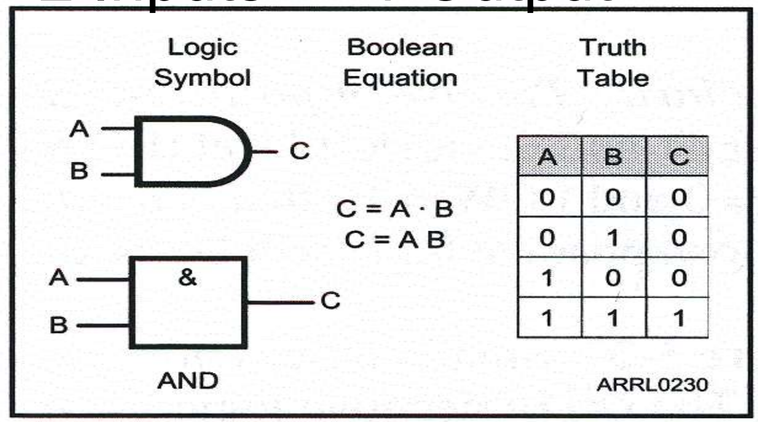


Figure 5.31 — Schematic symbols for a two-input AND gate are shown. The distinctive (round-nosed) shape is used by ARRL and in most US publications. The square symbols in this and following figures are an alternate. The Boolean equation and truth table for the operation are also given.

Digital Logic 5.3

Logic Basics

Logic Basics Two Input – One output device

- **OR gate**.
  - Output true if one or more of the inputs are true.

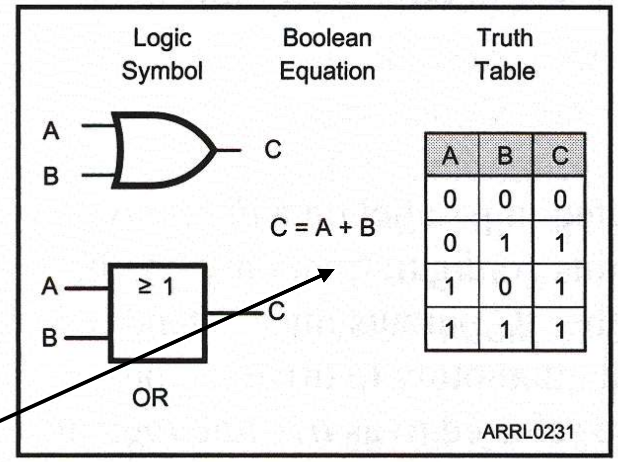
In The Truth Table:

C = A + B

Either A or B must be 1's for C to be 1

- **The logical operation that an OR Gate performs is: It produces logic 1 at its output if any or all inputs are logic 1. [E7A08]**

2 Inputs → 1 Output



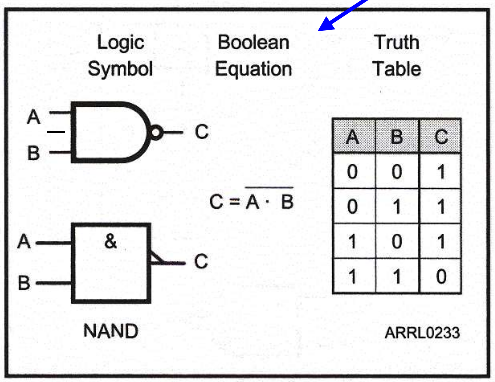
A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

Figure 5.32 — Schematic symbols for a two-input OR gate are shown. The Boolean equation and truth table for the operation are also given.

In Boolean algebra notation, a **+** sign is placed between the variables to represent the **OR** function.

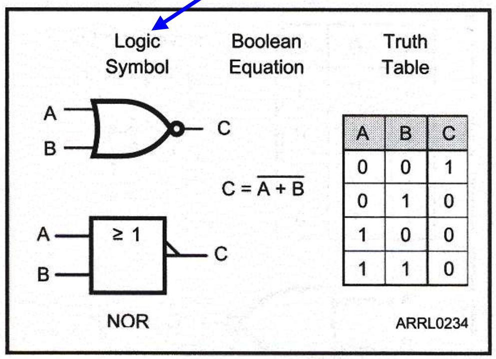
Logic Basics – the Negative Operation.

Symbols for: NAND NOR Exclusive NOR



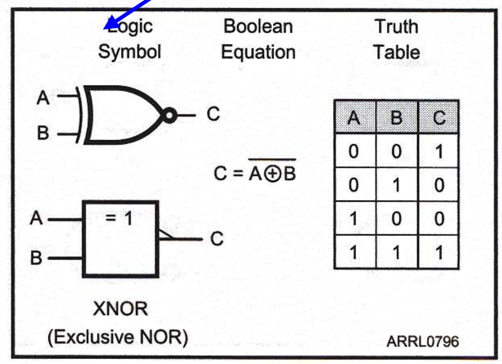
A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

Figure 5.33 — Schematic symbols for a two-input NAND gate are shown. The Boolean equation and truth table for the operation are also given.



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

Figure 5.34 — Schematic symbols for a two-input NOR gate are shown. The Boolean equation and truth table for the operation are included.



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

Figure 5.35 — Schematic symbols for a two-input EXCLUSIVE NOR (XNOR) gate are shown. The Boolean equation and truth table for the operation are included.

In Boolean notation, the NAND is represented by a dot between the variables and a bar over the combination Fig 5-33. $C = \overline{A \cdot B}$

- **The logical operation the NAND gate performs is:**
  It produces logic "0" at its output only when all inputs are logic "1". [E7A07]
- **The logical operation performed by an OR gate is:**
  It produces logic "1" at its output if any input is logic "1". [E7A08]

Digital Logic 5.3

Logic Basics

Logic Basics

- **Positive & Negative logic.**
  - Positive logic.
    - A "True" is represented by highest voltage.
  - Negative logic.
    - A "True" represented by lowest voltage.
  - Positive logic NAND is functionally equivalent to negative logic NOR (it has the same truth table).

For real...think about it – or just compare truth tables:

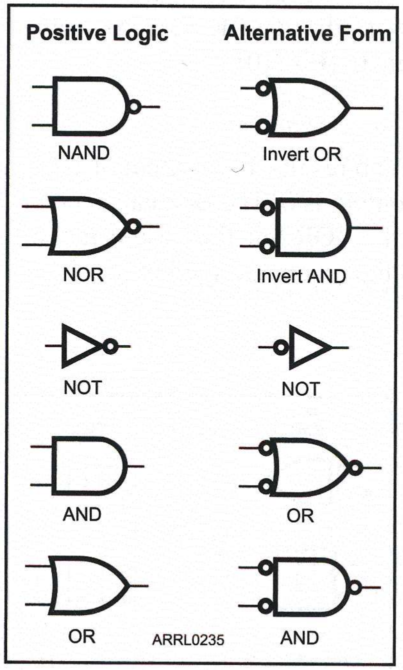


Figure 5.36 — A comparison of positive- and negative-true logic symbols for the common logic elements. The small circles at an input or output indicate negative-true logic.

- The type of logic that defines "1" as a high voltage is Positive Logic [E7A11]
- The type of logic that defines "0" as a high voltage is Negative Logic. This is not common and can be difficult to keep straight in your head. Just use positive logic.

Digital Logic 5.3

Logic Basics

Pg: 5-22

- Tri-State Logic
  - Allows multiple devices to be connected in parallel on same output bus.
    - Three output states.
      - Low (0).
      - High (1).
      - Off (high impedance).
    - Allows multiple devices to be connected in parallel on same output bus.
    - Only one device can be "on" at a time.
      - All others MUST be in the high-impedance state.

In this configuration only one IC output may control the signals at a time, all others stand by changing their outputs to a high impedance so that they do not drive the buss connection to a HIGH or LOW.

- **Tri-State Logic is Logic devices with 0, 1 and high impedance output states. [E6C03]**
- The primary advantage of Tri-State Logic is it's ability to connect many device outputs to a common bus.

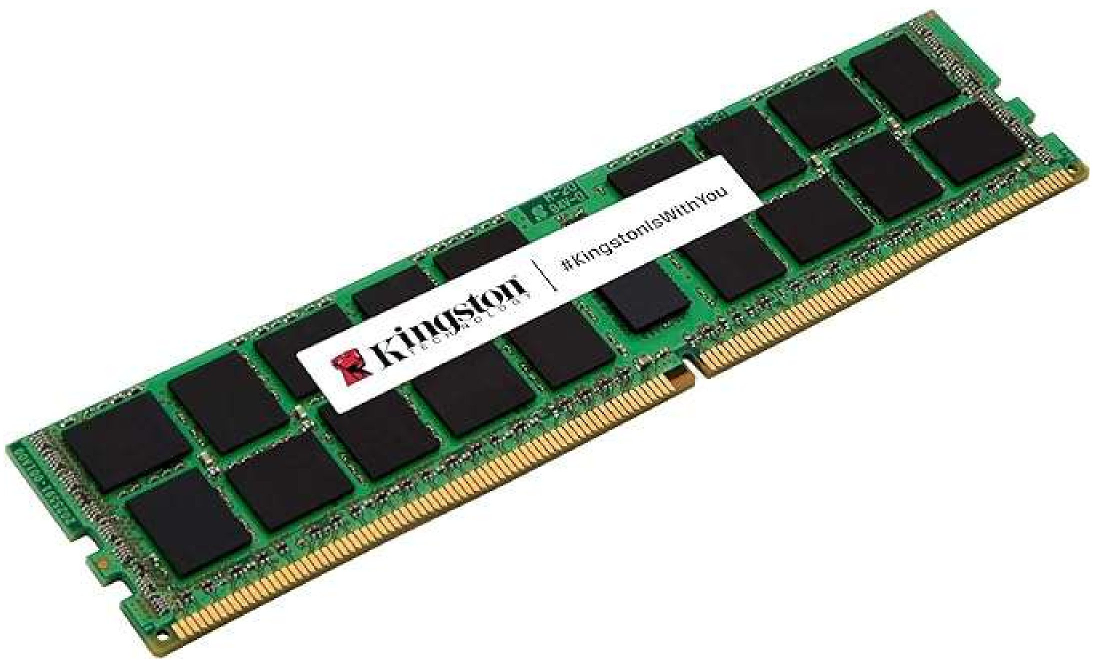
Digital Logic 5.3

Synchronous Logic

Pg: 5-23

Sequential logic

- The output state of a sequential-logic circuit is determined by both its present inputs and previous output states.
- Sequential Logic must include some form of "memory".



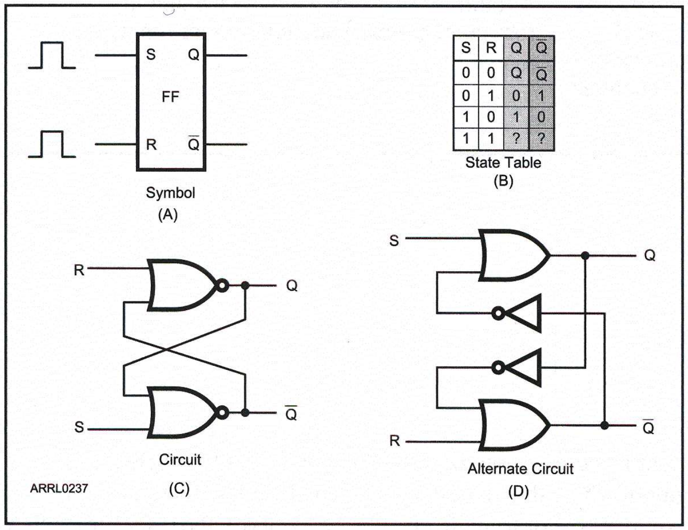
Digital Logic 5.3

Synchronous Logic

Pg: 5-23

Flip-flops.

- Also known as - Bi-stable multivibrator, latch. Two states 0 & 1.
- Several different types.
  - S-R which is Set-Reset
  - J-K which can do S-R or Toggle
  - D which stores Data on clock
  - T which will Toggle on clock
  - Gated, non-gated.
  - Clocked, non-clocked.



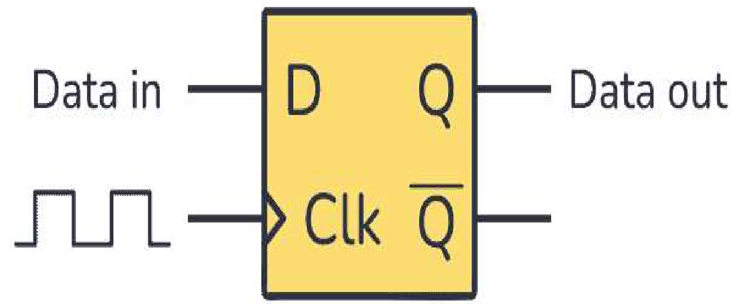
S	R	Q	$\overline{Q}$
0	0	Q	$\overline{Q}$
0	1	0	1
1	0	1	0
1	1	?	?

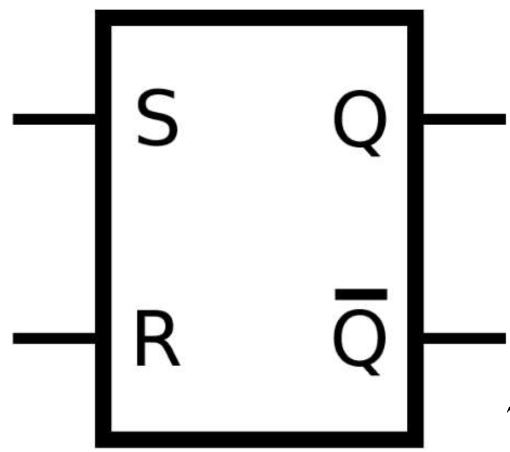
Figure 5.38 — A positive-logic, unclocked R-S flip-flop is used to illustrate the operation of flip-flops in general. Where Q and $\overline{Q}$ are shown in the state table, the previous output states are retained. A question mark (?) indicates an invalid state in which you can not be sure what the output will be. C shows an R-S flip-flop made from two NOR gates. The circuit shown at D is another implementation using two OR gates and two inverters.

- There are <u>synchronous</u> and <u>asynchronous</u> flip-flops.
  - Synchronous flip-flops.
    - Clock input: Changes state ONLY at time determined by clock input.
  - Asynchronous flip-flops.
    - No clock input: Changes state whenever any input changes state.

Dynamic versus Static Inputs

- Dynamic inputs.
    - Edge-triggered Flip-Flop.
    - Flip-flop acts ONLY when clock input changes state.
    - Positive-edge triggered. No bubble in Clock line.
    - Negative-edge triggered. Bubble on Clock line.
- Static inputs.
    - Level-triggered Flip-Flop or SR Latch.
    - Flip-flop acts when any input changes state.





Digital Logic 5.3

Synchronous Logic

Pg: 5-24

Table 5.1
Flip-Flop Output Designations

Output	*Action*	*Restrictions*
Q (Set)	Normal output	Only two output states are possible: Q = 1 and Q = 0
$\overline{Q}$ (Reset)	Inverted output	Output states are the opposite of Q: $\overline{Q}$ = 0 and $\overline{Q}$ = 1

Notes
1) $\overline{Q}$ is the complement of Q.
2) The normal output is normally marked Q or unmarked.
3) The inverted output is normally marked $\overline{Q}$. If there is a 1 state at Q, there will be a 0 state at $\overline{Q}$.
4) Alternatively the inverted output may have a (negative) polarity indicated (a small right triangle on the outside of the flip-flop rectangle at the inverted output line). For lines with polarity indicators, be aware that a 1 state in negative logic is the same as a 0 state in positive logic. This is the convention followed by the International Electrotechnical Commission.

Timing Diagram for a Flip Flop – output changes on the leading edge of the clock pulse.

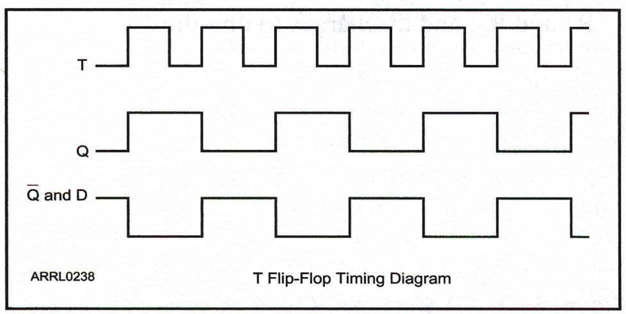


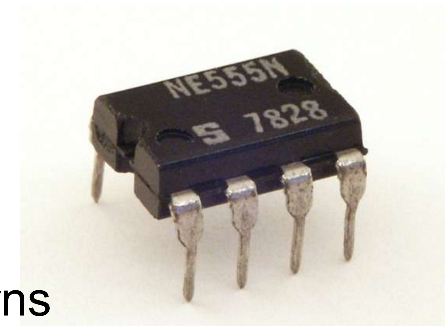
Figure 5.39—The timing diagram for a T flip-flop is shown. Since the output changes at half the rate of the input signal, the T flip-flop acts as a divide-by-two counter.

The flip-flop provides one complete output pulse for every two input pulses, dividing the signal's frequency by two.

- **The following can divide the frequency of a pulse train by 2: A Flip-Flop. [E7A03]**
- **How many flip-flops are required to divide a signal frequency by 16? 4 [E7A04]**

One-Shot or Monostable Multivibrator NE555 Timer

- One of the most popular ICs ever made -1 billion/year.
- Stay in the unstable state for time determined by the RC circuit (RC time constant)
- When triggered, it switched to the unstable state then returns to it's original state after the RC time constant



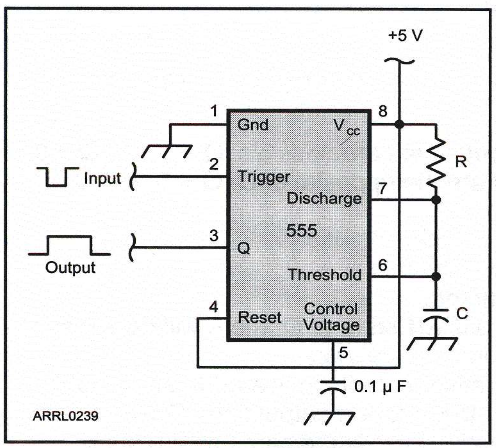


Figure 5.40 — A 555 timer IC can be connected to act as a one-shot multivibrator. See text for the formula to calculate values for R and C.

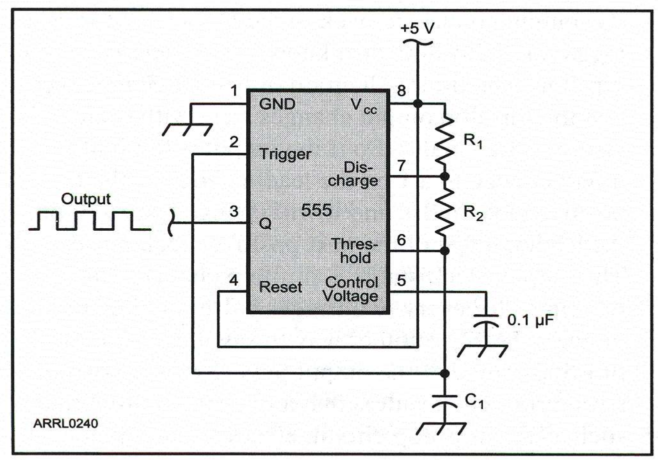


Figure 5.41 — A 555 timer IC can be connected as an astable multivibrator. See text for the formula to calculate values of R_1, R_2 and C_1.

- **A characteristic of a monostable multivibrator is it switches momentarily to the opposite binary state and then returns to its original state after a set time. [E7A06]**

Digital Logic 5.3

Synchronous Logic

Pg: 5-24

NE555 Timer

- Astable multivibrator

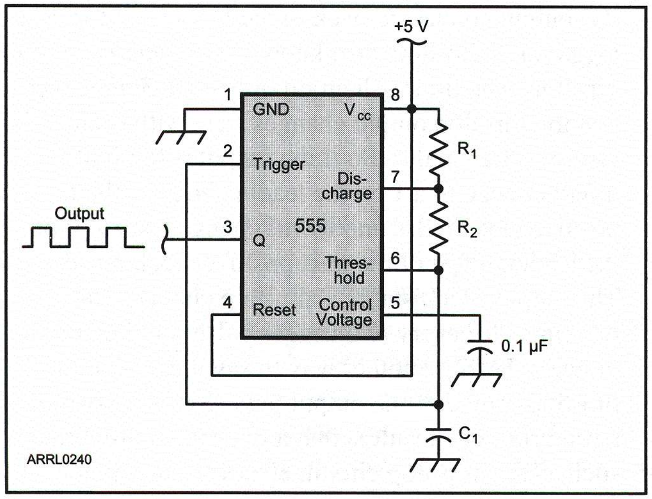
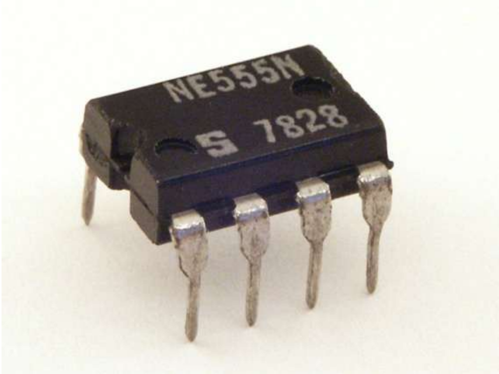


Figure 5.41 — A 555 timer IC can be connected as an astable multivibrator. See text for the formula to calculate values of R_1, R_2 and C_1.



RC Time Constant :

$$f = \frac{1.46}{C_1[R_1 + (2 \times R_2)]} \qquad \text{(Equation 5.7)}$$

where:
R is resistance in ohms.
C is capacitance in farads.

- **An astable or free running multivibrator continuously switches between two unstable states without any external clock. [E7A05]**

Example: A NE555 timer IC Fig 5.41, charges to 2/3 Vcc [thru R1& R2] and discharges to 1/3 Vcc [thru R2] so the ratio of R1:R2 sets duty cycle, using Equation 5.4.

Digital Logic 5.3

Synchronous Logic

Pg: 5-25

Dividers and Counters

Counter, divider, divide-by-N counter

- When the first stage changes state, it affects the second stage and so on.
- A series of flip-flops are connected so that one output pulse occurs after every N pulses.
- Each flip-flop divides by 2.
- Most counters provide an input to clear count.
- Counters can either count up or down.
- A ripple, ripple-carry or asynchronous counter passes the count from stage to stage
- A decade counter divides by 10 (The last flip-flop stage produces one output pulse for every 10 input pulses.)

- **The function of a decade counter digital IC: It produces one output pulse for every ten input pulses. [E7A02]**

Digital Logic 5.3

Logic Families

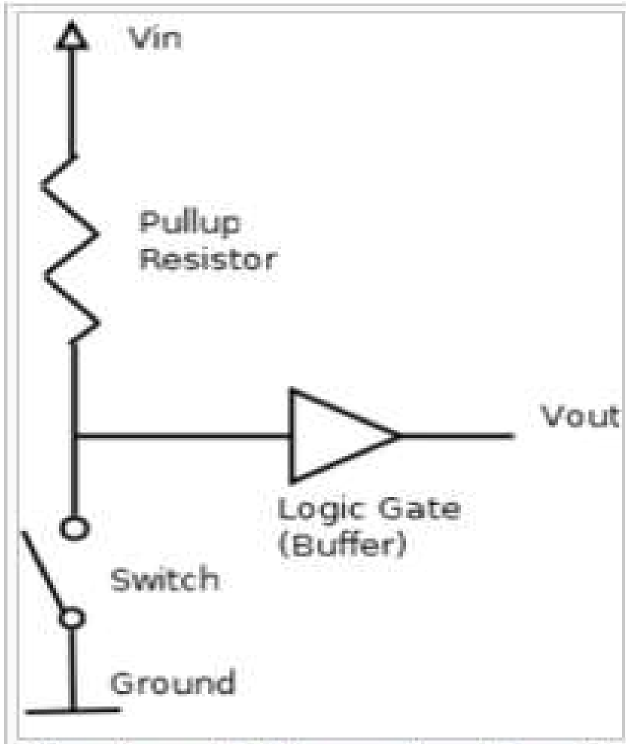
Pg: 5-26

Transistor-Transistor-Logic (TTL)

- +5VDC supply voltage.
- High level: >2.0 VDC
- Low level: < 0.8 VDC
- Low threshold: ~0.7 VDC
- Open inputs assume a high logic state
- Pull-up resistors tie Highs to the power supply
- Ground connections for Lows or pull-down resistors

Examples:

- 7400 quad NAND gate
  7432 quad OR gate
  7408 quad AND gate
- 7474 dual D-type Flip-flop
  etc.



When the switch is open the voltage of the gate input is pulled up to the level of Vin. When the switch is closed, the input voltage at the gate goes to ground.

TTL Characteristics

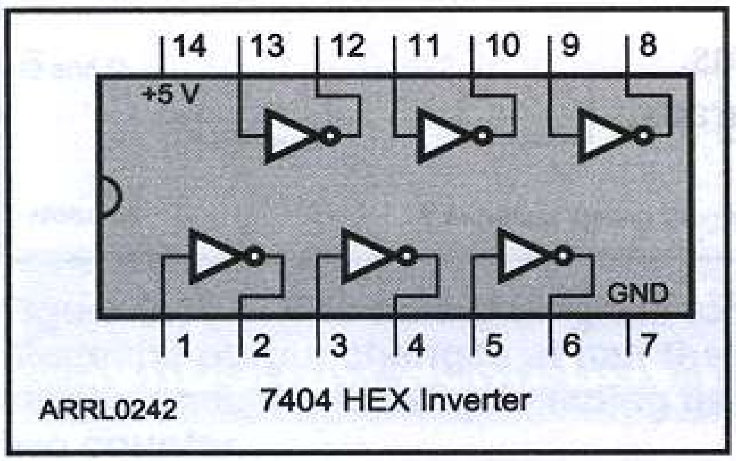


Figure 5.42 — This symbol is the schematic representation of a 7404 TTL hex inverter.

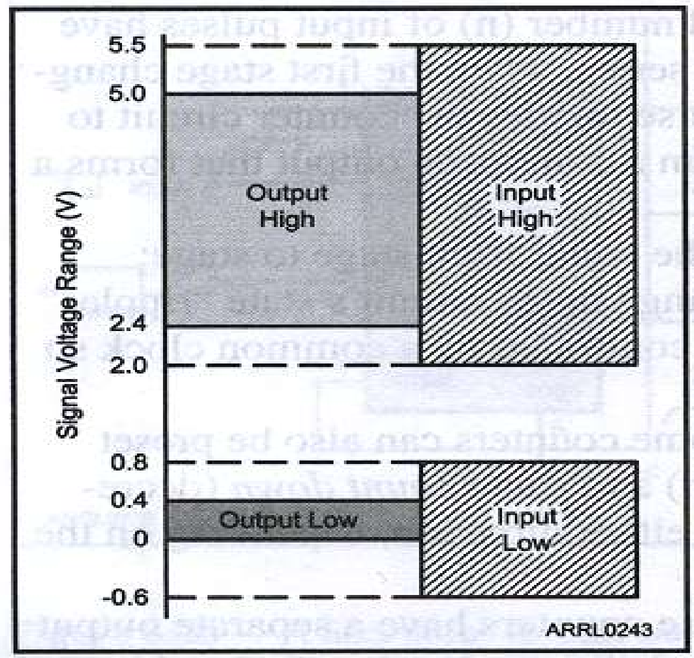


Figure 5.43 — The input and output signal-voltage ranges for the TTL family of logic devices.

Note the voltage differences between a HIGH and a LOW.
(what output voltage value of voltage separates them about 2V → 2.4V to 0.4V.)

Logic Families

CMOS Characteristics

- The initials CMOS stands for:
  Complementary Metal-Oxide Semiconductor:
- Devices that are composed of N-channel and P-channel FET combined on the same substrate
- The switching threshold for CMOS is approximately half the supply voltages.
- **Fig 5.44 shows <u>The wide range of input voltages gives the CMOS family great immunity to noise,</u> [E6C06]** since noise spikes will generally not cause a transition in the input state.

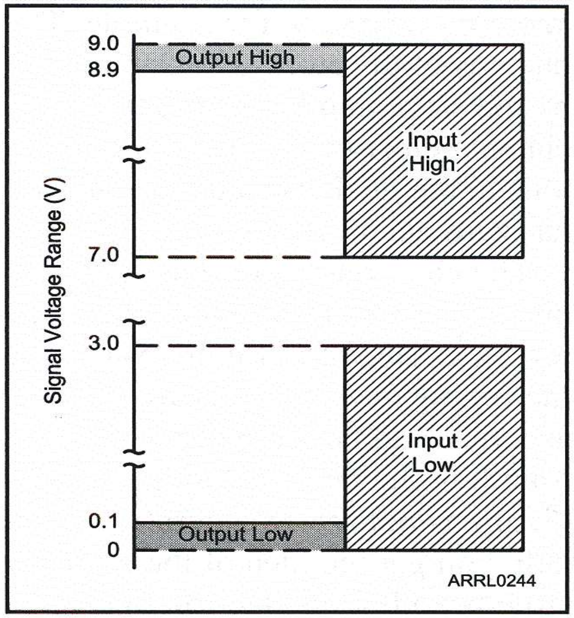


Figure 5.44 — This diagram shows 4000-series CMOS-device input and output signal-voltage ranges with a 9-V supply.

- CMOS logic has become the most widely used digital logic because of it's high switching speed, small size and far lower power consumption than TTL.
  When CMOS is not switching, it draws very little power.
- **Advantage of CMOS logic over TTL devices is: Lower power consumption. [E6C05]**
- Today, there are newer CMOS logic families than 4000-series.

Digital Logic 5.3

Logic Families

Pg: 5-28

BiCMOS Logic Characteristics

- Combines Bipolar & CMOS devices on same chip
- Get the high input impedance of CMOS.
- Static-sensitive
- Get the low output impedance of bipolar.
- Higher power consumption
- Allows ICs to combine **analog functions (amplifiers) with digital functions**(control and switching circuits).
- Complex manufacturing process.
- More expensive.

- **BiCMOS Logic is an integrated circuit logic family using both bipolar and CMOS transistors. [E6C04]**
- **BiCMOS Logic has the high input impedance of CMOS and the low output impedance of bipolar transistors. [E6C06]**

Digital Logic 5.3

Programmable Logic

Pg: 5-28

Programmable Logic

- Instead of creating complex logic functions from individual ICs, it is more practical to use programmable logic devices or PLDs as a single IC.
- PLDs, PGAs and FPGAs contain sequential logic, switches, resistors, and other complex functions up to and including microprocessors in a single integrated circuit.

- **Hardware Description Language is used to design the configuration of FPGAs. [E6C09]**
- Many SDR radios use FPGAs to implement all the filtering, modulation, and demodulation functions. Note - This is a correction to the book that says "PLDs are used in SDR radios". PLDs are smaller devices and without SRAM. FPGA larger device and can be are reprogrammed in the field. PGA are custom fixed function devices that are factory programmed.

Digital Logic 5.3

Programmable Logic

Logic Basics Summary

- There are 3 basic logic gates that are used to make all the rest of digital functions happen in integrated circuits.
- AND, OR and NOT.
- AND – means that inputs have to be HIGH for the output to be HIGH.
- OR – means that either input is HIGH and the output will be HIGH.
- NOT – means if input is HIGH then output is LOW, if input is LOW then output is HIGH.

The rest of the logic functions (NAND, NOR, XOR, XNOR) are combinations of the basic functions.

NAND is the AND gate with a NOT at the output.
NOR is an OR gate with a NOT at the output.
XOR is a gate that will have a HIGH output when only one input is HIGH.
XNOR is a gate that will have a LOW output when only one input is HIGH. Opposite of XOR.

Tri-state Logic is where the output will be in HIGH, LOW or high-impedance state.

The End

Questions ?

That's all folks

References & Credits:

- ARRL Extra Class License Manual twelfth edition
- Gfycat https://gfycat.com/discover/diode-gifs
- CircuitBread https://www.circuitbread.com/search?q=How+does+a+diode+work%3F
- Webber You @webberyou (BJT electron flow)
- Best Bjt GIFs | Gfycat https://gfycat.com/gifs/search/bjt
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