Amateur Extra License Class

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Amateur Extra Class

Chapter 5 Components and Building Blocks

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Semiconductor Devices

Materials

- Atomic Structure.
  - Nucleus (Protons & Neutrons).
  - Electrons.
    - Orbits (Shells).
    - Valence electrons.
    - 8 Valence electrons completes a shell.
  - Atomic number.
    - Number of protons in nucleus.
    - Number of electrons (non-ionized).

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Semiconductor Devices

Periodic Table of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VII	VII	VII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	O
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 110	111 111	112 112	113 113					

* Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+ Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

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Semiconductor Devices

Materials

- Electrons in outer shell are called valence electrons.
  - Valence electrons allow atoms to interact with other atoms to form compounds.
  - Atoms want to have their outer shell of electrons filled.
    - Full shell = 8 electrons.
  - Atoms can share valence electrons with other atoms to fill their outer shell forming a compound.

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Semiconductor Devices

Materials

- Atoms with fewer than 4 valence electrons are normally conductors (metals).
- Atoms with more than 4 valence electrons are normally non-conductors.
- Atoms with 4 valence electrons are normally semi-conductors.
  - Silicon
  - Germanium

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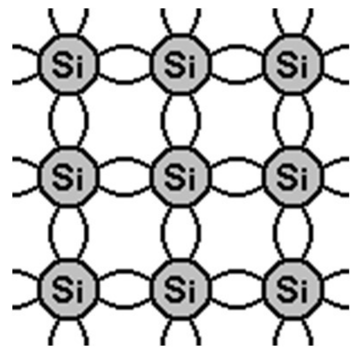
Semiconductor Devices

Materials

- Atoms can arrange themselves into a regular pattern by sharing valence electrons to form a crystal.
- Crystals of pure silicon (Si) or germanium (Ge) are not normally good conductors.



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Semiconductor Devices

Materials

- Crystals of pure semi-conductor atoms, such as silicon (Si), can have a precisely-controlled number of other atoms inserted into the crystal structure.
  - This process is called “doping”.
- Doping with atoms having 3 or 5 valence electrons causes the crystal to become more conductive.

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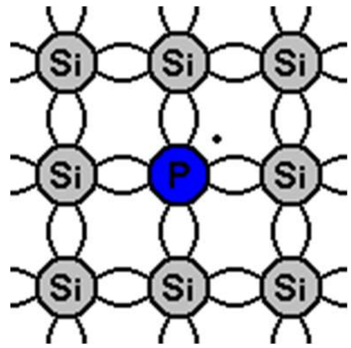
Semiconductor Devices

Materials

- Adding an element with 5 valence electrons (donor impurity) creates N-type material.
  - Excess free electrons.
- Typical donor impurities:
  - Arsenic
  - Antimony
  - Phosphorus



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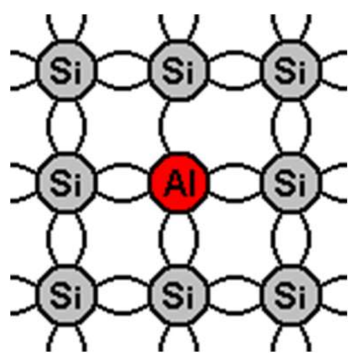
Semiconductor Devices

Materials

- Adding an element with 3 valence electrons (acceptor impurity) creates P-type material.
  - Shortage of free electrons (holes).
- Typical acceptor impurities:
  - Aluminum
  - Gallium
  - Indium



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Semiconductor Devices

Materials

- Majority Charge Carriers.
  - N-Type Material = Electron
  - P-Type Material = Hole
- Other semiconductor materials.
  - Gallium-Arsenide (GaAs).
    - LED's
    - Microwave frequencies.
  - Gallium-Arsenide-Phosphide (GaAsP).
    - LED's

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E6A02 -- Which of the following semiconductor materials contains excess free electrons?

A. N-type
B. P-type
C. Bipolar
D. Insulated gate

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E6A04 -- What is the name given to an impurity atom that adds holes to a semiconductor crystal structure?

A. Insulator impurity

B. N-type impurity

➡ C. Acceptor impurity

D. Donor impurity

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Semiconductor Devices

Junction Diodes

- A diode allows current to flow in one direction and resists current flow in the other direction.
- Two terminals:
  - Anode
  - Cathode.
- Electrons flow from cathode to anode.
- Holes flow from anode to cathode.

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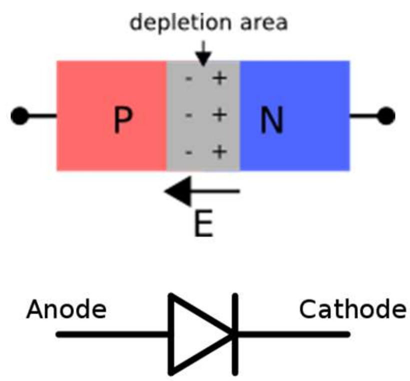
Semiconductor Devices

Junction Diodes

- With no voltage applied, electrons & holes combine at the junction forming a depletion region.



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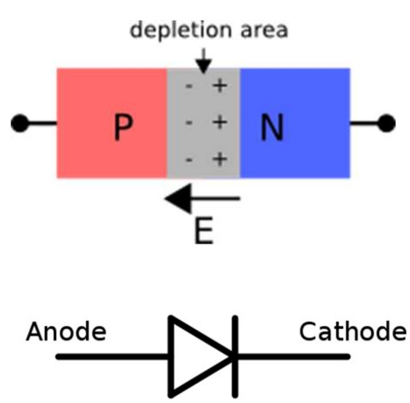
Semiconductor Devices

Junction Diodes

- A positive voltage applied to anode will attract electrons in the N-type material.
  - The depletion area collapses.
  - Electrons flow from the N-type material to the P-type material.



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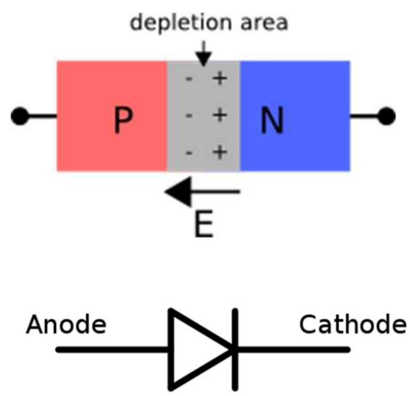
Semiconductor Devices

Junction Diodes

- A negative voltage applied to anode will repel electrons in the N-type material.
  - The depletion area gets wider.
  - No electron flow.



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Semiconductor Devices

Junction Diodes

- Forward Voltage Drop – Minimum forward voltage required for current to flow.
  - Silicon = 0.7 Volts (approx.)
  - Germanium = 0.3 Volts (approx.)
  - GaAs & GaAsP = 1.2 Volts to 1.5 Volts (approx.)

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Semiconductor Devices

Junction Diodes

- Diode Ratings.
  - Peak Inverse Voltage (PIV).
    - Avalanche voltage.
  - Maximum Average Forward Current.
    - Maximum Allowable Junction Temperature.

Note: The most common result of a failed semiconductor junction is a short circuit.

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E6A03 -- Why does a PN-junction diode not conduct current when reverse biased?

A. Only P-type semiconductor material can conduct current

B. Only N-type semiconductor material can conduct current

→ C. Holes in P-type material and electrons in the N-type material are separated by the applied voltage, widening the depletion region

D. Excess holes in P-type material combine with the electrons in N-type material, converting the entire diode into an insulator

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E6A03 -- What is the failure mechanism when a junction diode fails due to excessive current?

A. Excessive inverse voltage

B. Excessive junction temperature

C. Insufficient forward voltage

D. Charge carrier depletion

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Semiconductor Devices

Schottky Barrier Diodes

- P-type material replaced with a layer of metal.
  - Point-Contact Diodes.
  - Hot-Carrier Diodes.
- Lower forward voltage drop.
  - Less power dissipation.
  - Power supplies.

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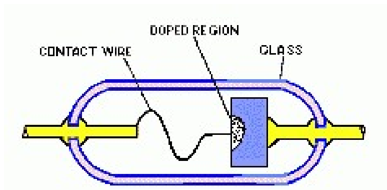
Semiconductor Devices

Schottky Barrier Diodes

- Point-Contact Diodes.
  - Very low junction capacitance.
  - Very low current.
  - Better for VHF & UHF detectors than normal junction diode.



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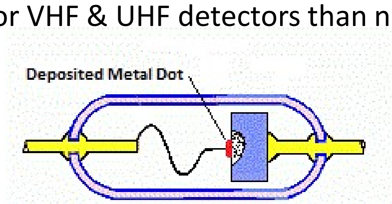
Semiconductor Devices

Schottky Barrier Diodes

- Hot-Carrier Diodes.
  - Similar to point-contact diode.
    - More stable mechanically.
    - Lower contact resistance ➔ Higher current capability.
  - Better for VHF & UHF detectors than normal junction diode.



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E6B02 -- What is an important characteristic of a Schottky diode as compared to an ordinary silicon diode when used as a power supply rectifier?

A. Much higher reverse voltage breakdown
B. Controlled reverse avalanche voltage
C. Enhanced carrier retention time
➡ D. Less forward voltage drop

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E6B08 -- Which of the following is a Schottky barrier diode?

➡ A. Metal-semiconductor junction
B. Electrolytic rectifier
C. PIN junction
D. Thermionic emission diode

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E6B09 -- What is a common use for point contact diodes?

A. As a constant current source
B. As a constant voltage source
C. As an RF detector
D. As a high voltage rectifier

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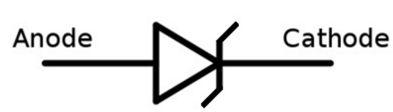
Semiconductor Devices

Zener Diodes

- Operates with reverse bias.
- Operates at avalanche voltage.
- Large change in avalanche current results in small change in voltage.
- Designed to withstand avalanche current with proper heat sink.



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E6B01 -- What is the most useful characteristic of a Zener diode?

A. A constant current drop under conditions of varying voltage

B. A constant voltage drop under conditions of varying current

C. A negative resistance region

D. An internal capacitance that varies with the applied voltage

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Semiconductor Devices

Varactor Diodes

- Operates with reverse bias.
- Varying voltage varies junction capacitance.
  - Changes width of depletion region.
  - A few picofarads to >100 pF.
- Used for variable-frequency oscillators & for FM modulators.

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E6B04 -- What type of semiconductor device is designed for use as a voltage-controlled capacitor?

A. Varactor diode

B. Tunnel diode

C. Silicon-controlled rectifier

D. Zener diode

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Semiconductor Devices

PIN Diodes

- 3^{rd} layer of undoped (intrinsic) material.
- Forward resistance varies with forward bias voltage.
  - More voltage → lower resistance.
- Used for RF attenuation & switching.

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E6B05 -- What characteristic of a PIN diode makes it useful as an RF switch?

A. Extremely high reverse breakdown voltage
B. Ability to dissipate large amounts of power
C. Reverse bias controls its forward voltage drop
➡ D. Low junction capacitance

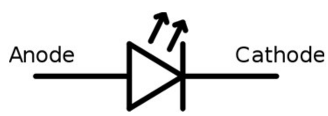
E6B11 -- What is used to control the attenuation of RF signals by a PIN diode?

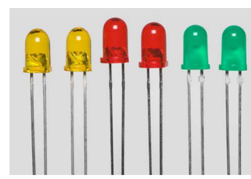
➡ A. Forward DC bias current
B. A sub-harmonic pump signal
C. Reverse voltage larger than the RF signal
D. Capacitance of an RF coupling capacitor

Semiconductor Devices

Diodes, Transistors, and Integrated Circuits.

- Light-Emitting Diodes (LEDs).
  - Special types of diodes that emit light from the junction when current flows (forward bias).
    - Color of the light determined by the type of semi-conductor material used.
    - Commonly used as visual indicators.





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E6B03 -- What type of bias is required for an LED to emit light?

A. Reverse bias

B. Forward bias

C. Zero bias

D. Inductive bias

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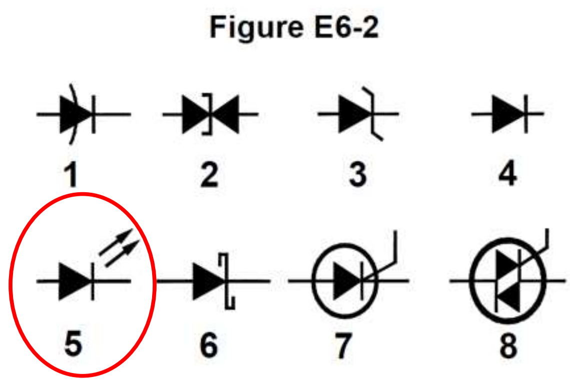
E6B10 -- In Figure E6-2, what is the schematic symbol for a light-emitting diode?

A. 1
B. 5
C. 6
D. 7



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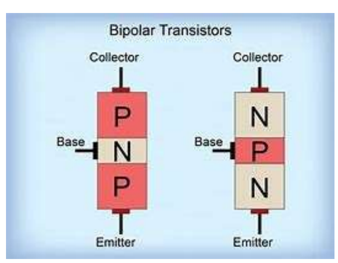
Semiconductor Devices

- Bipolar Transistors
  - Adding another doped layer to a P-N junction diode results in a device capable of amplifying signals.



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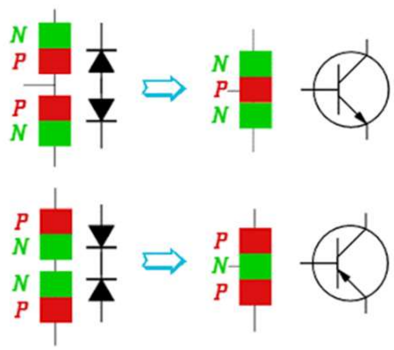
Semiconductor Devices

- Bipolar Transistors



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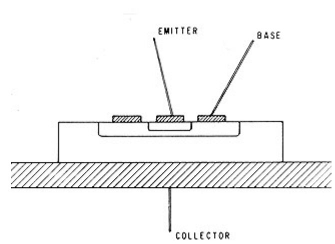
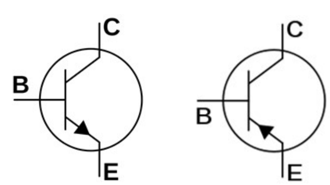
Semiconductor Devices

- Bipolar Transistors
  - 3 doped layers.
    - N-P-N.
    - P-N-P.
  - 3 terminals.
    - Collector.
    - Base.
    - Emitter.





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Semiconductor Devices

- Bipolar Transistors
  - The base region is very thin.
  - The base-emitter junction is forward biased.
  - The collector-base junction is reverse biased.
  - A small current flowing through the base-emitter junction causes a large current to flow through the collector-base junction.
  - A bipolar transistor has low input impedance.
  - A bipolar transistor has low output impedance.

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Semiconductor Devices

- Bipolar Transistors
  - Transistor characteristics.
    - Current gain (β).
      - $\beta = I_C/I_B$
    - Alpha (α).
      - $\alpha = I_C/I_E$

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Semiconductor Devices

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

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Semiconductor Devices

- Bipolar Transistors
  - Transistor characteristics.
    - Saturation – A bi-polar transistor is said to be "saturated" when an additional increase in base current does not result in an additional increase in collector current.
    - Cut-off – A bi-polar transistor is said to be "cut off" if there is insufficient base current to allow any collector current to flow.

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Semiconductor Devices

- Bipolar Transistors
  - Transistor characteristics.
    - Since the base-emitter junction is a forward-biased diode, it will have a forward voltage drop when the transistor is biased “on” and there is collector-to-emitter current flow.
      - Germanium transistor: approximately 0.3v
      - Silicon transistor: approximately 0.6 to 0.7 volts

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E6A06 -- What is the beta of a bipolar junction transistor?

A. The frequency at which the current gain is reduced to 0.707

B. The change in collector current with respect to base current

C. The breakdown voltage of the base to collector junction

D. The switching speed

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E6A07 -- Which of the following indicates that a silicon NPN junction transistor is biased on?

A. Base-to-emitter resistance of approximately 6 to 7 ohms

B. Base-to-emitter resistance of approximately 0.6 to 0.7 ohms

C. Base-to-emitter voltage of approximately 6 to 7 volts

➡ D. Base-to-emitter voltage of approximately 0.6 to 0.7 volts

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E6A08 -- What term indicates the frequency at which the grounded-base current gain of a transistor has decreased to 0.7 of the gain obtainable at 1 kHz?

A. Corner frequency

B. Alpha rejection frequency

C. Beta cutoff frequency

➡ D. Alpha cutoff frequency

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Semiconductor Devices

Field Effect Transistors

- Field effect transistors or FETs differ from bipolar transistors.
  - An electric field (voltage) controls the current flow.
  - Two common types of FETs:
    - Junction field effect transistor (JFET).
    - Metal oxide semiconductor field effect transistor (MOSFET).
  - Both types of FETs have a very high input impedance.
    - JFET typically >10 megohm.
    - MOSFET typically >100 megohm.

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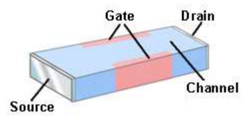
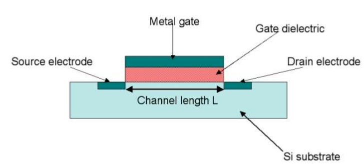
Semiconductor Devices

Field Effect Transistors

- The gate voltage controls the channel current.
- Gain is measured in transconductance.
  - Unit of measurement is Siemens.
  - $G = I_D / V_G$





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Semiconductor Devices

Field-Effect Transistors

- JFETs.
  - Junction Field-Effect Transistor.
  - A reverse-biased voltage between the gate & source junction controls the source-drain current.
  - Gate terminal is always reverse-biased.
    - Very little gate current flow.
  - High input impedance.
  - Low output impedance.

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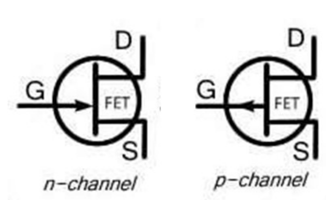
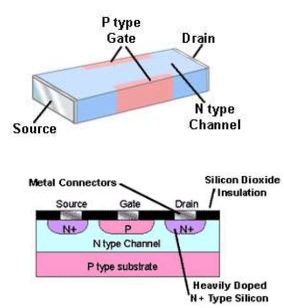
Semiconductor Devices

- Field-Effect Transistors
  - JFETs.
    - Junction Field-Effect Transistor.





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Semiconductor Devices

Field-Effect Transistors

- MOSFET.
  - Metal Oxide Semiconductor Field-Effect Transistor.
  - Gate is insulated from the source-drain channel by a layer of metal oxide.
    - No gate current flow.
  - Extremely high input impedance.
    - Susceptible to damage from static discharge.
      - Often have internal Zener diodes to protect gate.
  - Low output impedance.

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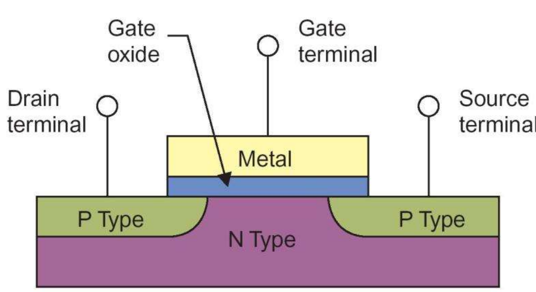
Semiconductor Devices

Field-Effect Transistors

- MOSFETs.



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Semiconductor Devices

Field-Effect Transistors

- Enhancement and depletion mode FET's.
  - Enhancement mode.
    - $V_G = 0\ V_{DC}$ → No source-drain current flow.
    - Increasing gate voltage → larger source-drain current.
    - JFETs are always enhancement mode.
  - Depletion mode.
    - $V_G = 0\ V_{DC}$ → Maximum source-drain current flow.
    - Increasing gate voltage → smaller source-drain current.

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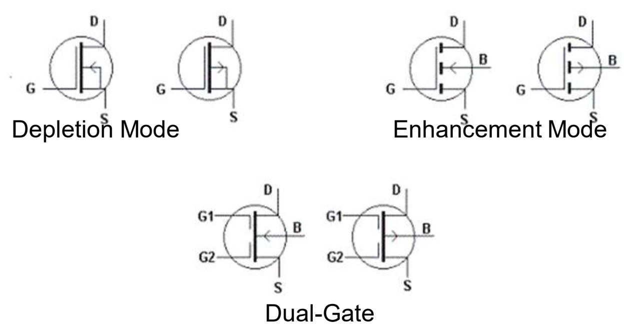
Semiconductor Devices

Field-Effect Transistors

- MOSFETs.



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E6A05 -- How does DC input impedance at the gate of a field-effect transistor compare with the DC input impedance of a bipolar transistor?

A. They are both low impedance
B. An FET has lower input impedance
➡ C. An FET has higher input impedance
D. They are both high impedance

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E6A09 -- What is a depletion-mode FET?

➡ A. An FET that exhibits a current flow between source and drain when no gate voltage is applied
B. An FET that has no current flow between source and drain when no gate voltage is applied
C. Any FET without a channel
D. Any FET for which holes are the majority carriers

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E6A10 -- In Figure E6-1, what is the schematic symbol for an N-channel dual-gate MOSFET?

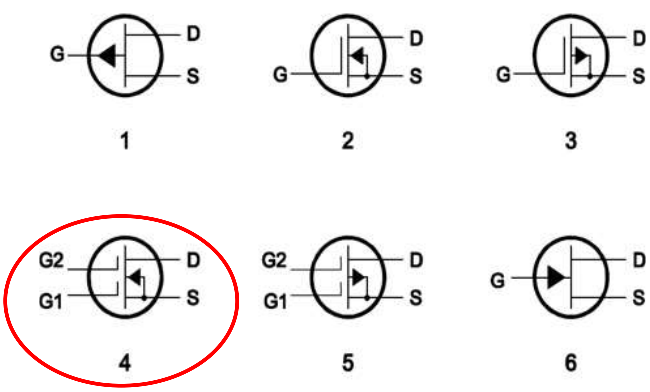
A. 2

B. 4

C. 5

D. 6

Figure E6-1



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E6A11 -- In Figure E6-1, what is the schematic symbol for a P-channel junction FET?

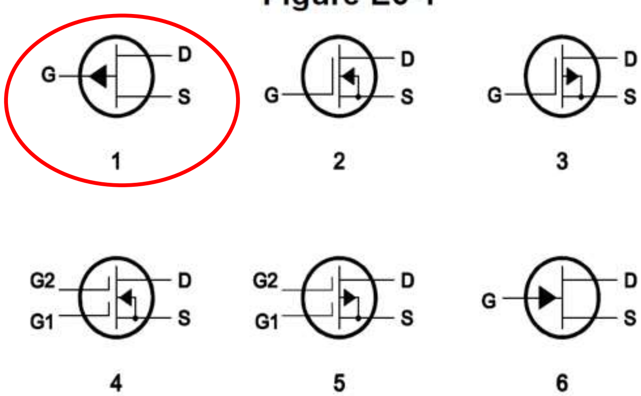
A. 1

B. 2

C. 3

D. 6

Figure E6-1



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E6A12 -- Why do many MOSFET devices have internally connected Zener diodes on the gate?

A. To provide a voltage reference for the correct amount of reverse-bias gate voltage

B. To protect the substrate from excessive voltages

C. To keep the gate voltage within specifications and prevent the device from overheating

→ D. To reduce the chance of static damage to the gate

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Semiconductor Devices

RF Integrated Devices

- Monolithic microwave integrated circuit (MMIC).
  - Silicon & germanium semiconductors do not preform well in the lower UHF range & higher frequencies.
    - Poor electron mobility.
  - MMICs are constructed of Gallium Arsenide (GaAs) or Gallium Nitride (GaN) which have higher electron mobility.
  - MMICs are commonly used as low-level amplifiers at VHF, UHF, & microwave frequencies.

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Semiconductor Devices

RF Integrated Devices

- Monolithic microwave integrated circuit (MMIC).
  - MMICs are commonly used as low-level amplifiers at VHF, UHF, & microwave frequencies.
  - MMICs usually have input & output impedances of 50Ω.
  - MMICs have a low noise figure.
    - Typically 2.0 dB.

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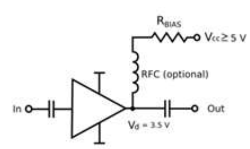
Semiconductor Devices

- RF Integrated Devices
  - MMICs have 4 terminals.
    - Input connection.
    - Output connection.
    - 2 ground connections.
    - DC power is applied to the output terminal through a resistor and/or an RF choke.



1- Input
2 - Ground (GND)
3 - Output
4 - Ground (GND)

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Semiconductor Devices

RF Integrated Devices

- Microstrip construction.
  - Conventional construction techniques have too much stray inductance and are not suitable for use above the lower UHF frequencies.
  - Special construction techniques, called microstrip, are used to reduce this problem.

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Semiconductor Devices

RF Integrated Devices

- Microstrip Construction.
  - Uses a double-sided PCB.
    - One side of the PCB is a ground plane.
  - Precisely-sized traces form 50Ω transmission line segments.
  - Components are soldered directly to the transmission line segments.

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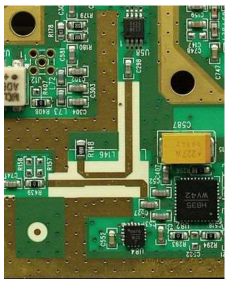
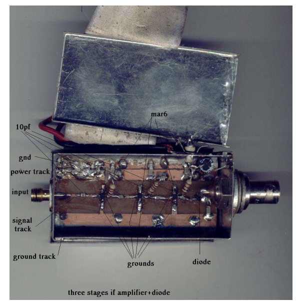
Semiconductor Devices

RF Integrated Devices

- Microstrip Construction.





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E5D03 -- What is microstrip?

A. Lightweight transmission line made of common zip cord

B. Miniature coax used for low power applications

C. Short lengths of coax mounted on printed circuit boards to minimize time delay between microwave circuits

→ D. Precision printed circuit conductors above a ground plane that provide constant impedance interconnects at microwave frequencies

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E6A01 -- In what application is gallium arsenide used as a semiconductor material?

A. In high-current rectifier circuits

B. In high-power audio circuits

➡ C. In microwave circuits

D. In very low frequency RF circuits

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E6E01 -- Why is gallium arsenide (GaAs) useful for semiconductor devices operating at UHF and higher frequencies?

A. Higher noise figures

➡ B. Higher electron mobility

C. Lower junction voltage drop

D. Lower transconductance

70

E6E03 -- Which of the following materials is likely to provide the highest frequency of operation when used in MMICs?

A. Silicon
B. Silicon nitride
C. Silicon dioxide
➡ D. Gallium nitride

71

E6E04 -- What is the most common input and output impedance of circuits that use MMICs?

➡ A. 50 ohms
B. 300 ohms
C. 450 ohms
D. 10 ohms

72

E6E05 -- Which of the following noise figure values is typical of a low-noise UHF preamplifier?

➡ A. 2 dB
B. -10 dB
C. 44 dBm
D. -20 dBm

73

E6E06 -- What characteristics of the MMIC make it a popular choice for VHF through microwave circuits?

A. The ability to retrieve information from a single signal even in the presence of other strong signals.
B. Plate current that is controlled by a control grid
C. Nearly infinite gain, very high input impedance, and very low output impedance
➡ D. Controlled gain, low noise figure, and constant input and output impedance over the specified frequency range

74

E6E07 -- What type of transmission line is used for connections to MMIC?

A. Miniature coax
B. Circular waveguide
C. Parallel wire
D. Microstrip

75

E6E08 -- How is power supplied to the most common type of MMIC)?

A. Through a resistor and/or RF choke connected to the amplifier output lead
B. MMICs require no operating bias
C. Through a capacitor and RF choke connected to the amplifier input lead
D. Directly to the bias-voltage (VCC IN) lead

76

Break

77

Optoelectronics

Photoconductivity

- Photoconductive effect.
  - Light striking a photosensitive material knocks electrons loose, thereby increasing the conductivity (lower resistance).
  - The photoconductive effect is most pronounced for crystalline semiconductors.
    - Cadmium-Sulfide: Visible light.
    - Lead-Sulfide: Infra-red light.
  - **<u>ALL</u>** semiconductor junctions exhibit the photoconductive effect.

78

Optoelectronics

Optoelectronic Components

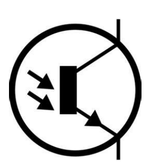
- Most semiconductor devices are enclosed in a metal or plastic package to prevent the photoconductive effect from ambient light from affecting the operation of the device.
- Optoelectronic semiconductors have a transparent case or a window in the case to allow ambient light to reach the junction & alter the operation of the device.

79

Optoelectronics

Optoelectronic Components

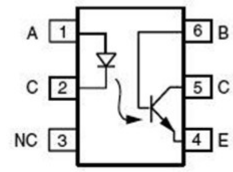
- Phototransistor.
  - A transistor in a package that allows light to hit the junction.
  - The transistor turns on when it is exposed to light.
  - An external base connection may or may not be provided.



80

Optoelectronics

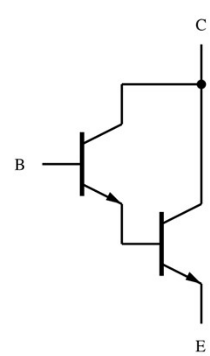
- Optoelectronic Components
  - Optocouplers and optoisolators.
    - An LED & a phototransistor in the same package
    - Very high impedance between the light source & the phototransistor.
    - A high degree of isolation between the control circuit & the controlled circuit.
    - Functions as a solid-state relay.



81

Optoelectronics

- Optoelectronic Components
  - Optocouplers and optoisolators.
    - The main parameter of interest is the current transfer ratio (CTR).
      - The ratio of output current to input current.
    - Can use a Darlington phototransistor to increase the CTR.



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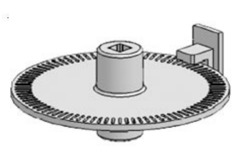
Optoelectronics

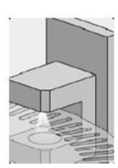
- Optoelectronic Components
  - Optocouplers and optoisolators.
    - Sometimes a separate LED & phototransistor separated by a small gap are used.
    - This allows the detection of the presence or the absence of an object.
      - Can work by an object interrupting the light from the LED or by the object reflecting the light from the LED.

83

Optoelectronics

- Optoelectronic Components
  - The Optical Shaft Encoder.
    - Used for VFO knobs & other controls in many modern radios.
    - Using 2 detectors allows the speed & direction of the rotation to be detected.





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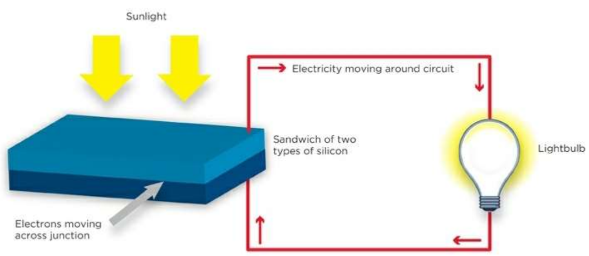
Optoelectronics

Photovoltaic Cells

- The photoconductive (a.k.a. – photoelectric) effect can be used in reverse to generate power.



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Optoelectronics

Photovoltaic Cells

- If sufficient light falls on a P-N junction, free electrons in the N-type material will absorb energy & flow across the junction into the P-type material.
  - The most common material used is Silicon.
  - The most efficient material is Gallium-Arsenide.
    - The efficiency is the relative fraction of the light energy that is converted to electrical energy.
  - A fully-illuminated junction yields about 0.5 VDC.

86

Optoelectronics

Photovoltaic Cells

- Photovoltaic cells are rapidly becoming widely used for commercial power generation.

87

E6F01 -- What absorbs the energy from light falling on a photovoltaic cell?

A. Protons

B. Photons

C. Electrons

D. Holes

88

E6F02 -- What happens to the conductivity of a photoconductive material when light shines on it?

A. It increases
B. It decreases
C. It stays the same
D. It becomes unstable

89

E6F03 -- What is the most common configuration of an optoisolator or optocoupler?

A. A lens and a photomultiplier
B. A frequency modulated helium-neon laser
C. An amplitude modulated helium-neon laser
D. An LED and a phototransistor

90

E6F04 -- What is the photovoltaic effect?

A. The conversion of voltage to current when exposed to light

➡ B. The conversion of light to electrical energy

C. The conversion of electrical energy to mechanical energy

D. The tendency of a battery to discharge when used outside

91

E6F05 -- Which describes an optical shaft encoder?

➡ A. A device which detects rotation of a control by interrupting a light source with a patterned wheel

B. A device which measures the strength a beam of light using analog to digital conversion

C. A digital encryption device often used to encrypt spacecraft control signals

D. A device for generating RTTY signals by means of a rotating light source.

92

E6F06 -- Which of these materials is most commonly used to create photoconductive devices?

➡ A. A crystalline semiconductor

B. An ordinary metal

C. A heavy metal

D. A liquid semiconductor

93

E6F07 -- What is a solid state relay?

A. A relay using transistors to drive the relay coil

➡ B. A device that uses semiconductors to implement the functions of an electromechanical relay

C. A mechanical relay that latches in the on or off state each time it is pulsed

D. A semiconductor passive delay line

94

E6F08 -- Why are optoisolators often used in conjunction with solid state circuits when switching 120 VAC?

A. Optoisolators provide a low impedance link between a control circuit and a power circuit
B. Optoisolators provide impedance matching between the control circuit and power circuit
C. Optoisolators provide a very high degree of electrical isolation between a control circuit and the circuit being switched
D. Optoisolators eliminate the effects of reflected light in the control circuit

95

E6F09 -- What is the efficiency of a photovoltaic cell?

A. The output RF power divided by the input DC power
B. Cost per kilowatt-hour generated
C. The open-circuit voltage divided by the short-circuit current under full illumination
D. The relative fraction of light that is converted to current

96

E6F10 -- What is the most common type of photovoltaic cell used for electrical power generation?

A. Selenium

➡ B. Silicon

C. Cadmium Sulfide

D. Copper oxide

97

E6F11 -- What is the approximate open-circuit voltage produced by a fully-illuminated silicon photovoltaic cell?

A. 0.1 V

➡ B. 0.5 V

C. 1.5 V

D. 12 V

98

Digital Logic

Logic Basics

- There are 2 different types of digital logic circuits that we will be discussing:
  - Combinational logic.
    - The output state is determined by a combination of the current input states.
  - Sequential (or synchronous) logic.
    - The output state is determined by a combination of the current input states **and** the previous output state.

99

Digital Logic

Logic Basics

- Boolean Algebra.
  - Boolean algebra was introduced by George Boole in 1847in his book *The Mathematical Analysis of Logic*.
  - The use of Boolean algebra is essential to the design and understanding of digital logic circuits.

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Digital Logic

Logic Basics

- Boolean Algebra.
  - In Boolean algebra, variables have only 2 values.
    - 0 or 1.
    - False or True.
    - Off or On.
  - A "truth table" is used to show the resulting outputs with all possible combinations of inputs.

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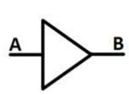
Digital Logic

Logic Basics

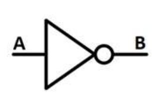
- One-input elements.

Non-Inverting Buffer



A	B
0	0
1	1

Inverting Buffer (NOT Gate)



A	B
0	1
1	0

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Digital Logic

Logic Basics

- The AND/NAND operations.
  - The output is true/false only if ALL inputs are true.

AND Gate

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

NAND Gate

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

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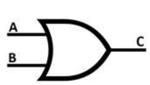
Digital Logic

Logic Basics

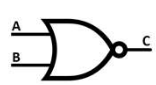
- The OR/NOR operations.
  - The output is true/false if one or more of the inputs are true.

OR Gate



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

NOR Gate



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

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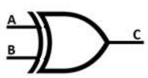
Digital Logic

Logic Basics

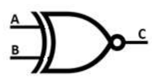
- The Exclusive OR (XOR/NOR) operations.
  - The output is true/false if one and only one of the inputs is true.

XOR Gate



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

XNOR Gate



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

105

Digital Logic

- Logic Basics
  - Positive & negative logic.
    - Positive logic.
      - True is represented by the highest voltage.
    - Negative logic.
      - True is represented by the lowest voltage.
    - A positive logic NAND gate is functionally equivalent to a negative logic NOR gate.
      - They have the same truth table.

106

Digital Logic

Logic Basics

- 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).
  - Only one device can be "on" at a time.
    - All others MUST be in the high-impedance state.

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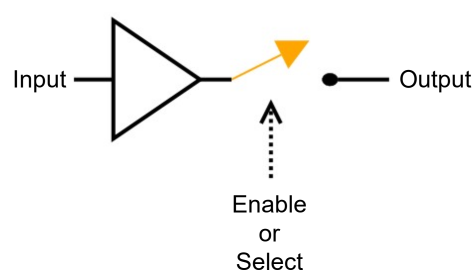
Digital Logic

Tri-State Logic



108

E6C03 -- What is tri-state logic?

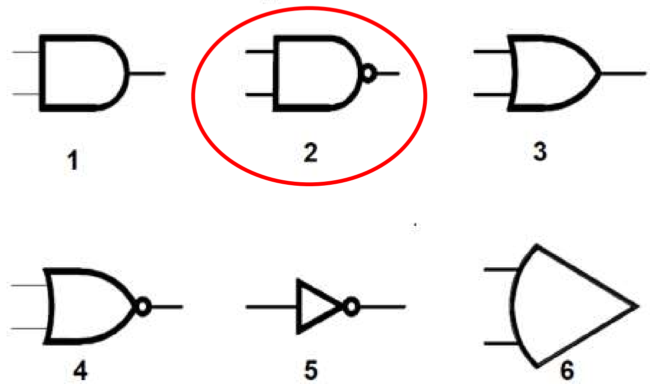
A. Logic devices with 0, 1, and high impedance output states
B. Logic devices that utilize ternary math
C. Low power logic devices designed to operate at 3 volts
D. Proprietary logic devices manufactured by Tri-State Devices

109

E6C08 -- In Figure E6-3, what is the schematic symbol for a NAND gate?

A. 1
B. 2
C. 3
D. 4

Figure E6-3

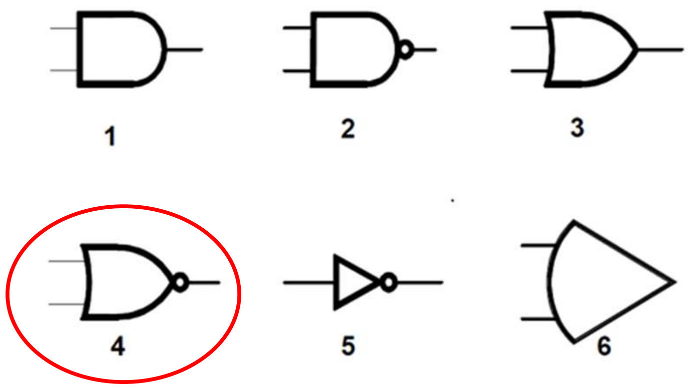


110

E6C10 -- In Figure E6-3, what is the schematic symbol for a NOR gate?

A. 1
B. 2
C. 3
D. 4

Figure E6-3

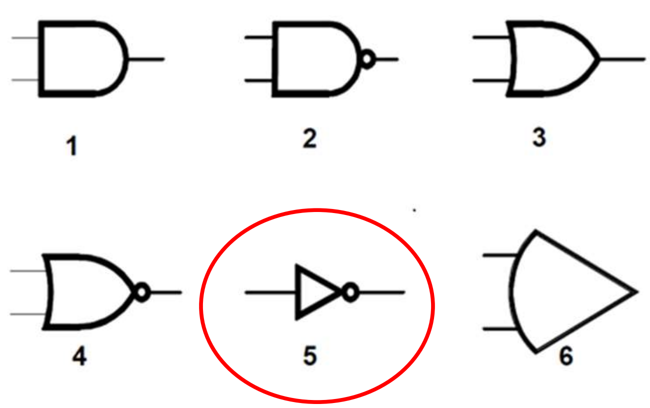


111

E6C11 -- In Figure E6-3, what is the schematic symbol for the NOT operation (inverter)?

A. 2
B. 4
C. 5
D. 6

Figure E6-3



112

E7A07 -- What logical operation does a NAND gate perform?

A. It produces logic 0 at its output only when all inputs are logic 0

B. It produces logic 1 at its output only when all inputs are logic 1

C. It produces logic 0 at its output if some but not all inputs are logic 1

➡ D. It produces logic 0 at its output only when all inputs are logic 1

113

E7A08 -- What logical operation does an OR gate perform?

➡ A. It produces logic 1 at its output if any or all inputs are logic 1

B. It produces logic 0 at its output if all inputs are logic 1

C. It only produces logic 0 at its output when all inputs are logic 1

D. It produces logic 1 at its output if all inputs are logic 0

114

E7A09 -- What logical operation is performed by an exclusive NOR gate?

A. It produces logic 0 at its output only if all inputs are logic 0

B. It produces logic 1 at its output only if all inputs are logic 1

➡ C. It produces logic 0 at its output if only one input is logic 1

D. It produces logic 1 at its output if only one input is logic 1

115

E7A10 -- What is a truth table?

A. A table of logic symbols that indicate the high logic states of an op-amp

B. A diagram showing logic states when the digital device output is true

➡ C. A list of inputs and corresponding outputs for a digital device

D. A table of logic symbols that indicates the low logic states of an op-amp

116

E7A11 -- What is the name for logic which represents a logic "1" as a high voltage?

A. Reverse Logic
B. Assertive Logic
C. Negative logic
D. Positive Logic

117

Digital Logic

Sequential and Synchronous Logic

- The current output state is dependent on both the current input states and on the previous output states.
  - Must include some form of “memory”.

118

Digital Logic

Sequential and Synchronous Logic

- Flip-flops.
  - a.k.a -- Bi-stable multivibrator, latch.
  - A flip-flop has 2 stable states.
  - There are several different types of flip-flops.
    - S-R, J-K, D, T.
    - Gated, non-gated.
    - Clocked, non-clocked.
  - Can be used as frequency divider.
    - Each flip-flop divides by 2.

119

Digital Logic

Sequential and Synchronous Logic

- Synchronous and asynchronous flip-flops.
  - Synchronous flip-flops.
    - There is an additional input called the “clock” input.
    - The output state changes **ONLY** at time determined by the clock input.
  - Asynchronous flip-flops.
    - There is no clock input.
    - The output state changes whenever any input changes state.

120

Digital Logic

Sequential and Synchronous Logic

- Dynamic versus Static Inputs.
  - Dynamic inputs.
    - a.k.a. – Edge-triggered.
    - The flip-flop acts **ONLY** when the clock input changes state.
    - The flip-flop is positive edge triggered if the output changes state on the 0-to-1 transition of the clock pulse.
  - The flip-flop is positive edge triggered if the output changes state on the 0-to-1 transition of the clock pulse.
  - The flip-flop is negative edge triggered if the output changes state on the 1-to-0 transition of the clock pulse.

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Digital Logic

Sequential and Synchronous Logic

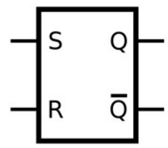
- Dynamic versus Static Inputs.
  - Static inputs.
    - a.k.a. – Level-triggered.
    - The flip-flop changes state when any input changes state.

122

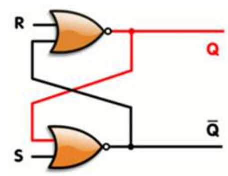
Digital Logic

Sequential and Synchronous Logic

- Set-Reset (SR) Latch
  - Most basic latch type.



S	R	Action
0	0	No change
0	1	Q = 0
1	0	Q = 1
1	1	Forbidden

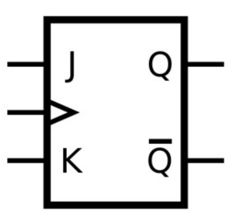


123

Digital Logic

Sequential and Synchronous Logic

- J-K flip-flop
  - Adds toggle function to SR latch.
  - Must be clocked.



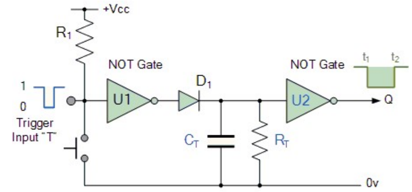
Clock (>)	J	K	Action
0	--	--	No change
1	0	0	No change
1	0	1	Q = 0
1	1	0	Q = 1
1	1	1	Toggle (Q = not Q)

124

Digital Logic

Sequential and Synchronous Logic

- One-Shot or Monostable Multivibrator.
  - A one-shot generates one output pulse each time that a trigger pulse is received.
  - The length of the pulse is determined by the R-C time constant.



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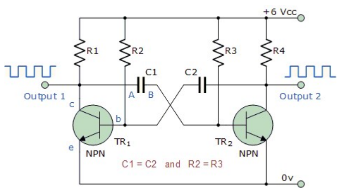
Digital Logic

Sequential and Synchronous Logic

- Astable multivibrator.
  - An astable multivibrator generates a series of pulses.
    - The digital equivalent of an oscillator.
  - The pulse length & the time between pulses are determined by R-C time constants.



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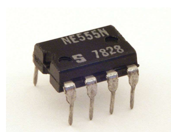
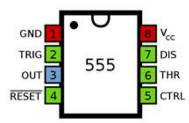
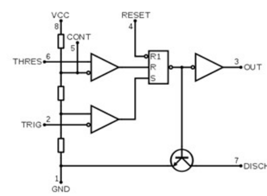
Digital Logic

Sequential and Synchronous Logic

- 555 Timer I.C.
  - One of the most popular ICs ever made.
    - ~1 billion/year.
  - Can be configured as either a monostable or as an astable multivibrator.







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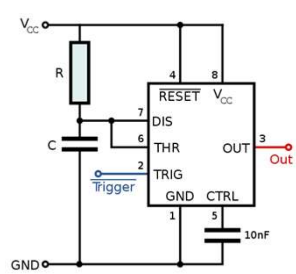
Digital Logic

Sequential and Synchronous Logic

- 555 Timer I.C.
  - Configured as a monostable multivibrator.
    - T = 1.1 x R x C



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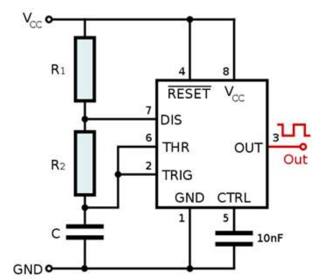
Digital Logic

Sequential and Synchronous Logic

- 555 Timer I.C.
  - Configured as an astable multivibrator
  - $f = \dfrac{1.46}{C1 \times (R1 + (2 \times R2))}$
  - The ratio of R1 to R2 determines the duty cycle.



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Digital Logic

Sequential and Synchronous Logic

- Dividers and Counters.
  - Divide-by-N counter.
    - A series of flip-flops connected so that one output pulse occurs after every N input pulses.
    - Each flip-flop divides by 2.
    - Most counters provide an input to clear the count.
    - Counters can either count up or down.
    - A decade counter divides by 10.
      - A 4-stage counter (divide by 16) with feedback to reset counter to “0” after 10 input pulses.

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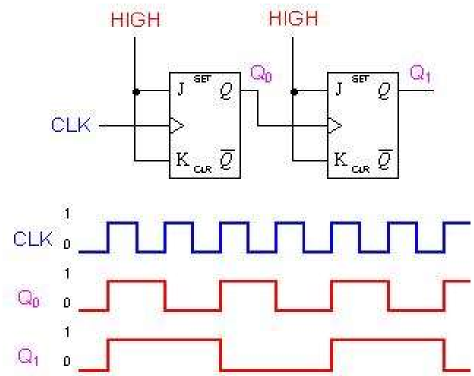
Digital Logic

- Sequential and Synchronous Logic
  - Frequency divider.
    - Cascaded J-K flip-flops.



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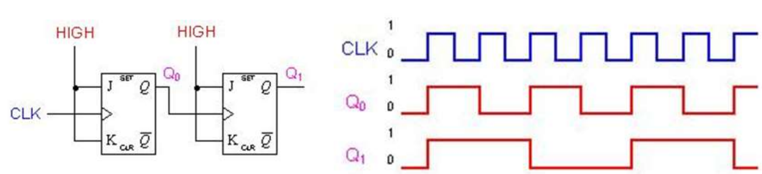
Digital Logic

Sequential and Synchronous Logic

- Frequency Dividers and Counters
  - Asynchronous (ripple) counter.
    - Each input pulse triggers the following stage, so the count “ripples” along the chain.



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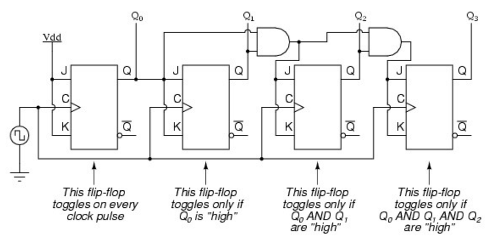
Digital Logic

- Sequential and Synchronous Logic
  - Frequency Dividers and Counters
    - Synchronous counter.
      - Each stage in counter triggered by common clock, so each stage in counter changes state at the same time.



133

E7A01 -- Which circuit is bistable?

A. An AND gate
B. An OR gate
C. A flip-flop
D. A bipolar amplifier

134

E7A02 -- What is the function of a decade counter?

A. It produces one output pulse for every 10 input pulses
B. It decodes a decimal number for display on a seven-segment LED display
C. It produces 10 output pulses for every input pulse
D. It decodes a binary number for display on a seven-segment LED display

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E7A03 -- Which of the following can divide the frequency of a pulse train by 2?

A. An XOR gate
B. A flip-flop
C. An OR gate
D. A multiplexer

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E7A04 -- How many flip-flops are required to divide a signal frequency by 4?

A. 1
B. 2
C. 4
D. 8

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E7A05 -- Which of the following is a circuit that continuously alternates between two states without an external clock?

A. Monostable multivibrator
B. J-K flip-flop
C. T flip-flop
D. Astable multivibrator

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E7A06 -- What is a characteristic of a monostable multivibrator?

A. It switches momentarily to the opposite binary state and then returns to its original state after a set time

B. It produces a continuous square wave oscillating between 1 and 0

C. It stores one bit of data in either a 0 or 1 state

D. It maintains a constant output voltage, regardless of variations in the input voltage

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Digital Logic

Logic Families

- Several different technologies can be used to build digital circuits.
  - Vacuum tube.
  - RTL
  - ECL
  - TTL
  - CMOS
  - BiCMOS
- Tri-State Logic

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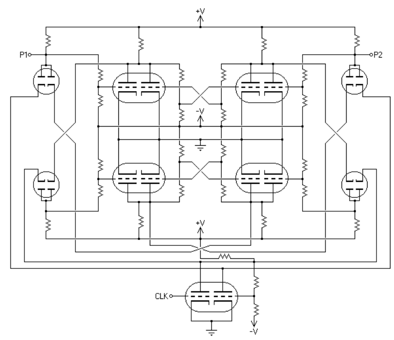
Digital Logic

Logic Families (Ancient History)

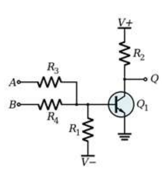
- Vacuum tube.

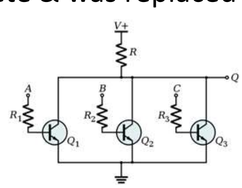


Digital Logic

Logic Families (Ancient History)

- Resistor-Transistor-Logic (RTL).
  - The first IC digital logic family.
    - Introduced in 1961.
    - Used in the Apollo guidance system.
  - Quickly became obsolete & was replaced by TTL.

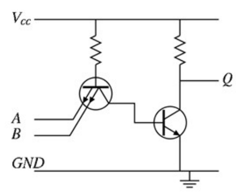




Digital Logic

Logic Families

- TTL Characteristics.
  - Transistor-Transistor-Logic.
  - Introduced in 1963 by Sylvania.
  - +5VDC supply voltage.
  - High level: >2.0 volts.
  - Low level: < 0.8 volts.
  - Threshold: ~0.7 volts.



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Digital Logic

Logic Families

- TTL Characteristics.
  - Relatively high current consumption.
  - Relatively poor noise immunity.
    - ~1.2 volts.
  - Unconnected inputs are in a high logic state.
  - The best practice is to use pull-up or pull-down resistors on unused inputs.
    - A resistor tied to +5V to force a high voltage input state.
    - A resistor tied to 0V to force a low voltage input state.

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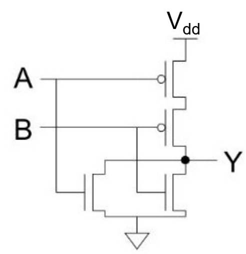
Digital Logic

- Logic Families
  - CMOS Characteristics.
    - Complementary Metal-Oxide Semiconductor.
    - Introduced by RCA in the late 1960s.



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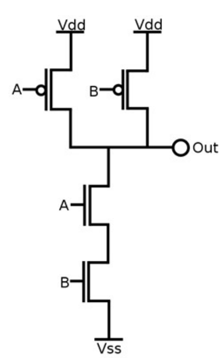
Digital Logic

- Logic Families
  - CMOS Characteristics.
    - 3-18 VDC supply voltage.
    - High level: V_{dd} – 0.1 volts.
    - Low level: V_{ss} + 0.1 volts.
    - Threshold: ~ ½ supply voltage.
    - High noise immunity
      - ~V_{dd} – 0.2 volts.
    - Sensitive to static damage.
    - Low power consumption.
      - A current pulse occurs during switchover.



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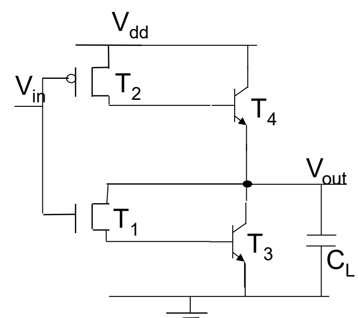
Digital Logic

BiCMOS Logic

- Both bipolar & CMOS devices on the same chip.
  - Has the high input impedance of CMOS.
    - Static-sensitive.
  - Has the low output impedance of bipolar.
    - Higher power consumption.
  - Complex manufacturing process.
    - More expensive.



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Digital Logic

Programmable Logic

- Programmable Logic Device (PLD).
  - A programmable collection of logic gates and circuits in a single integrated circuit.
- Programmable Gate Array (PGA).
  - Complex logic functions can be created in a single integrated circuit.
- Field-Programmable Gate Array (FPGA).
  - The device can be programmed by the customer & not just by the manufacturer.

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E6C04 -- Which of the following is an advantage of BiCMOS logic?

A. Its simplicity results in much less expensive devices than standard CMOS
B. It is immune to electrostatic damage
➡ C. It has the high input impedance of CMOS and the low output impedance of bipolar transistors
D. All these choices are correct

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E6C05 -- What is an advantage of CMOS logic devices over TTL devices?

A. Differential output capability
B. Lower distortion
C. Immune to damage from static discharge
➡ D. Lower power consumption

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E6C06 -- Why do CMOS digital integrated circuits have high immunity to noise on the input signal or power supply?

A. Large bypass capacitance is inherent
B. The input switching threshold is about two times the power supply voltage
➡ C. The input switching threshold is about one-half the power supply voltage
D. Bandwidth is very limited

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E6C07 -- What best describes a pull-up or pull-down resistor?

A. A resistor in a keying circuit used to reduce key clicks
➡ B. A resistor connected to the positive or negative supply line used to establish a voltage when an input or output is an open circuit
C. A resistor that ensures that an oscillator frequency does not drift
D. A resistor connected to an op-amp output that prevents signals from exceeding the power supply voltage

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E6C09 -- What is a Programmable Logic Device (PLD)?

A. A logic circuit that can be modified during use

B. A programmable collection of logic gates and circuits in a single integrated circuit

C. Programmable equipment used for testing digital logic integrated circuits

D. A type of transistor whose gain can be changed by digital logic circuits

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Questions?

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Amateur Extra Class

Next Week

Chapter 6 (Part 1)

Electronic Circuits

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