Amateur Extra License Class

1

Amateur Extra Class

Chapter 5 Components and Building Blocks

2

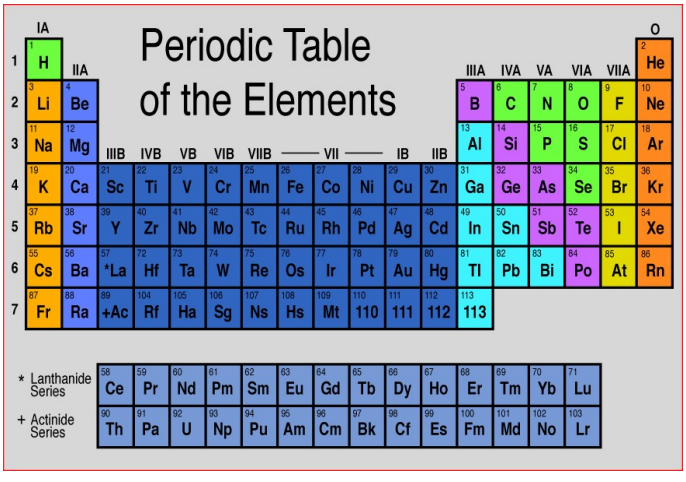
Semiconductor Devices

Materials

- Atomic Structure.
  - Nucleus (Protons & Neutrons).
  - Electrons.
    - Electrons are organized into orbits around the nucleus.
    - These orbits are layered in what are called “shells”.
  - Every element is assigned an atomic number.
    - Atomic number = Number of protons in nucleus.
    - Atomic number = Number of electrons (if atom is not ionized).

3

Semiconductor Devices



4

Semiconductor Devices

Materials

- The electrons in the 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.
    - For Hydrogen & Helium, a full shell = 2 electrons.
    - For all other elements, a 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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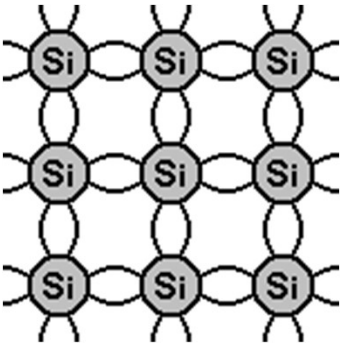
Semiconductor Devices

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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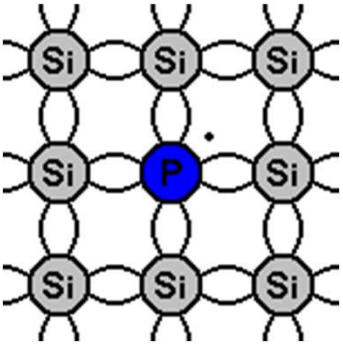
Semiconductor Devices

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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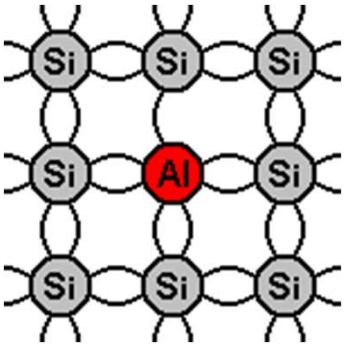
Semiconductor Devices

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

11

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

A. N-type

B. P-type

C. Bipolar

D. Insulated gate

12

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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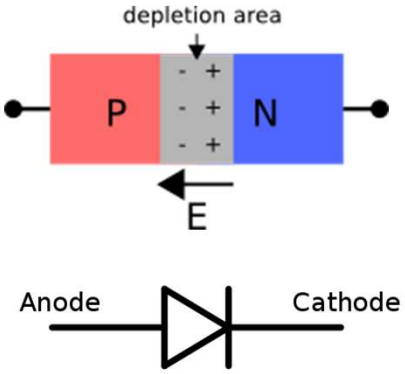
Semiconductor Devices

Junction Diodes

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



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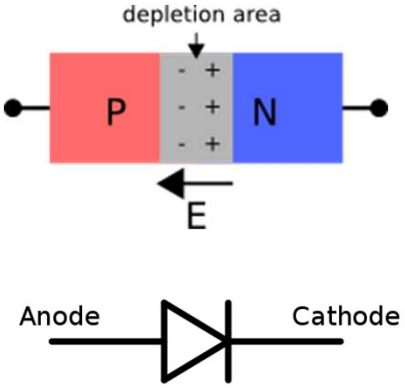
Semiconductor Devices

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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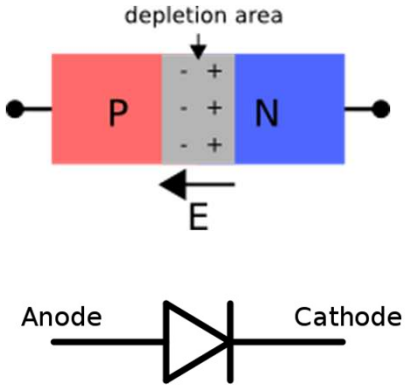
Semiconductor Devices

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

- All junction diodes must have a minimum forward voltage applied before current can flow.
- This voltage is called the “Forward Voltage Drop” and varies according to the type of material.
  - 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

- All junction diodes as rated for a maximum reverse voltage and a maximum forward current flow.
  - The maximum reverse voltage is called the “Peak Inverse Voltage” or “PIV”.
    - Also known as the “avalanche voltage”.
  - The Maximum Average Forward Current rating is really a rating of the maximum allowable junction temperature.

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

19

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

20

E6B07 -- What causes a junction diode to fail from excessive current

A. Excessive inverse voltage
B. Excessive junction temperature
C. Insufficient forward voltage
D. Charge carrier depletion

21

Semiconductor Devices

Schottky Barrier Diodes

- P-type material is 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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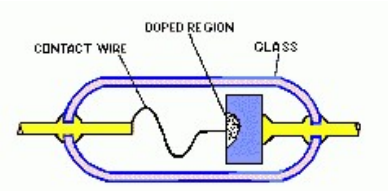
Semiconductor Devices

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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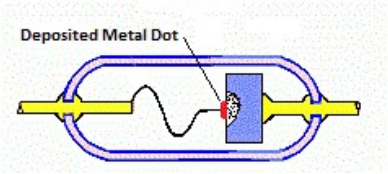
Semiconductor Devices

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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Semiconductor Devices

Schottky Barrier Diodes

- Lower forward voltage drop results in less power loss (higher efficiency) in high-current applications such as power supplies.

25

E6B02 -- Which characteristic of a Schottky diode makes it a better choice than a silicon junction diode for use as a power supply rectifier?

A. Much higher reverse voltage breakdown

B. More constant reverse avalanche voltage

C. Longer carrier retention time

➡ D. Lower forward voltage drop

26

E6B06 -- Which of the following is a common use of a Schottky diode?

A. In oscillator circuits as the negative resistance element
B. As a variable capacitance in an automatic frequency control circuit
C. In power supplies as a constant voltage reference
D. As a VHF/UHF mixer or detector

27

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

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

28

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

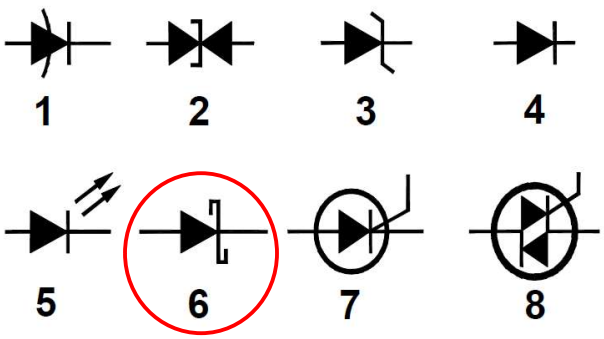
A. As a constant current source
B. As a constant voltage source
C. As an RF detector
D. As a high voltage rectifier

29

E6B10 -- In Figure E6-2, which is the schematic symbol for a Schottky diode?

A. 1
B. 6
C. 2
D. 3

Figure E6-2



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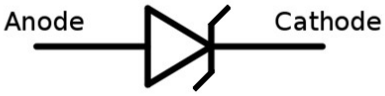
Semiconductor Devices

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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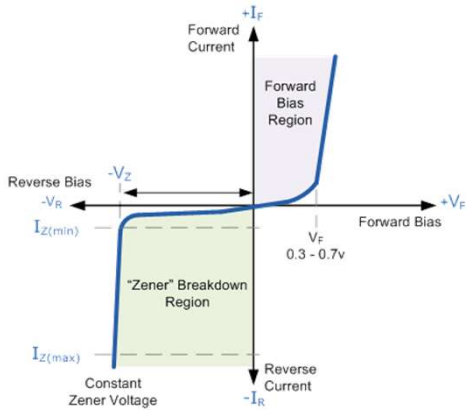
Semiconductor Devices

Zener Diodes



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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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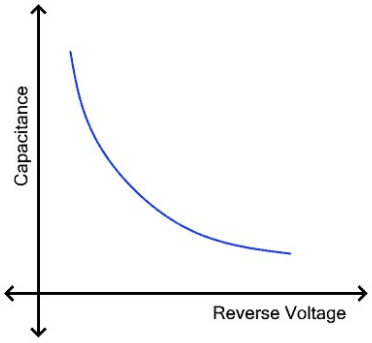
Semiconductor Devices

Varactor Diodes



Characteristics curve of Varactor Diode

35

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

- A 3rd layer of undoped (intrinsic) material is added between the p-type material & the n-type material.
- The forward resistance varies with the forward bias voltage.
  - More voltage → lower resistance.

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Semiconductor Devices

PIN Diodes

- The layer of undoped material increases the thickness of the depletion layer, resulting in a low junction capacitance
  - Used for RF attenuation & switching.
    - Nearly all hand-held transceivers use PIN diodes to switch the antenna between the transmitter & the receiver.

38

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

39

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

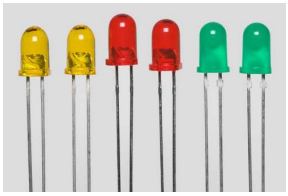
➡ A. Forward DC bias current
B. A variable RF reference voltage
C. Reverse voltage larger than the RF signal
D. Capacitance of an RF coupling capacitor

40

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).



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Semiconductor Devices

Diodes, Transistors, and Integrated Circuits.

- Light-Emitting Diodes (LEDs).
  - LEDs produce light by the recombination of electrons and holes in the junction.
  - The holes (valence band) and electrons (conduction band)) have different energy levels.
  - This energy difference is called the “band gap”

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Semiconductor Devices

Diodes, Transistors, and Integrated Circuits.

- Light-Emitting Diodes (LEDs).
  - The size of the band gap is determined by the semi-conductor material used to construct the diode.
  - The size of the band gap determines the frequency (color) of the light emitted.
  - The size of the band gap determines the forward voltage drop of the diode.

43

E6B03 -- What property of an LED's semiconductor material determines its forward voltage drop?

A. Intrinsic resistance

B. Band gap

C. Junction capacitance

D. Junction depth

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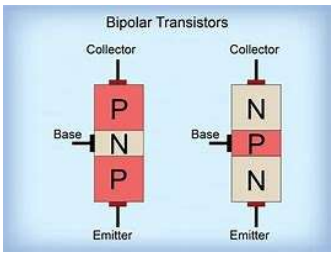
Semiconductor Devices

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



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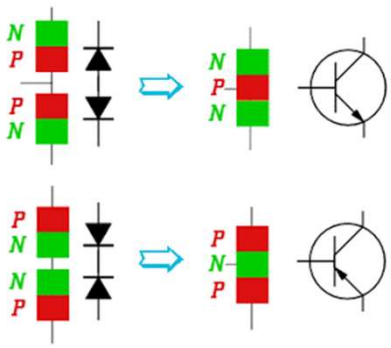
Semiconductor Devices

- Bipolar Transistors



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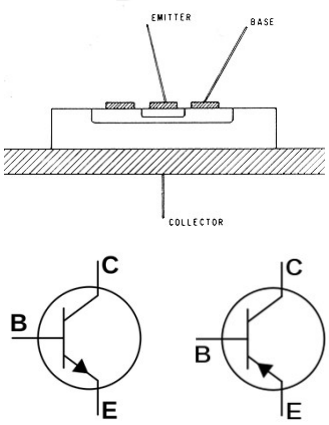
Semiconductor Devices

- 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.

48

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 the change in base current

C. The breakdown voltage of the base-to-collector junction

D. The switching speed

53

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

54

E6A08 -- What is the term for the frequency at which the grounded-base current gain of a bipolar junction 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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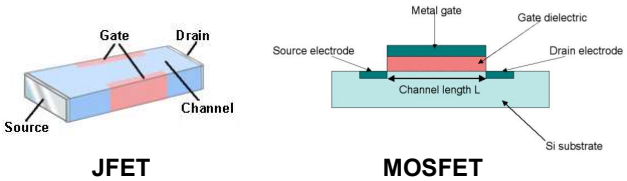
Semiconductor Devices

Field Effect Transistors

- There are two common types of FETs:
  - Junction field effect transistor (JFET).
  - Metal oxide semiconductor field effect transistor (MOSFET).



JFET MOSFET

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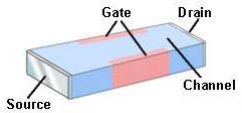
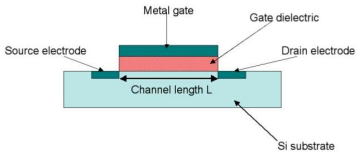
Semiconductor Devices

Field Effect Transistors

- The first type of FET invented was the JFET.
- Today, the most common type of FET is the MOSFET.



JFET



MOSFET

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Semiconductor Devices

Field Effect Transistors

- Field effect transistors or FETs are different than bipolar transistors.

	Bipolar Transistor	JFET	MOSFET
Controlled by	Base Current	Gate Voltage	Gate Voltage
Input Impedance	Low	>10 MΩ	>100 MΩ

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Semiconductor Devices

Field Effect Transistors

- The gain of a FET is measured in transconductance.
  - Unit of measurement is Siemens.
  - $G = I_D / V_G$

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Semiconductor Devices

Field-Effect Transistors

- JFETs.
  - 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 (>10 MΩ).
  - Low output impedance.

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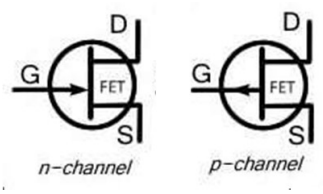
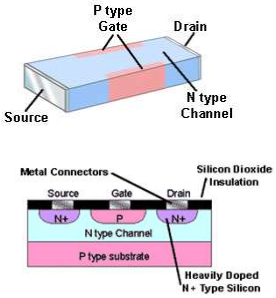
Semiconductor Devices

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





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Semiconductor Devices

Field-Effect Transistors

- MOSFET.
  - Gate is insulated from the source-drain channel by a layer of metal oxide.
    - No gate current flow.
  - Extremely high input impedance (>100 MΩ).
    - Susceptible to damage from static discharge.
      - Often have internal Zener diodes to protect gate.
  - Low output impedance.

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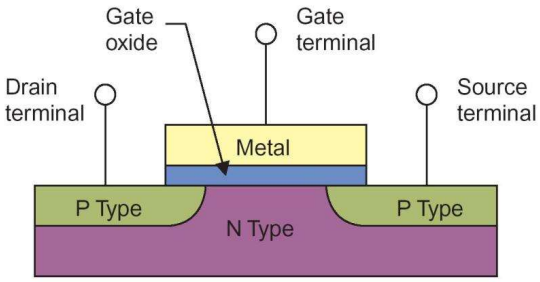
Semiconductor Devices

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

- 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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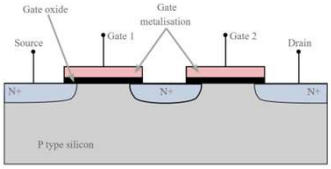
Semiconductor Devices

Field-Effect Transistors

- Dual-gate FET's.
  - MOSFETs can be constructed with more than one gate.
  - Second gate allows 2 input signals to control the current flow.
    - RF Mixers.



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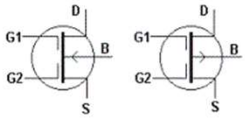
Semiconductor Devices

Field-Effect Transistors

- MOSFETs.

Depletion Mode Enhancement Mode



Dual-Gate

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E6A05 -- How does DC input impedance at the gate of a field-effect transistor (FET) compare with that 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

68

E6A09 -- What is a depletion-mode field-effect transistor (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. An FET that exhibits very high electron mobility due to a lack of holes in the N-type material

D. An 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?

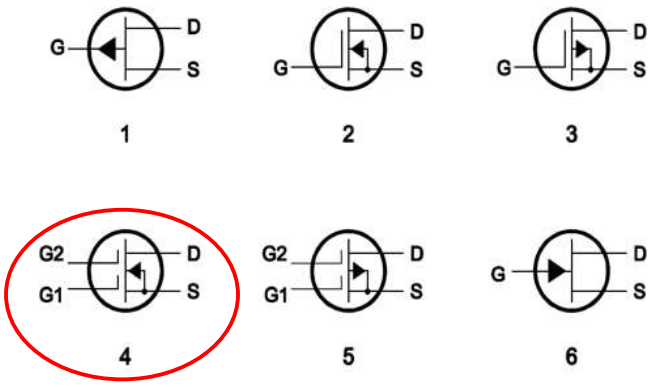
A. 2

B. 4

C. 5

D. 6

Figure E6-1

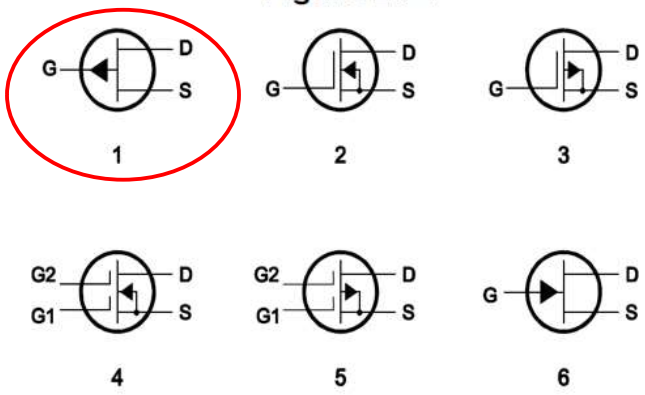


70

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



71

E6A12 -- What is the purpose of connecting Zener diodes between a MOSFET gate and its source or drain?

- 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 protect the gate from static damage

72

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.

73

Semiconductor Devices

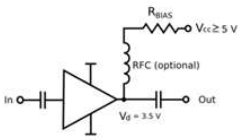
RF Integrated Devices

- 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.
    - MMICs are available with noise figures of 0.5 dB or less.

74

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)

75

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.

76

Semiconductor Devices

RF Integrated Devices

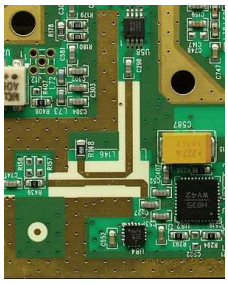
- Microstrip Construction.
  - Uses a double-sided PCB.
    - One side of the PCB is a ground plane.
  - Precisely-sized traces form 50Ω transmission line segments.
  - Components are soldered directly to the transmission line segments.

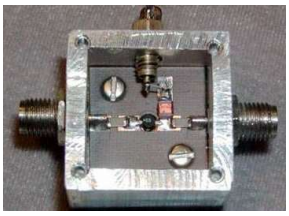
77

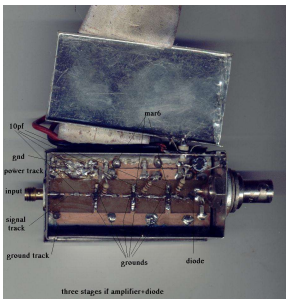
Semiconductor Devices

RF Integrated Devices

- Microstrip Construction.







78

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

79

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

80

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

81

E6E04 -- Which is the most common input and output impedance of MMICs?

A. 50 ohms
B. 300 ohms
C. 450 ohms
D. 75 ohms

82

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

A. 0.5 dB
B. -10 dB
C. 44 dBm
D. -20 dBm

83

E6E06 -- What characteristics of MMICs make them 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. Extremely high Q factor and high stability over a wide temperature range
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

84

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

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

85

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

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

86

E9F05 -- What is microstrip?

A. Special shielding material designed for microwave frequencies

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

87

Break

88

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.
  - **ALL** semiconductor junctions exhibit the photoconductive effect.

89

Optoelectronics

Optoelectronic Components

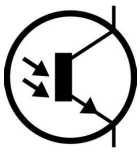
- Most semiconductor devices are enclosed in a metal or plastic package to prevent ambient light from affecting the operation of the device.
- Optoelectronic semiconductors have a transparent case or a window in the case to allow ambient light to reach the junction & alter the operation of the device.

90

Optoelectronics

Optoelectronic Components

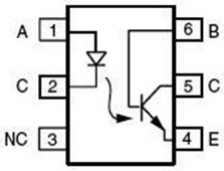
- Phototransistor.
  - A transistor in a package that allows light to hit the junction.
  - The transistor turns on when it is exposed to light.
  - An external base connection may or may not be provided.

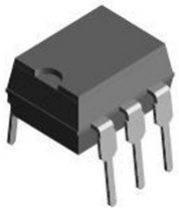


91

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.

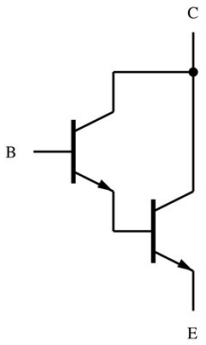




92

Optoelectronics

- Optoelectronic Components
  - Optocouplers and optoisolators.
    - One 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.



93

Optoelectronics

- Optoelectronic Components
  - Optocouplers and optoisolators.
    - Instead of the LED and phototransistor being enclosed in an opaque package, sometimes there are transparent “windows” that allow external factors to affect the operation.
    - This allows the detection of the presence or the absence of an object.

94

Optoelectronics

- Optoelectronic Components
  - Optocouplers and optoisolators.
    - An LED & a phototransistor may be packaged facing each other with small gap between them.
    - This allows detecting the presence or the absence of an object by blocking the light from the LED.

95

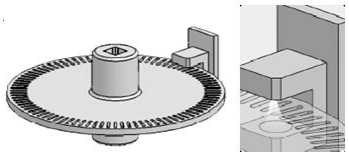
Optoelectronics

- Optoelectronic Components
  - Optocouplers and optoisolators.
    - An LED & a phototransistor may be packaged facing the same direction.
    - This allows the detection of the presence or the absence of an object by reflecting the light from the LED off of the external object.

96

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.

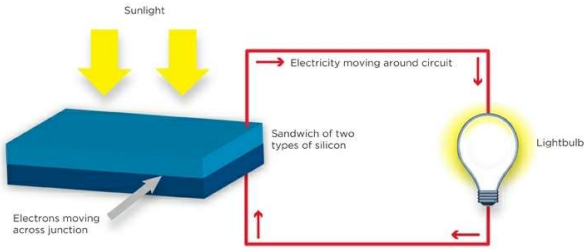


97

Optoelectronics

Photovoltaic Cells

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



98

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.
    - Efficiency is the relative fraction of the light energy that is converted to electrical energy.
  - A fully-illuminated junction yields about 0.5 VDC.

99

Optoelectronics

Photovoltaic Cells

- Photovoltaic cells are rapidly becoming widely used for commercial power generation.
- Inverters are used to convert the DC voltage produced by the photovoltaic cells to an AC voltage.

100

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

A. Protons
B. Photons
C. Electrons
D. Holes

101

E6F02 -- What happens to photoconductive material when light shines on it?

A. Resistance decreases
B. Resistance increases
C. Reflectivity increases
D. Reflectivity decreases

102

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

103

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 effect that causes a photodiode to emit light when a voltage is applied
D. The effect that causes a phototransistor s beta to decrease when exposed to light

104

E6F05 -- Which of the following describes an optical shaft encoder?

A. A device that detects rotation by interrupting a light source with a patterned wheel
B. A device that measures the strength of a beam of light using analog-to-digital conversion
C. An optical computing device in which light is coupled between devices by fiber optics
D. A device for generating RTTY signals by means of a rotating light source

105

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

A. Polyphenol acetate
B. Argon
C. Crystalline semiconductor
D. All these choices are correct

106

E6F07 -- What is a solid state relay?

A. A relay that uses 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 switch that uses a monostable multivibrator circuit

107

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 an electrical isolation between a control circuit and the circuit being switched

D. Optoisolators eliminate the effects of reflected light in the control circuit

108

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

A. The output RF power divided by the input DC power
B. The output in lumens divided by the input power in watts
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

109

E6F10 -- What is the most common material used in power-generating photovoltaic cells?

A. Selenium
B. Silicon
C. Cadmium sulfide
D. Indium arsenide

110

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

A. 0.5 volts
B. 0.7 volts
C. 1.1 volts
D. 1.5 volts

111

E7D11 -- What is the purpose of an inverter connected to a solar panel output?

A. Reduce AC ripple on the output
B. Maintain voltage with varying illumination levels
C. Prevent discharge when panel is not illuminated
D. Convert the panel s output from DC to AC

112

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.

113

Digital Logic

Logic Basics

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

114

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.

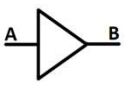
115

Digital Logic

Logic Basics

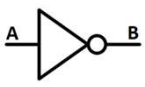
- One-input elements.

Non-Inverting Buffer



A	B
0	0
1	1

Inverting Buffer (NOT Gate)



A	B
0	1
1	0

116

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

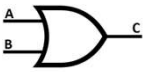
117

Digital Logic

Logic Basics

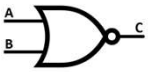
- The OR/NOR operations.
  - The output is true/false if one or more of the inputs are true.

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

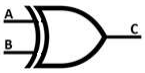
118

Digital Logic

Logic Basics

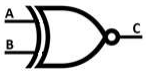
- The Exclusive OR (XOR/NOR) operations.
  - The output is true/false if one and only one of the inputs is true.

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

119

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.

120

Digital Logic

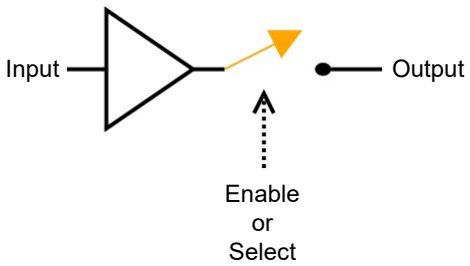
Logic Basics

- 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.

121

Digital Logic

Tri-State Logic



122

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. Logic with three output impedances which can be selected to better match the load impedance

D. A counter with eight states

123

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

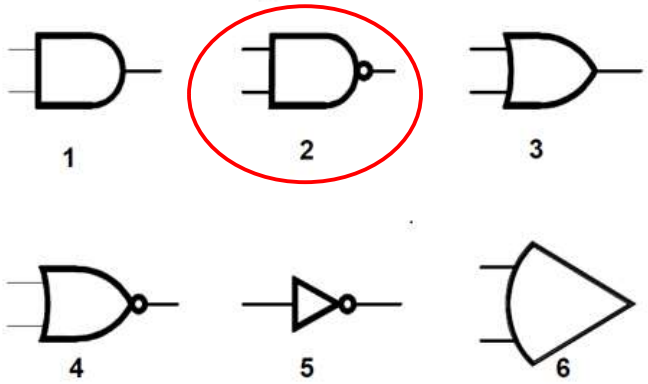
A. 1

B. 2

C. 3

D. 4

Figure E6-3

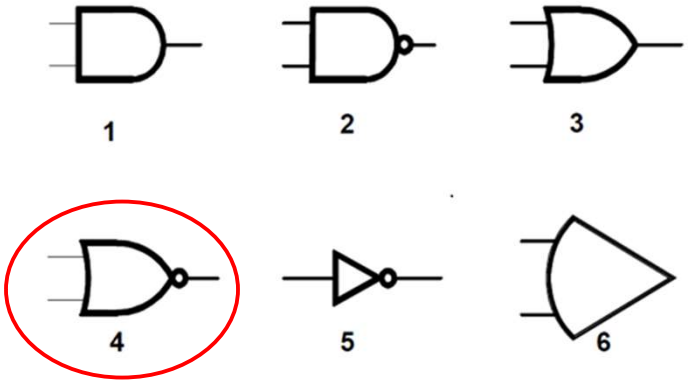


124

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

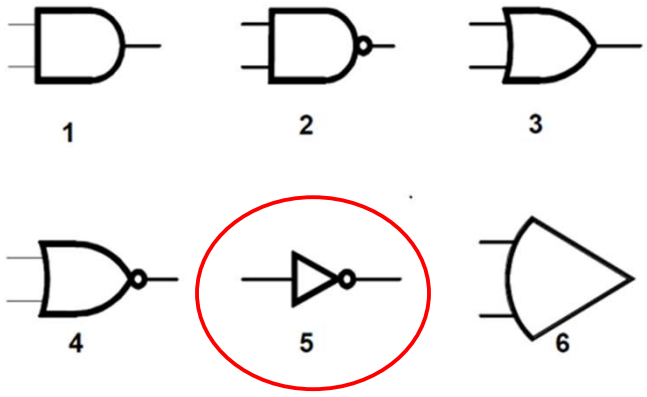


125

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



126

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

A. It produces a 0 at its output only if all inputs are 0
B. It produces a 1 at its output only if all inputs are 1
C. It produces a 0 at its output if some but not all inputs are 1
D. It produces a 0 at its output only if all inputs are 1

127

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

A. It produces a 1 at its output if any input is 1
B. It produces a 0 at its output if all inputs are 1
C. It produces a 0 at its output if some but not all inputs are 1
D. It produces a 1 at its output if all inputs are 0

128

E7A09 -- What logical operation is performed by a two-input exclusive NOR gate?

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

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

C. It produces a 0 at its output if one and only one of its inputs is 1

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

129

E7A10 -- What is a truth table?

A. A list of inputs and corresponding outputs for an op-amp

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

C. A diagram showing logic states when the digital gate output is true

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

130

E7A11 -- What does positive logic mean in reference to logic devices?

A. The logic devices have high noise immunity
B. High voltage represents a 1, low voltage a 0
C. The logic circuit is in the true condition
D. 1s and 0s are defined as different positive voltage levels

131

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”.

132

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.

133

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.

134

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 negative edge triggered if the output changes state on the 1-to-0 transition of the clock pulse.

135

Digital Logic

Sequential and Synchronous Logic

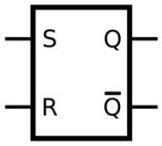
- Dynamic versus Static Inputs.
  - Static inputs.
    - a.k.a. – Level-triggered.
    - The flip-flop changes state when any input changes state.

136

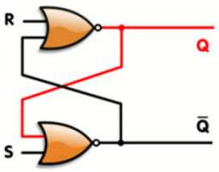
Digital Logic

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



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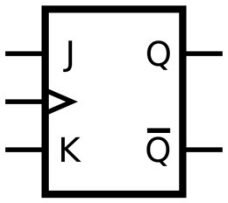
Digital Logic

Sequential and Synchronous Logic

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



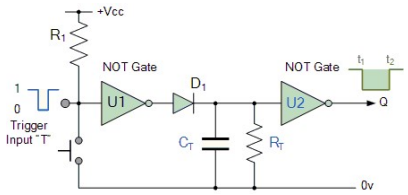
Clock (>)	J	K	Action
0	--	--	No change
1	0	0	No change
1	0	1	Q = 0
1	1	0	Q = 1
1	1	1	Toggle (Q = not Q)

138

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 an R-C time constant.



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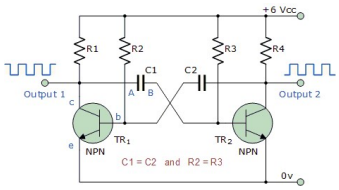
Digital Logic

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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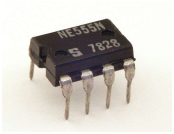
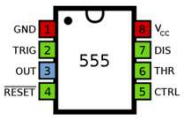
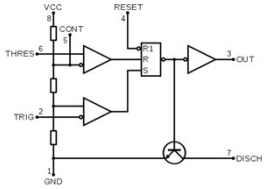
Digital Logic

Sequential and Synchronous Logic

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







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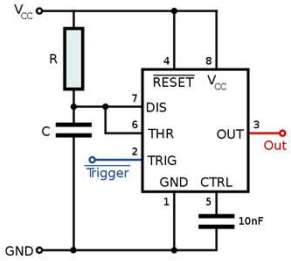
Digital Logic

Sequential and Synchronous Logic

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



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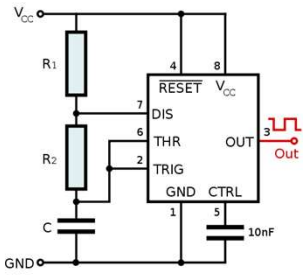
Digital Logic

Sequential and Synchronous Logic

- 555 Timer I.C.
  - Configured as an astable multivibrator
  - $f = \frac{1.46}{C1 \times (R1 + (2 \times R2))}$
  - 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 count 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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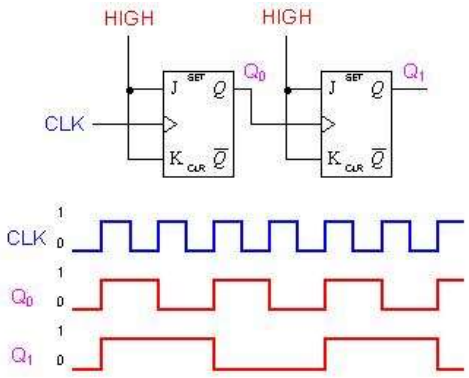
Digital Logic

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



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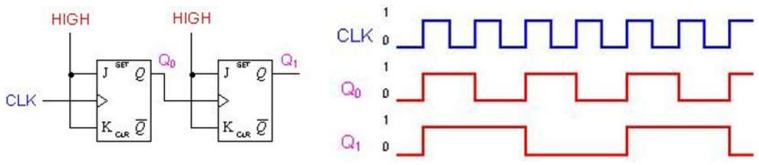
Digital Logic

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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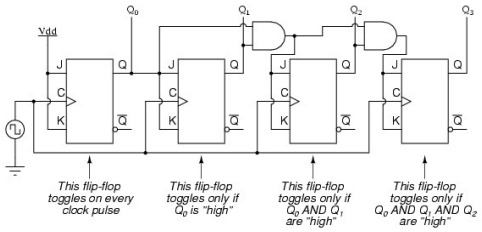
Digital Logic

- 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.



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E7A01 -- Which circuit is bistable?

A. An AND gate

B. An OR gate

C. A flip-flop

D. A bipolar amplifier

148

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

149

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

150

E7A04 -- How many flip-flops are required to divide a signal frequency by 16?

A. 4
B. 6
C. 8
D. 16

151

E7A05 -- Which of the following circuits continuously alternates between two states without an external clock signal?

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

152

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

A. It switches temporarily to an alternate state for a set time
B. It produces a continuous square wave
C. It stores one bit of data
D. It maintains a constant output voltage, regardless of variations in the input voltage

153

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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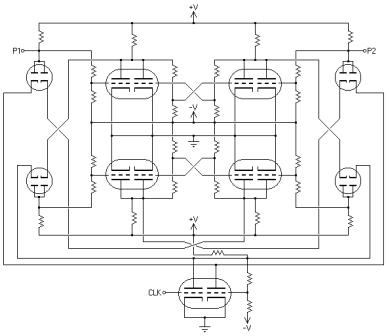
Digital Logic

Logic Families (Ancient History)

- Vacuum tube.



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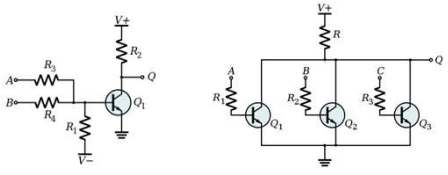
Digital Logic

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.



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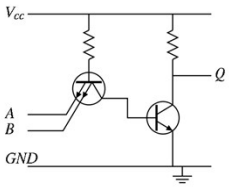
Digital Logic

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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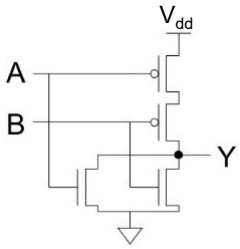
Digital Logic

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



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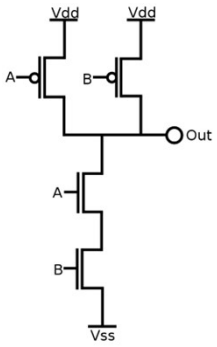
Digital Logic

- 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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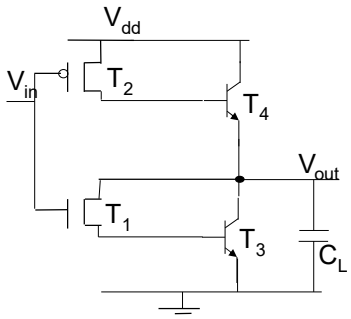
Digital Logic

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.
  - Programing is accomplished using a special language called “Hardware Description Language (HDL)”.

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Digital Logic

Programmable Logic

- Programmable Gate Array (PGA).
  - Complex logic functions can be created in a single integrated circuit.
  - Originally, programming was done at design time and could be changed.
- Field-Programmable Gate Array (FPGA).
  - The device can be programmed by the customer & not just by the manufacturer.

163

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

164

E6C05 -- Which of the following digital logic families has the lowest power consumption?

A. Schottky TTL
B. ECL
C. NMOS
D. CMOS

165

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

166

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

167

E6C09 -- What is used to design the configuration of a field-programmable gate array (FPGA)?

A. Karnaugh maps

B. Hardware description language (HDL)

C. An auto-router

D. Machine and assembly language

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Questions?

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Amateur Extra Class

Next Week

Chapter 6 (Part 1)

Electronic Circuits

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