Components and Building Blocks

Chapter 5

Semiconductor Devices (Materials)

- Normally made from Silicon (Si) or Germanium (Ge)
- Atoms of both have 4 electrons in their outer layer of shell called valance electrons
  - These outer 4 electrons are shared with other atoms to form a crystal
- Crystals of pure Silicon or Germanium are not normally good conductors or insulators

Semiconductor Devices (Materials)

- Manufactures add other atoms into the crystals
  - This is called doping
  - These atoms are referred to as impurities
  - The impurities are chosen for there ability to alter the way electrons are shared within the crystal
- Arsenic (As) and antimony (Sb) examples of impurities
  - They have five electrons in there outer layer
  - Adds a free electron to create an N-type material

Semiconductor Devices (Materials)

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

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

Semiconductor Devices (Materials)

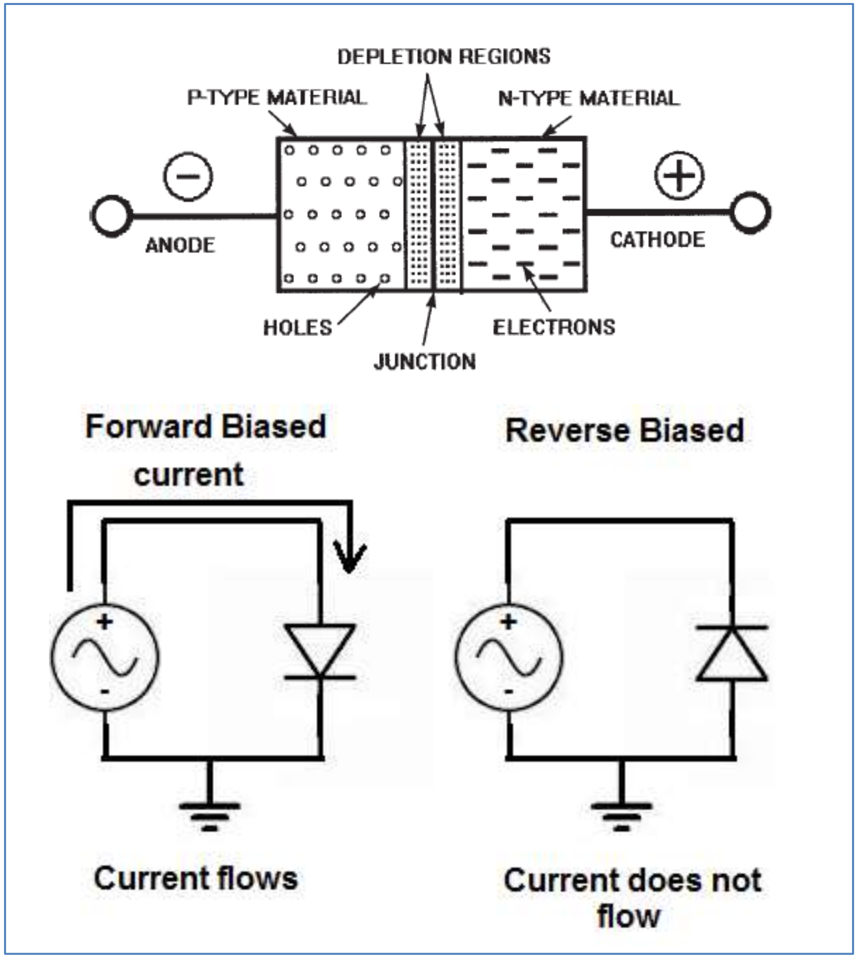
- Majority Charged Carriers
  - N-type material = Electron
  - P-type material = Hole
- Other semiconductor materials
  - Gallium-Arsenide (GaAs)
    - LED's
    - Microwave frequencies

Semiconductor Devices (Diodes)

- A diode allows current flow in one direction and resists current flow in the other direction.
- There are two terminals
  - Anode – P-type material
  - Cathode - N-type material
- Current flows with a positive connection to the Anode and a negative connection to the Cathode
  - Current is blocked if the leads are reversed

Junction Diodes

- Current flows with positive voltage on anode (Forward Bias)
- Current blocked if negative voltage on Anode (Reverse Bias)
- Forward Voltage
  - .6 V for Silicon
  - .3 for Germanium



Diode Ratings

- Peak Inverse Voltage (PIV)
  - Avalanche point
    - A voltage above this in the reverse direction will destroy the diode.
- Maximum Forward Current
  - Junction temperature rises with higher current
  - 6 watts is dissipated with 10 amps through a silicon diode $P = I \times E = 10 \times .6$
  - <u>Excessive junction temperature</u> will destroy diode

Schottky Barrier Diodes

- P-type material replaced with metal layer
- Lower forward voltage than an all semiconductor junction
  - ,2 to .5 compared to the .6 to .7 for silicon
- Results in lower power dissipation
- Widely used in power supply circuits

Point-Contact Diodes

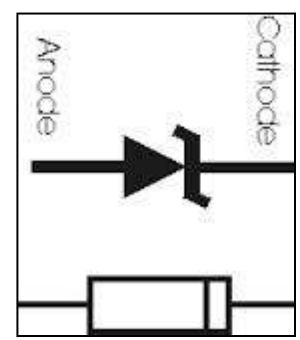
- Schottky Barrier
- Lower capacitance than junction diodes
  - Usually 1pf or less
- Designed for RF applications
- Smaller surface area at the junction
- Better suited for VHF & UHF applications
  - UHF mixers
  - RF detectors at VHF and below

Hot-Carrier Diodes

- Schottky Barrier
- Low internal capacitance
- Good high frequency characteristics
- Improved electrical and mechanical performance over a point-contact diode
- Used in VHF & UHF mixers and detectors

Zener Diodes

- Used as voltage reference and regulators
- The Zener voltage is the voltage required to cause avalanche
  - Can safely withstand avalanche current
- <u>Maintains a stable voltage over a wide current range</u>



Tunnel Diode

- No rectifying properties
- Has negative resistance when properly biased
  - As voltage increases current decreases
- <u>Capable of amplification and oscillation</u>
- Obsolete and not used today

Varactor Diode (Varicap)

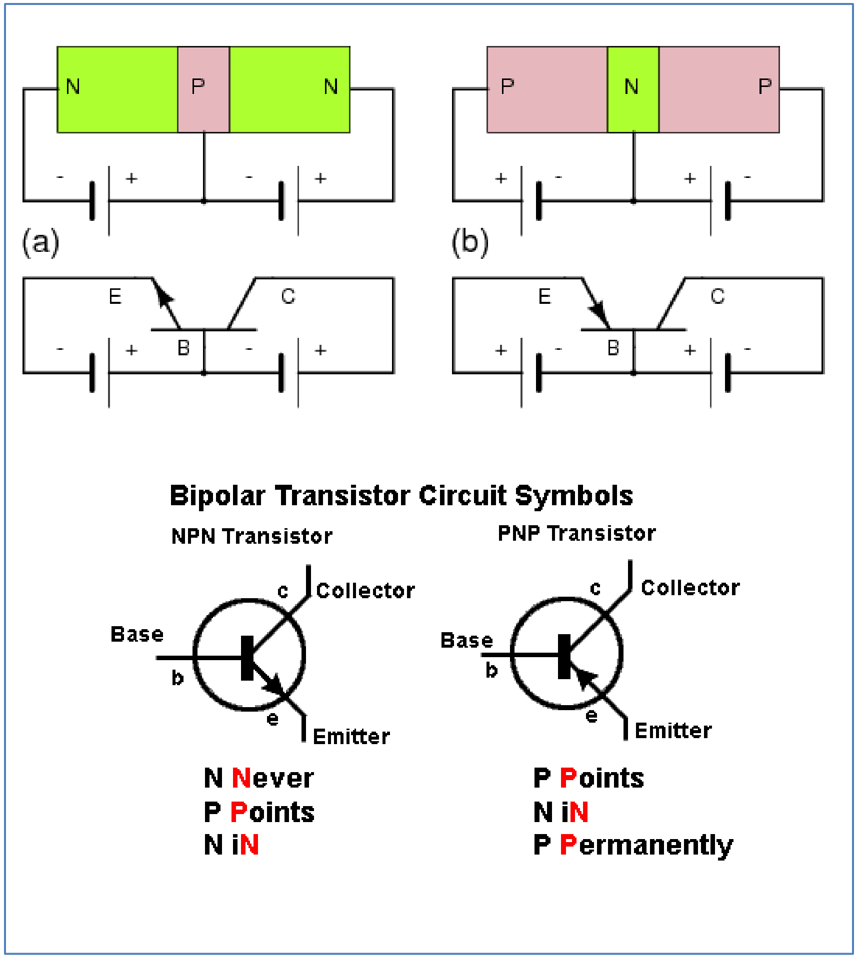
- Change capacitance by varying the reverse bias
  - <u>Creates voltage controlled capacitors</u>
- Range from a few pF to over 100 pF
- Used in frequency multipliers, tuned circuits and modulators

Pin Diode

- Formed by diffusing P-type and N-type layers onto opposite ends of a large almost pure intrinsic material layer.
- Forward resistance varies inversely with forward DC bias voltage
- The amount of resistance to RF signals can be changed by changing the forward bias
- Used as an RF switch or attenuator

Bipolar Transistor

- Three doped layers
  - NPN
  - PNP
- Three terminals
  - Base
  - Emitter
  - Collector
- Wide variety of applications



Bipolar Transistor Characteristics

- Current Gain
  - Beta "β"
    - Ratio of collector to base current
    - $\beta = I_c / I_b$
  - Alpha α
    - Ratio of collector to emitter current
    - $\alpha = I_c / I_e$

Bipolar Transistor Characteristics

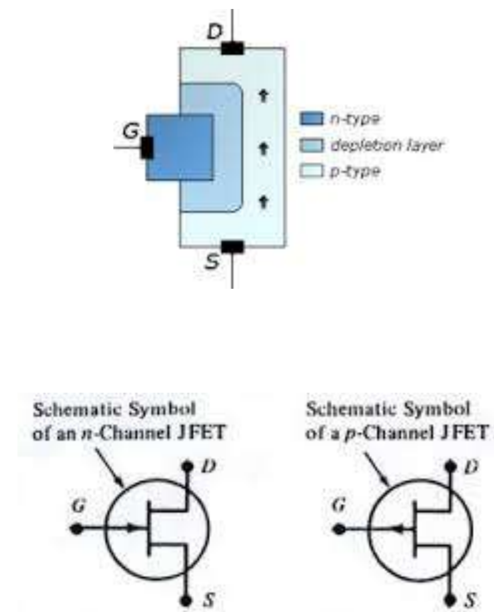
- Alpha cutoff frequency
  - <u>Frequency at which current gain drops to 0.707 times the gain at 1 kHz</u>
  - Practical upper frequency limit for common-base amplifier
- Beta cutoff frequency
  - Frequency at which current gain drops to 0.707 times the gain at 1 kHz
  - Practical upper frequency limit for common-emitter amplifier

Field Effect Transistor

- Gate voltage is used to control current flow
- Two types
  - Junction FET (JFET)
  - Metal-oxide semiconductor FET (MOSFET)
- High input impedance compared to Bipolar Transistor
  - Typically 1 meg ohm or greater

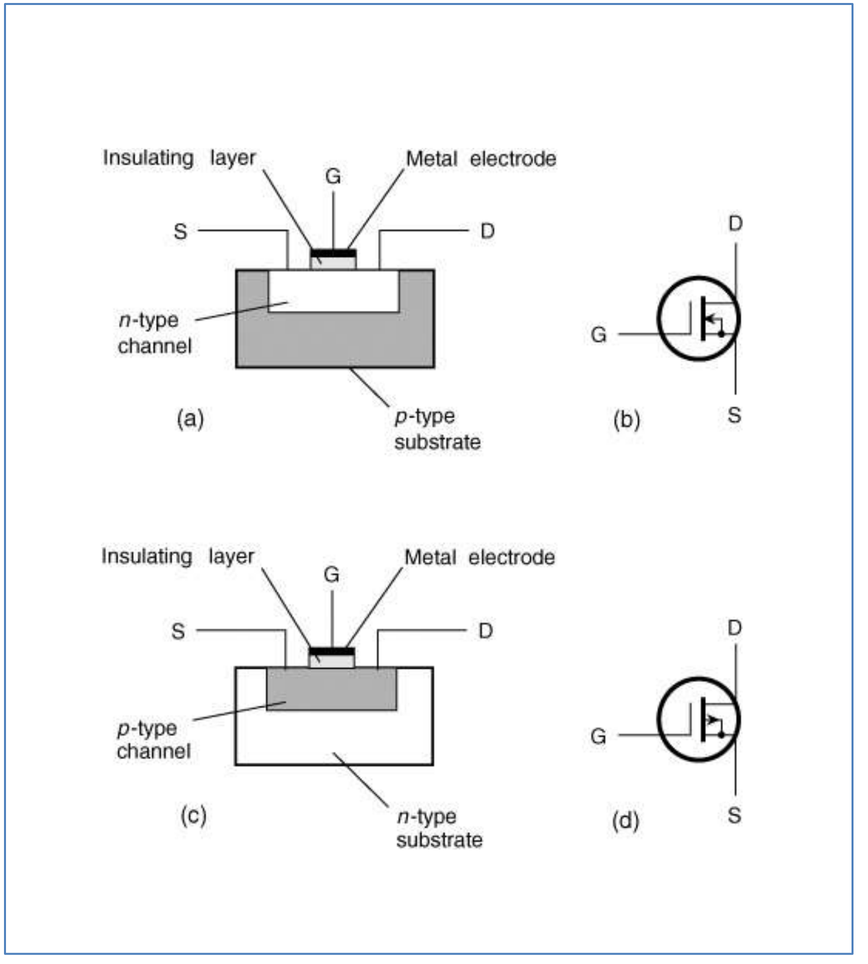
JFET Transistor

- <u>Has high input impedance compared to Bipolar Transistor</u>
- Three terminals
  - Source
  - Drain
  - Gate
- Source and Drain connected by the channel
  - Voltage change on the gate controls current flow in the channel



MOSFET Transistor

- Higher input impedance than JFET
- Some MOSFETs have two gates with different voltages for special applications
- Most MOSFETS have built in gate protecting Zener diodes



Enhancement & Depletion Mode FETs

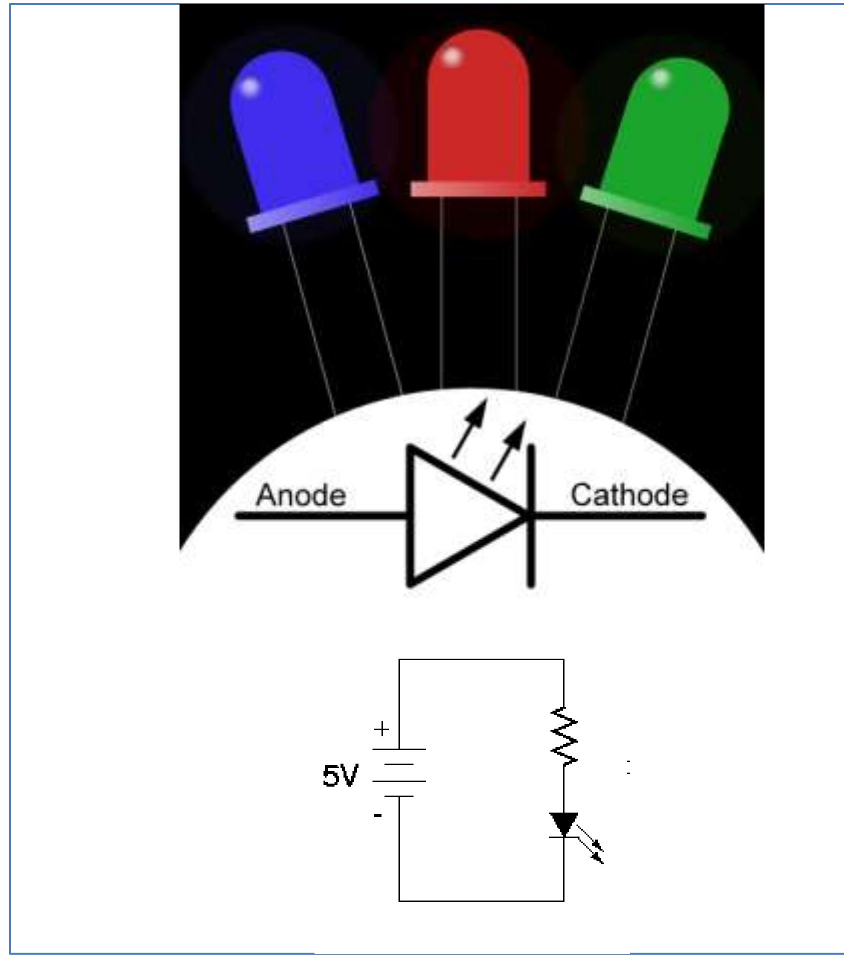
- Depletion Mode
  - <u>Current flows between source and drain when no gate voltage is applied</u>
  - Gate is reverse biased in operation
  - Current decreases when reverse bias is applied
- Enhancement Mode
  - Requires gate voltage for current to flow between source and gate
  - Current increases with increase in forward bias

RF Integrated Devices

- Monolithic microwave integrated circuit (MMIC)
  - VHF, UHF, microwaves
  - <u>Typically 50Ω input and output impedance</u>
  - <u>Controlled gain, Low Noise Figure, & constant impedance over frequency range</u>
  - <u>Microstrip Construction</u>
  - <u>DC voltage connected to output lead</u>

Light-Emitting-Diodes

- Emit light when they are forward biased
- Forward voltage drop varies by color
  - Red – 1.6 volts
  - Yellow – 2 Volts
  - Green – 4 Volts
- Typically 10 to 20 ma for full brightness



Liquid-Crystal-Displays

- <u>Uses crystalline liquid in conjunction with polarizing filters</u>
  - Becomes opaque when voltage is applied
- <u>A primary advantage is they consume very little power compared to other display types</u>
- Slow to operate at low temperatures
- May be damaged by high temperatures

Cathode-Ray Tubes

- Used in older TVs, computer displays and oscilloscopes
- Electromagnetic deflection
  - Computer monitors
  - TVs
- Electrostatic deflection
  - More precise deflection of electron beam
  - Better for high frequency displays
    - Oscilloscopes and other test equipment

Cathode-Ray Tubes

- An electron beam is accelerated by high voltage and strikes a glass surface coated with a phosphorescent material
  - Glows when struck
  - Persistence is the length of time the glow continues after being illuminated by the beam
- To high of anode voltage will cause the beam to generate X-rays when it strikes the phosphor

Charge-Coupled Devices

- Combine digital and analog signal processing
- Array of capacitors with MOSFET switches on input and output
- Basis for modern photographic and video cameras
  - Stores photo generated charges as signals corresponding to pixels

Charge-Coupled Devices

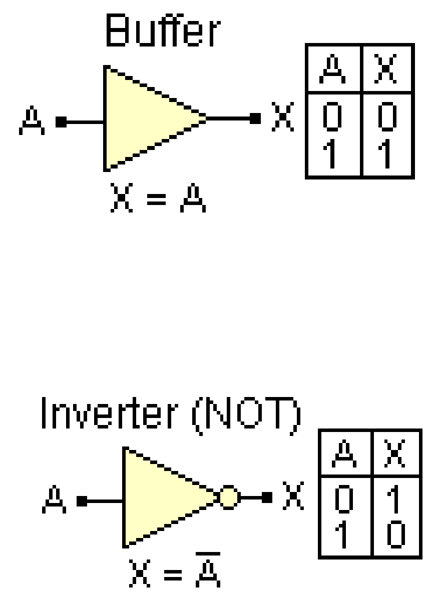
- Series of stages from the input to the output containing an analog voltage
- Values transfer from stage to stage when a clock pulse is received.
- Can not be used as an analog to digital converter

Digital Logic Basics

- The output is determined by the simultaneous levels of the inputs
- Boolean Algebra
  - Variables only have two values
    - 0 and 1
    - False or True
    - High or Low
  - Use truth tables
    - <u>Shows output for all combinations of input</u>

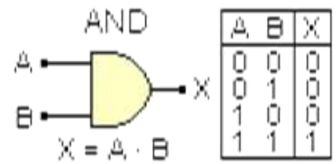
One-Input Elements

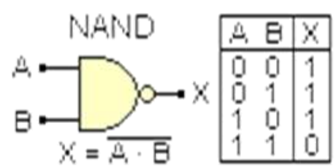
- <u>Two Elements have a single input</u>
  - Non-inverting buffer
    - Output same as input
  - Inverter or NOT
    - Output opposite of input
- The small circle on the output indicates inversion of the signal



And & NAND Gate

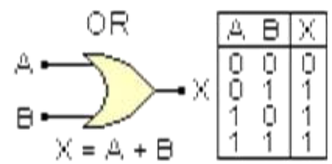
- Have two or more inputs
- Output of AND is 1 only if all inputs are 1
- Output of NAND gate is the inverse of the AND gate
- The NAND gate only has a 0 output when all of the inputs are 1

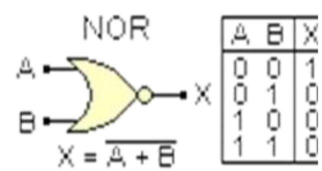




OR & NOR Gates

- The output of the OR gate is 1 if any or all inputs are 1
- The + sign is used between variables to show the OR Function
  - X = A + B
- The output of the NOR gate is the inverse of the OR gate



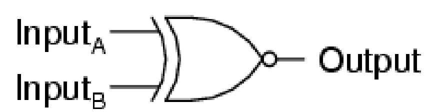


Exclusive OR & NOR Gate

- The Exclusive OR gate results in a 1 if only one of the inputs is 1
- <u>The Exclusive NOR gate results in a 0 if only 1 of the inputs are 1</u>

Exclusive-OR gate

A	B	Output
0	0	0
0	1	1
1	0	1
1	1	0



A	B	Output
0	0	1
0	1	0
1	0	0
1	1	1

Positive & Negative True Logic

- Positive logic uses highest voltage level for 1 and lowest voltage level for 0
- Negative logic is the opposite using the lowest voltage level for 1 and the highest voltage level for 0

Tri-State Logic

- Allows multiple device outputs to be connected on a single bus
- Device has a 0, 1 and High Impedance output
  - Allows only one IC to control the bus at a time
  - Other ICs are set to High Impedance which puts them in a standby state

Synchronous Logic Flip-Flops

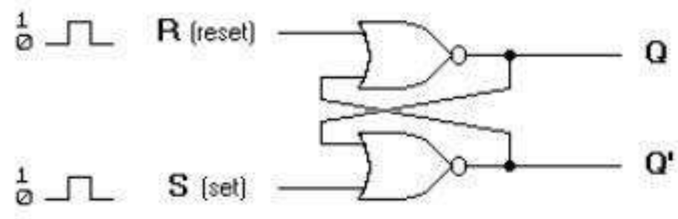
- Is a binary sequential-logic element
  - Has two stable states (bistable)
    - the set state (1 state)
    - The reset state (0 state)
  - Also know as bistable multivibrator
  - Can store 1 bit
- There are normally two outputs (Q & Q not)
  - If Q = 1 than Q not = 0
  - If Q = 0 than Q not = 1

Synchronous vs Asyncronous

- Synchronous flip-flops
  - Require a clock
  - Only change state if there is a clock signal
  - Also called clocked, clock-driven, or gated flip-flops
- Asynchronous flip-flops
  - Independent of clock
  - Output changes whenever the input changes
  - Also called unclocked or data-driven

R-S Flip-flop

- Inputs are Set and Reset
- If S and R are both 0 the output is the same as the last state change



(a) Logic diagram

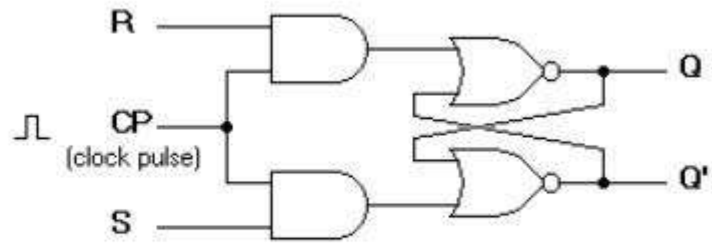
S	R	Q	Q'	
1	0	1	0	
0	0	1	0	(after S=1, R=0)
0	1	0	1	
0	0	0	1	(after S=0, R=1)
1	1	0	0	

(b) Truth table

Basic flip-flop circuit with NOR gates

Clocked R-S Flip-Flop

- Has an additional pin for the clock signal
- <u>No change in the output state can happen until a clock pulse is received</u>



(a) Logic diagram

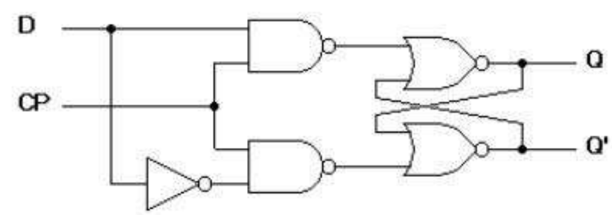
Q	S	R	Q(t+1)
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	indeterminate
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	indeterminate

(b) Truth table

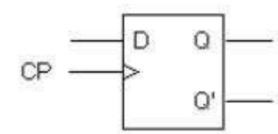
Clocked SR flip-flop

D Flip-Flop

- The Q output takes the value of the D input when the clock signal triggers the flip-flop



(a) Logic diagram with NAND gates



(b) Graphical symbol

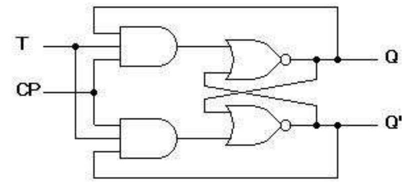
Q	D	Q(t+1)
0	0	0
0	1	1
1	0	0
1	1	1

(c) Transition table

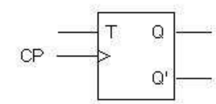
Clocked D flip-flop

T Flip-Flop

- The output of a bistable T flip-flop changes state two times for every two trigger pulses
- The bistable flip-flop divides the input signal by two
- Two flip-flops can be used to divide the signal by 4



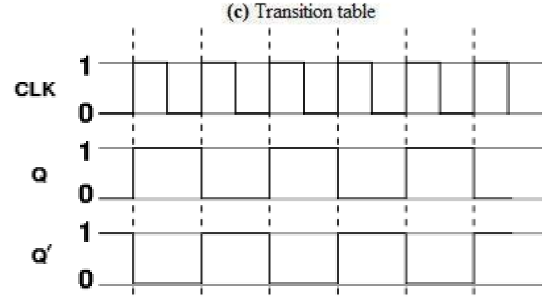
(a) Logic diagram



(b) Graphical symbol

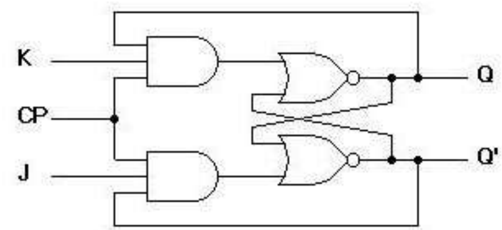
Q	T	Q(t+1)
0	0	0
0	1	1
1	0	1
1	1	0

(c) Transition table

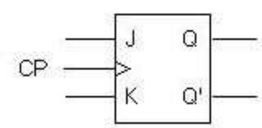


J-K Flip-Flop

- If J & K are at opposite states Q takes the value of J when the clock signal triggers the FF
- If J & K are both 0 the output does not change when the clock triggers
- If J & K are both 1 the clock trigger toggles the Q output



(a) Logic diagram



(b) Graphical symbol

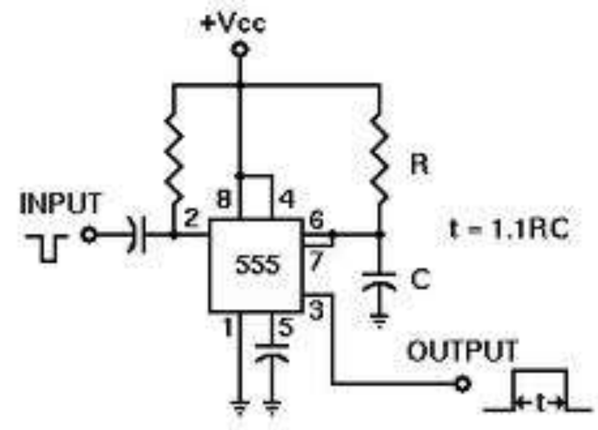
Q J K	Q(t+1)
0 0 0	0
0 0 1	0
0 1 0	1
0 1 1	1
1 0 0	1
1 0 1	0
1 1 0	1
1 1 1	0

(c) Transition table

Clocked JK flip-flop

One-Shot or Monostable Multivibrator

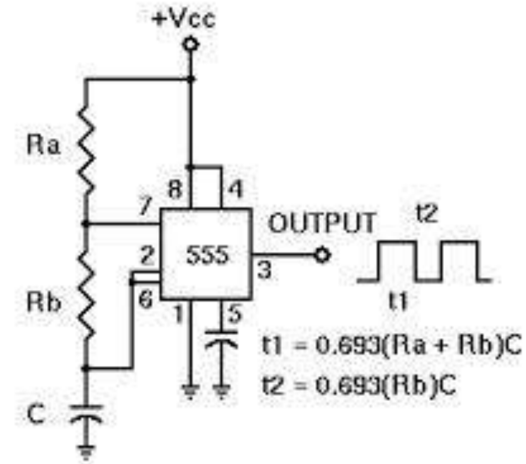
- Switches momentarily to the opposite binary state and then returns after a set time to its original state
  - Generates one pulse with each trigger
  - Pulse length determined by R-C circuit T= 1.1RC



Astable Multivibrator

- Free running
- <u>Continuously switches between two unstable states</u>
  - <u>No external clock</u>
- Frequency determined by:

$f = 1.46 / C[R_a + (2 \times R_b)]$



Divide by N counter

- A series of flip-flops connect so one output pulse occurs after every N pulses
- Each flip-flop divides by 2
- Most counters have the ability to clear to 0
- Counters can count up or down
- A decade counter divides by 10
  - One output pulse for every 10 input pulses

Frequency Counter

- A frequency counter is one of the most accurate ways to measure a frequency
  - Counts number of pulses during a specific interval and displays results
  - Gives a digital representation of the frequency of a signal
  - Accuracy depends on an internal crystal controlled oscillator or time base

Increased Oscillator accuracy

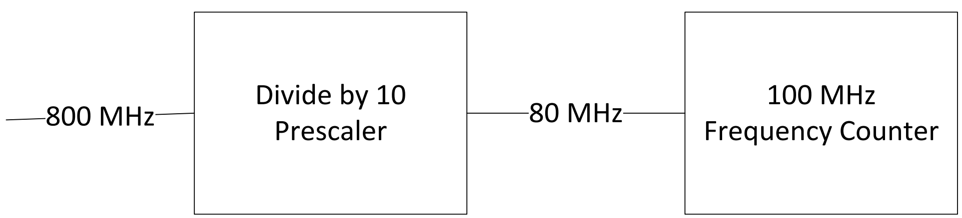
- Accuracy depends on an internal crystal controlled oscillator or time base
  - Temperature stable crystal oscillator
  - For extreme accuracy an external reference can be used
    - GPS-disciplined oscillator
    - Rubidium reference oscillator

Very Low Frequency Counting

- Alternate method of determining frequency
  - Used for very low frequency
  - Measure the period of a signal and mathematically compute the frequency
  - Much faster than counting slow pulses
    - Gives improved resolution of low frequency signals within a comparable time period

Prescaler

- For high frequencies a prescaler is used ahead of a lower frequency counter
  - Reduces the frequency by a factor of 10, 100, 1000 or other integer divisor



Marker Generators

- A high stability crystal oscillator that generates a series of reference signals
  - Used to calibrate a receivers frequency setting
  - Can use a 100 kHz oscillator
    - Use two flip-flops to divide to 50 and 25 kHz
      - Allows markers at the band edges as well as most license class and emission restrictions

Logic Families - TTL

- Transistor-transistor logic (TTL)
  - One of the oldest
  - Made entirely of bipolar transistors
  - Requires a 5 volt power supply
  - <u>If inputs are left open they assume a HIGH</u>
  - Usually identified by 7400/5400 numbering
  - A high logic is between 2 and 5 volts
  - A low logic is between 0 and .8 volts

Logic Families - CMOS

- Complimentary metal-oxide semiconductor
  - Composed of N-channel and P-channel FETs
- Most widely used form of digital logic
- When a CMOS gate is not switching it draws very little power
- The switching threshold for CMOS inputs is about half the supply voltage
  - Gives great immunity to noise

Logic Families - BICMOS

- Combined bipolar and CMOS technology
- Speed and low output impedance of bipolar
- High input impedance and reduced power consumption of CMOS

Photoconductivity

- Photo electric effect
  - Light striking photosensitive material knocks electrons loose, thereby increasing its conductivity (lower resistance)
  - Most pronounced for crystalline semiconductors
    - Cadmium-Sulfide: Visible light
    - Lead-Sulfide: Infra-red light
  - All semiconductor junctions exhibit photoelectric effect

Optoelectronics

- Photo Transistor
  - A transistor in a clear package to allow light to hit the junction
  - Transistor turns on when exposed to light
    - Can be used as a photo detector

Optocouplers and Optoisolators

- An LED and photo transistor sharing the same IC
- There is no current between the input and output
- Can be used as a Solid State Relay
  - Much faster than an electromechanical relay
- Often used to switch 120 V AC circuits with low power digital circuits

Optical Shaft Encoder

- Used to control the frequency of the VFO and other functions in modern radios
- A device which detects rotation of a control by interrupting a light source with a patterned wheel

Photovoltaic Cells – Solar Cells

- <u>Converts light to electrical energy</u>
- <u>If a PN junction is exposed to light photons will be absorbed by the electrons</u>
- The voltage developed by a photovoltaic cell depends on the material it is made from
  - <u>Silicon is the most common material</u>
  - <u>Silicon develops an open circuit vale of .5 volts</u>
- <u>The efficiency of a photovoltaic cell is based on the relative fraction of light that is converted to current</u>