Chapter 4
Active Components

Semiconductors, Vacuum Tubes, Integrated Circuits and Digital Fundamentals

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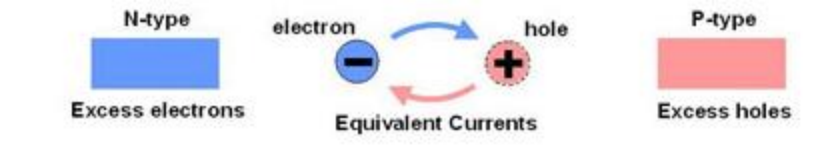
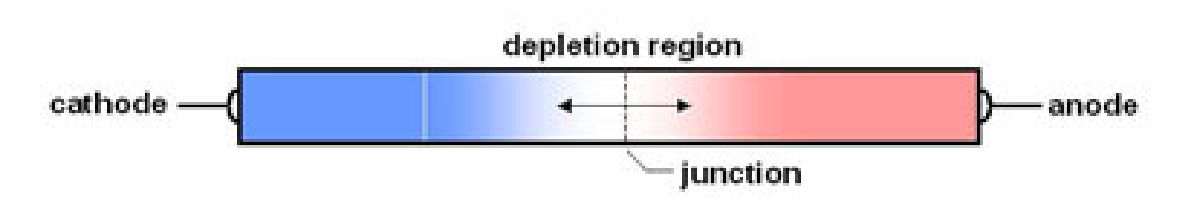
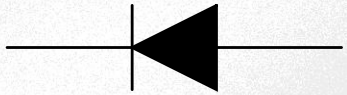
Semiconductor Properties

- Atoms in a conductor have a “sea” of electrons that are relatively free to move about.
- Semiconducting materials like silicon and germanium have atoms tightly bound together with fewer free electrons.
- Impurities are added to semiconductor material to make two types of semiconductors:
  - N-type material with an excess of free electrons
  - P-type material with an excess of holes.
- P and N are combined to make a PN Junction.

Semiconductor Junctions







Consider a bar (or disk) of silicon.

- One side of the bar is doped with negative material (excess electrons – called N material). This is the **cathode**.
- The other side is doped with positive material (excess holes – called P material). This is the **anode.**
- In between is a no man's land called the P-N junction.

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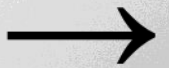


The PN Junction as a Rectifier

IF a voltage greater than the forward voltage, V_F, is applied with V+ to P, V- to N, the junction is ***Forward Biased*** and electron current flows from the N region to the P region

- Germanium V_F is about 0.3V
- Silicon V_F is about 0.7V

Junction is ***Reverse Biased*** **(**No current) if V- to P, V+ to N;

Junction can break down if:

- Voltage exceeds ***Peak Inverse Voltage*** (PIV) rating.
- Current exceeds maximum ***Average Forward Current*** rating.

Some types of PN Diodes

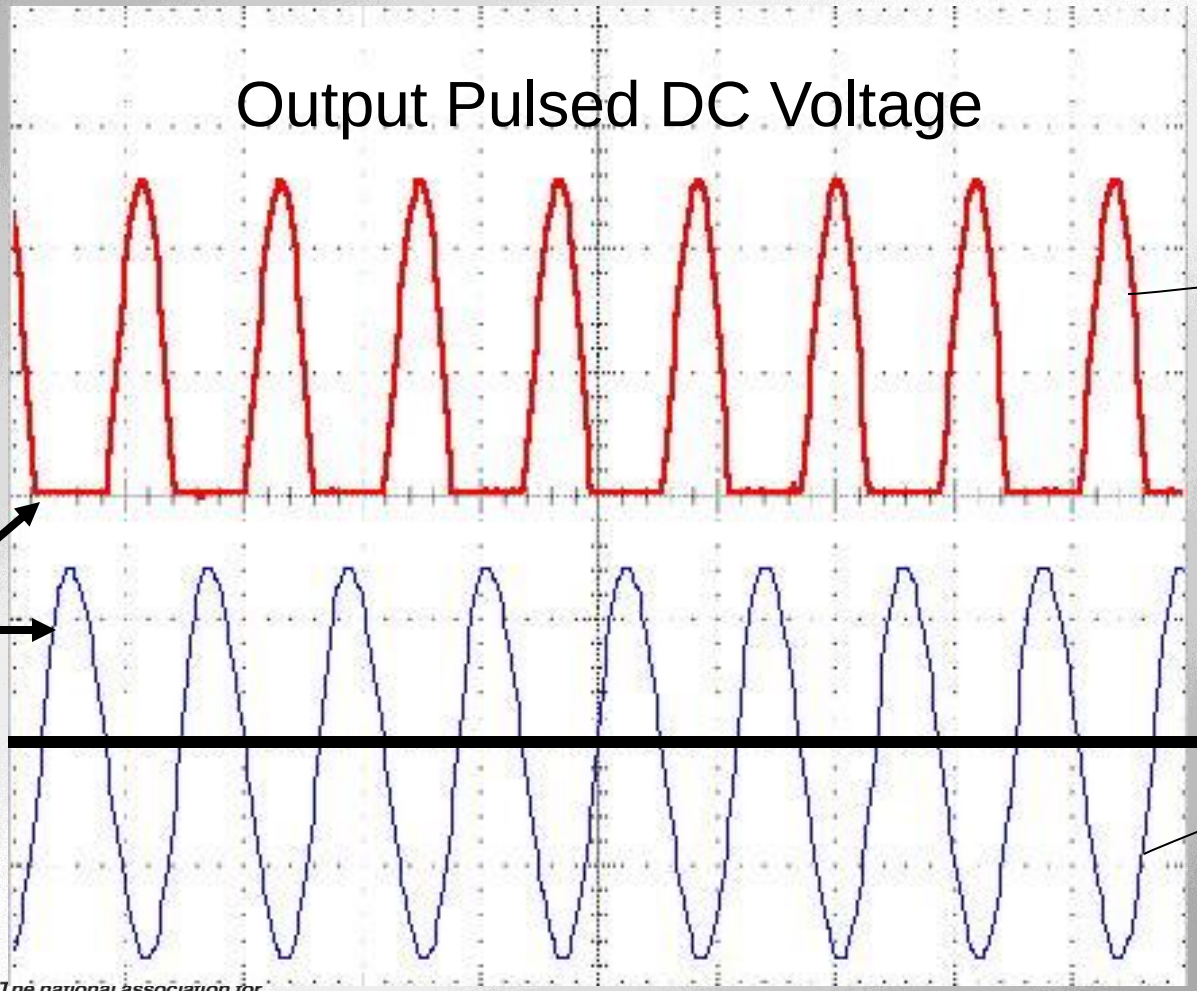
- Switching diodes – used for low-power signals
- Rectifier diodes – for high current or voltage
- PIN diodes – (I for intrinsic) used to switch RF
- Schottky diode – low capacitance for use at high frequencies and fast switching
- Varactor diode – used as a voltage controlled capacitor. Most diodes will exhibit this.
- Zener diode – voltage regulator when reverse biased at the Zener Voltage, V_Z

The Diode Response to AC

If AC is applied to a diode:

- During one half of the cycle, the diode is forward biased and current flows.
- During the other half of the cycle, the diode is reversed biased and current stops.

The Diode with AC Current



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The Diode Response to AC

- This is the process of rectification, allowing current to flow in only one direction.
- This is used to convert AC into pulsating DC.

The Light Emitting Diode (LED)

In **Forward biased** diodes, when electrons combine with holes, current flows and heat is produced. In a Light Emitting Diode, current flows and photons of light are emitted.

- LEDs are generally used as indicators, but they have the same properties as a regular diode.
- LEDs are more efficient than incandescent lamps.
- LEDs have higher forward voltage drop.

PN Bipolar Junction Transistors

Made with two junctions on one *Base*

- Base can be P or N type
- *Emitter* and *Collector* are type opposite of base
- PNP or NPN, middle letter is the base

Major current is from Emitter to Collector

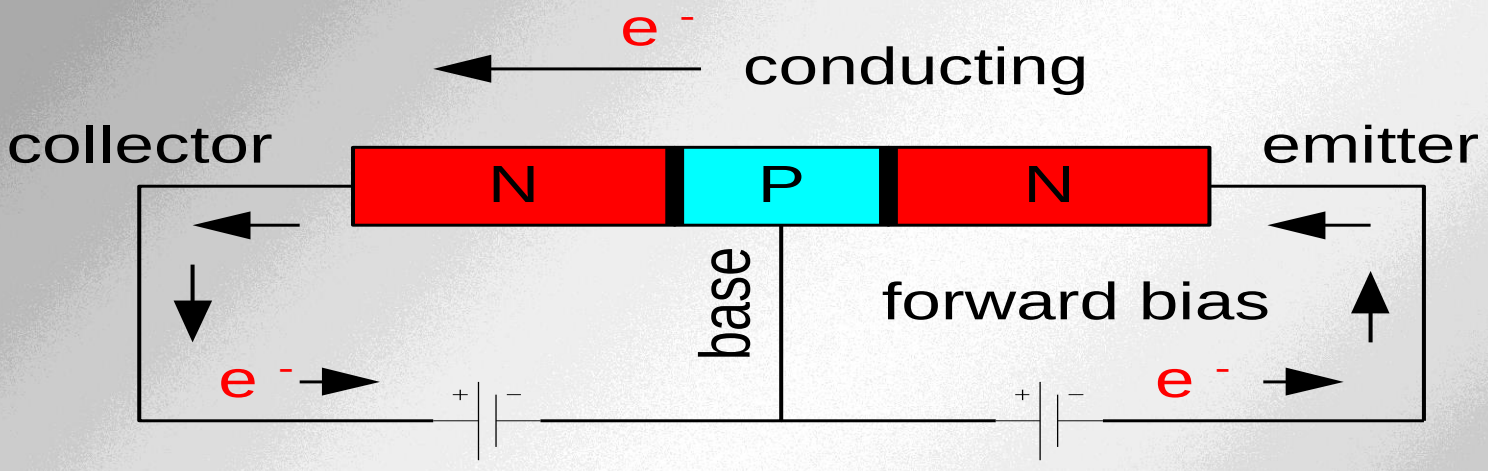
Small Base current controls a larger Collector current. Current Gain: Beta, Hfe = $I_C \div I_B$

For current in collector:

Base to Emitter is Forward Biased

Base to Collector is Reverse Biased

Junction Transistor



The collector to base is reverse biased. Base to emitter is forward biased. Electrons enter the base from emitter.

Some of the electrons which enter the base from the emitter will cross the barrier to the collector and become collector current.

Field Effect Transistors – FET

In an FET, current follows a *channel* of P or N material from *Source* to *Drain*. The channel is surrounded by a *Gate*.

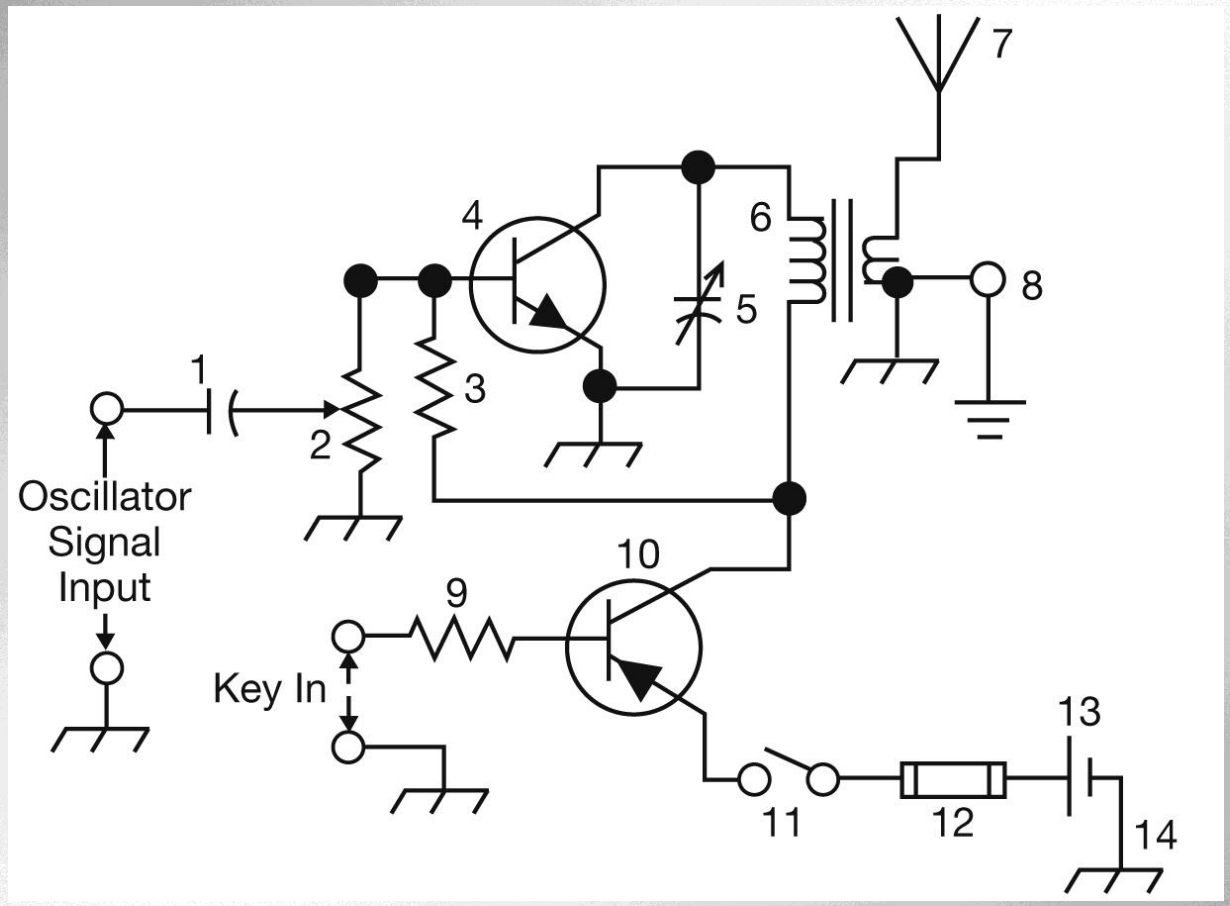
- The *Drain* current is controlled by the *Gate* to Source voltage. Id / Vg is referred to as *Transconductance*.
- The Gate in a Junction FET (JFET) is a junction.
- The Gate in a MOSFET is insulated from the channel.

Transistors as Switches

A transistor collector current or FET drain current can be ***cut off*** by applying a reverse voltage to the base or gate. The collector voltage will be *high*.

- When a large forward voltage is applied to the base or gate, the collector or drain current increases until the transistor is ***saturated*** and the collector or drain voltage will be *low*.
- These **high** and **low** states can represent ON and OFF logic levels.

Transistor Circuits



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Physical Packaging of Transistors

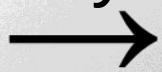
The package protects the device and removes heat.
Common packages are: TO, SIP, DIP, SMT

- TO-92 plastic package commonly used for low-power devices. Couples internal heat to air.
- High-power devices
  - Stud-Mounted
  - TO-3 - Large metal case to attach to heat sink
  - TO-220 – Plastic package with a metal tab
  - Collector, Emitter, or Drain may have internal connection to case. Heat sink needs an insulator.
  - Heat sink needs large surface area or moving air

Vacuum Tubes

Still used in power amplifiers and older radios.

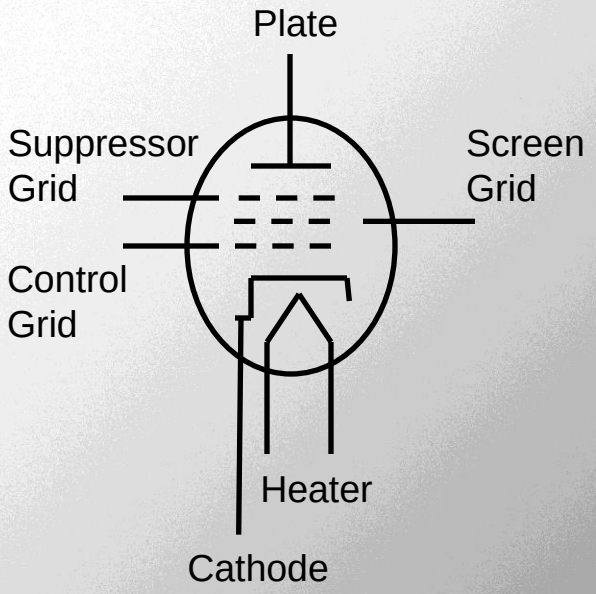
- Operate at higher voltages than transistors
- Electron current starts at a heated ***Cathode***.
- Electrons attracted to high voltage ***Plate***.
- ***Control Grid***, near cathode controls the number of electrons going toward the plate.
- ***Screen Grid***, near plate reduces the plate-to-grid capacitance and improves HF gain.
- ***Suppressor Grid***, between plate and screen grid, captures secondary electrons.



Classes of Vacuum Tubes

Classed by the number of *elements*, All have a heated cathode – directly or indirectly heated. All have a plate anode.

- *Diode* has no grids. (Used as a rectifier)
- *Triode* has a control grid.
- *Tetrode* has a control grid and a screen grid.
- *Pentode* has a control grid, screen grid, and supressor grid.



Operation of Vacuum Tubes

Source of electron current is the cathode. Control grid voltage variations cause plate current variations. Voltage gain is proportional to *Transconductance.* Tubes are similar to an FET.

- Plate and screen grid have large positive voltages with respect to cathode to attract electrons.
- Control grid has negative bias voltage to cathode. Usually no grid current. High impedance input.

Integrated Circuits

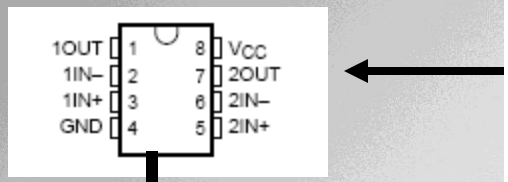
Analog ICs use transistors on a chip connected as *differential amplifiers which* have very high gain and can amplify DC and AC.

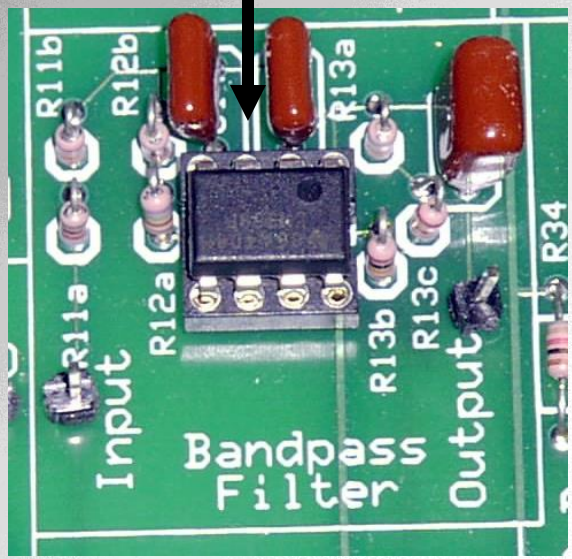
- *Operational Amplifiers* (OpAmps) are used with external feedback networks to control gain and improve linearity.
- *Voltage Regulators* contain a reference voltage and error amplifier to maintain a stable output voltage.

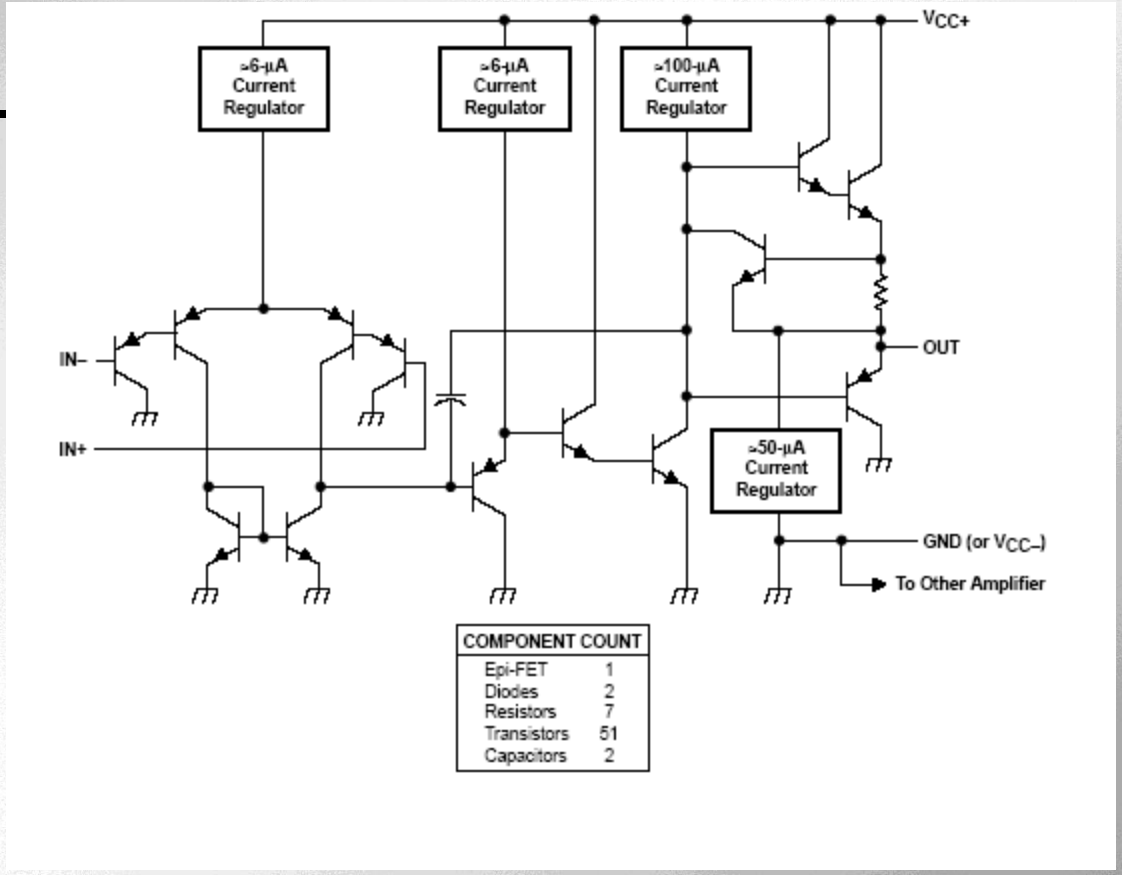
Digital ICs – the building blocks for logic circuits

- Transistors have two output states – ON and OFF
- Internal gates combine signals logically

LM358 Operational Amplifier IC







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Digital Logic Basics

Logic Families – RTL, TTL, LSTTL, CMOS, etc.

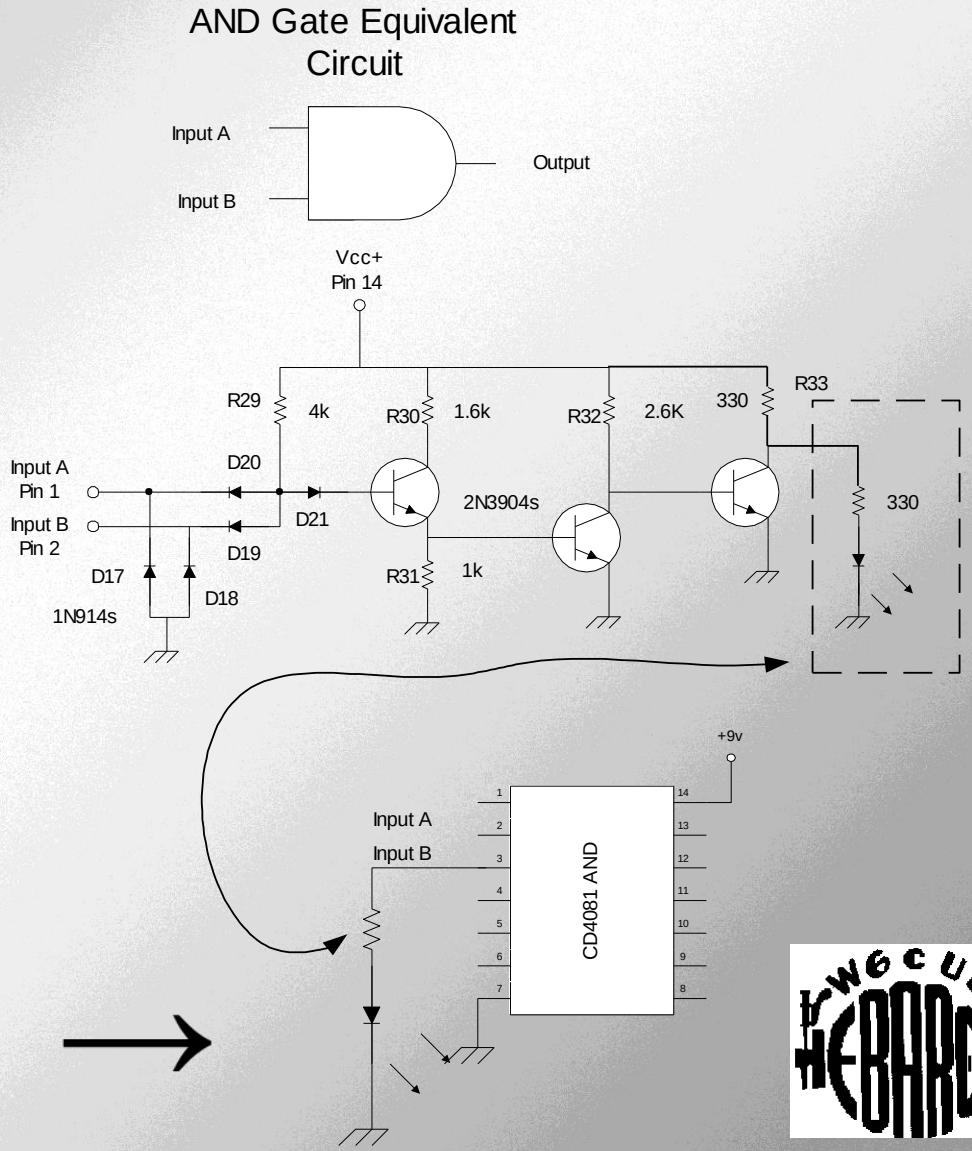
Logic functions are called *gates*. Gates have an output controlled by a number of inputs.

- Inverters or NOT gate – a “one” in makes a “zero” out
- OR gate – any “one” in is a “one” out
- NOR gate – any “one” in is a “zero” out
- AND gate – any “zero” in is a “zero” out
- NAND gate – any “zero” in is a “one” out

Truth Tables are used to describe the output for a combination of inputs.

Integrated Circuit

Input A	Input B	Output
Low	Low	Low
High	Low	Low
Low	High	Low
High	High	High



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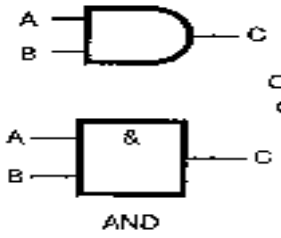
Logic Symbol | Boolean Equation | Truth Table

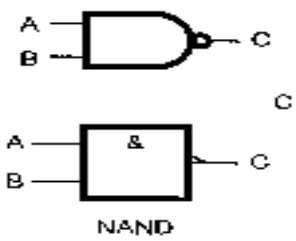


$C = A \cdot B$
$C = AB$

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

Two-input AND gate
(A)

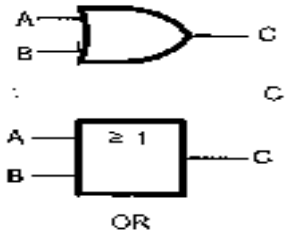
Logic Symbol | Boolean Equation | Truth Table



$C = \overline{A \cdot B}$

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

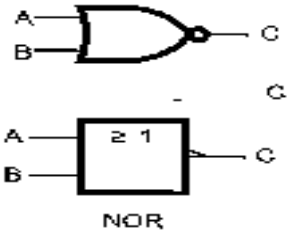
Two-input NAND gate
(D)



$C = A + B$

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

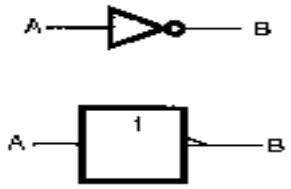
Two-input OR gate
(B)



$C = \overline{A + B}$

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

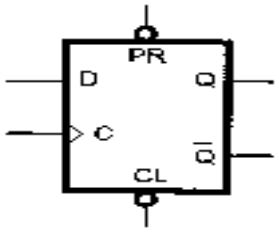
Two-input NOR gate
(E)



$B = \overline{A}$

A	B
0	1
1	0

Inverter
(C)



X=1 or 0

Clear	Preset	Clock	D	Q	Q̄	
0	1	X	X	0	1	
1	0	X	X	1	0	
0	0	X	X	1	1	Unused State
1	1	↑	1	1	0	
1	1	↑	0	0	1	

Truth Table for a positive edge-triggered D flip-flop

(F)

GLM3046

Complex Digital Logic Circuits

Combinatorial Logic is used to make

- Flip-Flops – stores a logic state
  - May be presettable
  - May be clocked
- Counters – cascaded flip-flops to accumulate counts
  - Outputs make up a binary number with “2 to the nth” states
  - Number of counts stored can be up to “2 to the nth - 1”
  - 3 flip-flops can store 0 to 7; 4 flip-flops can store 0 to 15
- Shift Registers – Parallel or Serial in, Serial out
  - Clock pulse shifts the binary value one bit at a time
  - May be able to shift right or left

RF Integrated Circuits

Functions for radios may be combined into one or several ICs.

- Amplifiers, Mixers, Modulators, Frequency Synthesizers, Signal Processors, etc.
- MMIC – *Monolithic Microwave Integrated Circuit*
  - Useable from LF to Microwave
  - Small package with large gain
  - Complete transceivers on a chip

Microprocessors and Microcontrollers

Small computing devices used in modern radio equipment especially for human interface and programmable functions.

- Microcontrollers have digital I/O ports, built-in analog converters, and timers to make smart accessory equipment.
- Made with *Complimentary Metal Oxide Semiconductor* (CMOS) process for very low power operation, sometimes battery operated.

Memories

Volatile memories store data only while powered.

- RAM, SRAM are static
- DRAM needs refreshing

Non-Volatile memories retain data while unpowered.

- *ROM and PROM*
- *EPROM*
- *EEPROM*
- *Disks, CD-Rom, DVD, Tape*

Digital Data Interfaces

Digital commands in; Digital data out

- Serial for longer distances at slow rates.
- Parallel can be faster but uses more wires
- RS232 COM ports not in most new computers.
- USB interfaces in many newer radios and devices.
- Ethernet is good for remote controlled accessories.
- WiFi and Bluetooth for wireless audio connections
- Keypads

Visual Interfaces

Simple Indicators:

- Lamps use more power and have shorter life
- LEDs use less power and are available in colors.

Displays for text and graphics

- LED displays for daylight display
- LCD uses Liquid Crystal cells inside glass
  - Applied logic makes cells twist and turn opaque
  - Needs a backlight to show contrast.