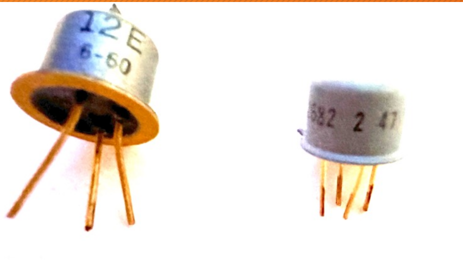


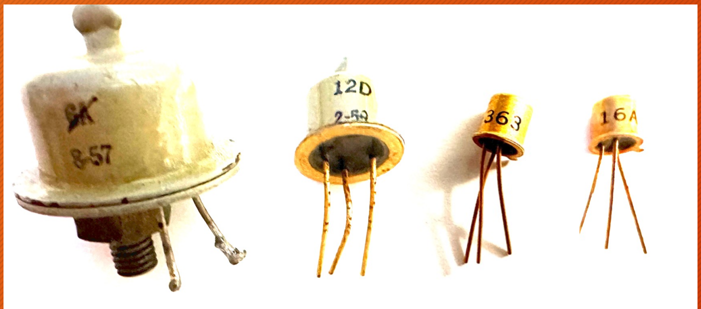
(Joseph E Wilkes, photo)

CDL Presents
Basic Electronics

Week 2
Diodes and Transistors

Joe Wilkes, PhD
WA2SFF

June 2025



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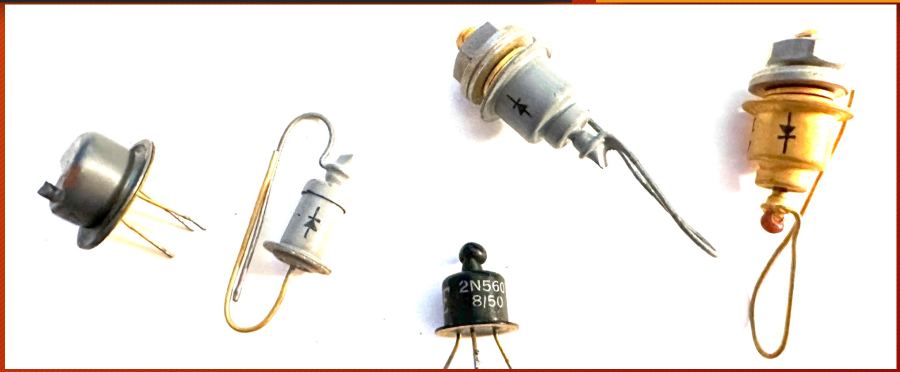


(Joseph E Wilkes, photo)

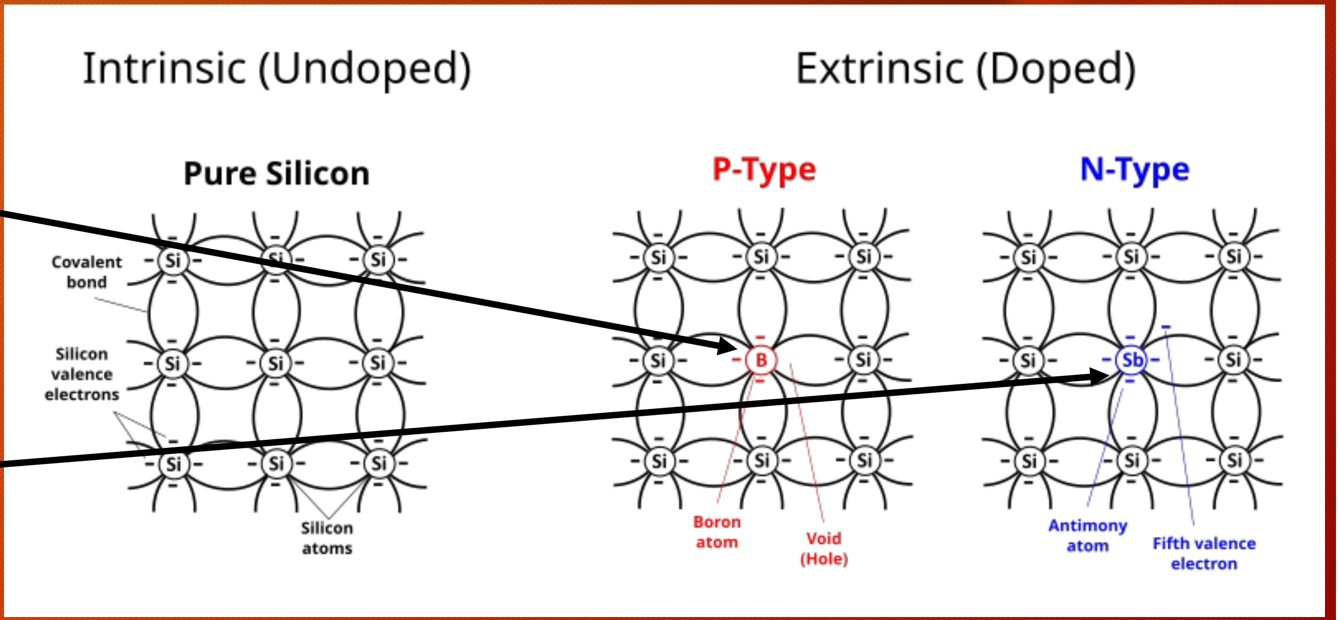
Questions from Last Week

How semiconductors are made

- Many Semiconductor are made from either
  - Germanium
  - Silicon
  - Other materials
- When a small amount of an impurity is added, the electrical properties of the material change and create
  - N material, or
  - P material
- By sandwiching P and N material together a semiconductor is made

Example of Doping of Silicon

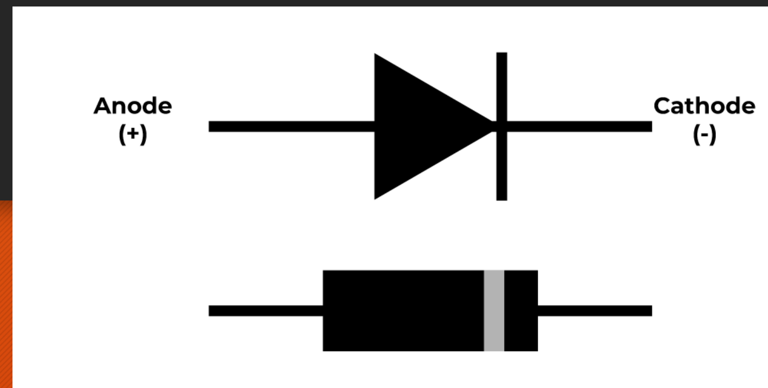
- Silicon P Type is doped with:
  - Boron
  - Aluminum
  - Gallium
  - indium
- Silicon N-type is doped with:
  - Phosphorus
  - Arsenic
  - Antimony
  - Bismuth
  - Lithium



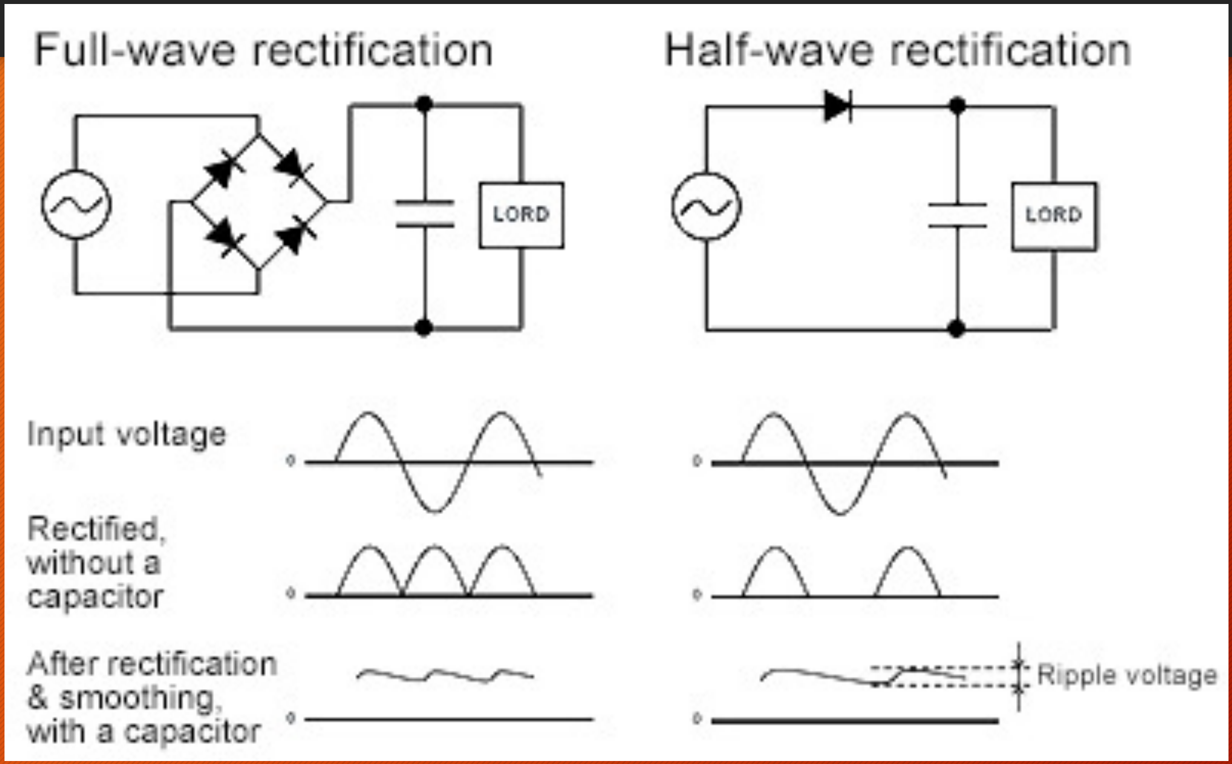
https://en.wikipedia.org/wiki/Doping_(semiconductor)

Diodes

- Diodes are electronic components that only conduct electricity in one direction
- They are useful for converting AC signals into DC signals
- There are several kinds
  - Germanium Diodes
  - Silicon Diodes
  - Schottky Diodes
  - Light Emitting Diodes
  - Zener Diodes



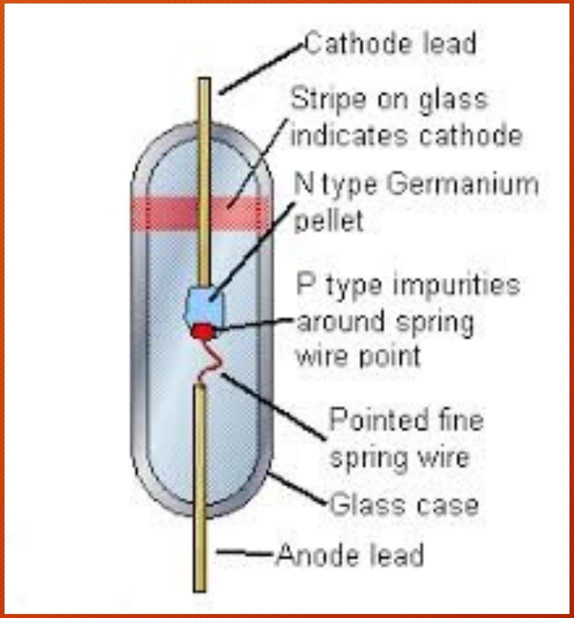
Diodes convert AC to DC

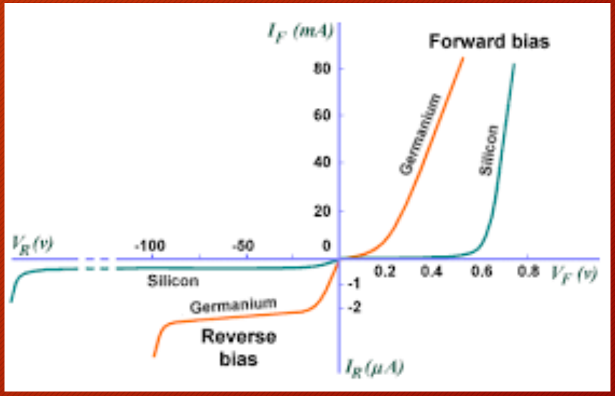


https://techweb.rohm.com/product/power-device/si/19487/

Germanium Diodes

- Germanium were one of the first diodes to be made.
- Germanium conducts electricity
- Adding impurities to the germanium makes it:
  - P type (positive)
  - N type (negative)
- P-type attached to N-type makes a diode
- They were used in early crystal radios
- There is a nominal forward voltage drop of 0.2 volts



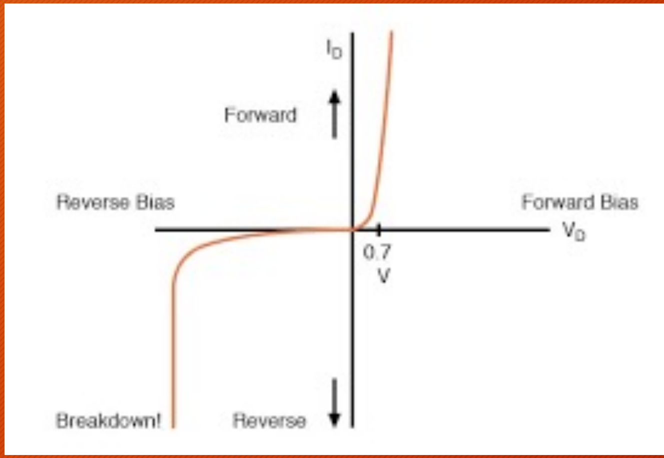


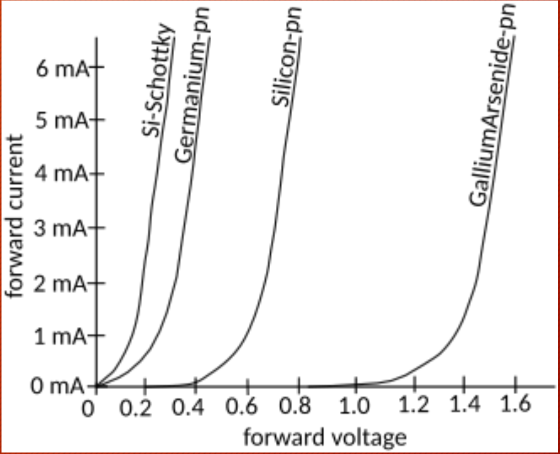
Common germanium diodes

- Examples: 1N34, 1N270, 1N60
- Germanium diodes are now considered obsolete and are not widely produced
- They are mostly used is simple receivers
- Finding these diodes in new stock can be difficult, and they are often sourced from surplus or vintage electronic suppliers
- Sometimes vendors will sell " Germanium" diode that are really Silicon diodes
- If you see a bunch at a flea market and need them, buy the entire lot.
- Sometimes Schottky diodes are used in simple receivers since they are readily available

Silicon Diodes

- Silicon Diodes are used for:
  - Low power applications
  - High power applications
- There is a nominal forward voltage drop of 0.7 volts





Common Silicon diodes

- Rectifier diodes
  - High Breakdown voltage
  - High Current Handling
  - Examples: 1N400X; e.g., 1N4001, 1N4007, etc.
- Small Signal Diodes
  - Used to limit small signals in amplifiers
  - Examples: 1N4148, 1N914

Schottky Diode

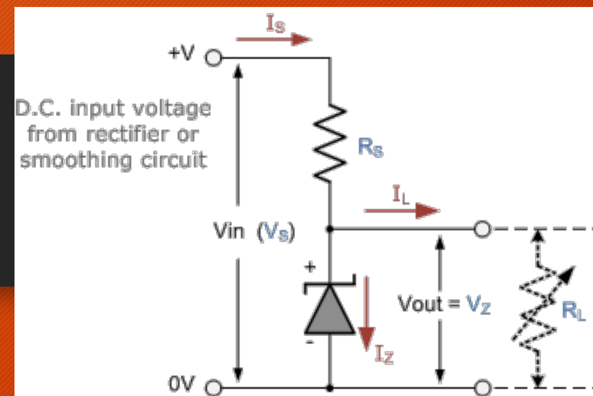
- Diodes have a maximum frequency where they work correctly
- In very high frequency electronics, when a germanium or silicon small signal diode will not work, Schottky diodes are used
- There is also a diode called a Schokley diode which is different
- Commonly encountered Schottky diodes include the 1N58xx series rectifiers,
  - 1N581x and 1N582x through-hole parts, and
  - SS1x and SS3x surface-mount parts.

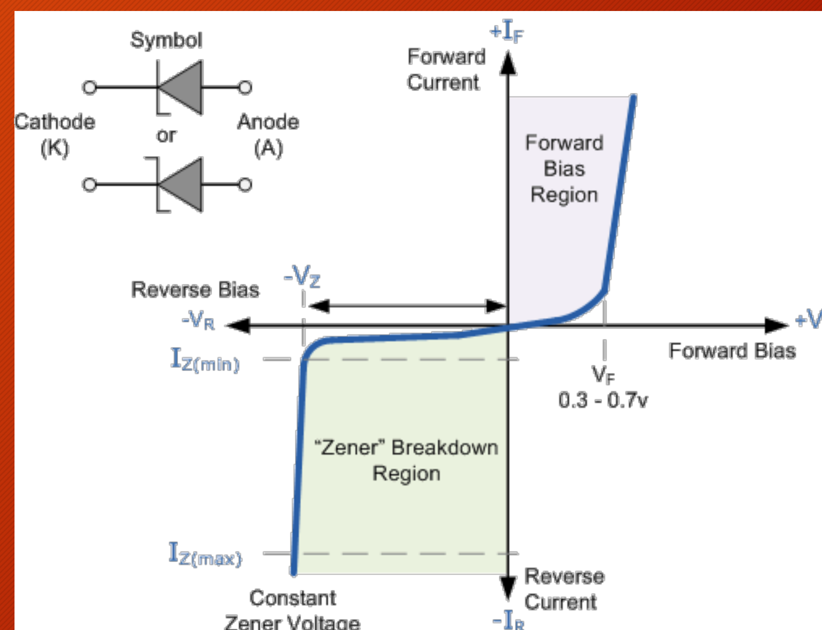
Gallium Arsenide Diodes

- Gallium arsenide (GaAs) diodes,
  - including PIN diodes and Gunn diodes,
- offer advantages like
  - high-speed switching and
  - low noise,
- making them suitable for various applications, particularly in microwave and high-frequency circuits.

Zener Diodes

- All diodes have a break down voltage when the polarity is reversed
- Zener diodes are special diodes where the break down voltage is tightly controlled
- It is put in the circuit in the reverse direction
- They are available for many different voltages



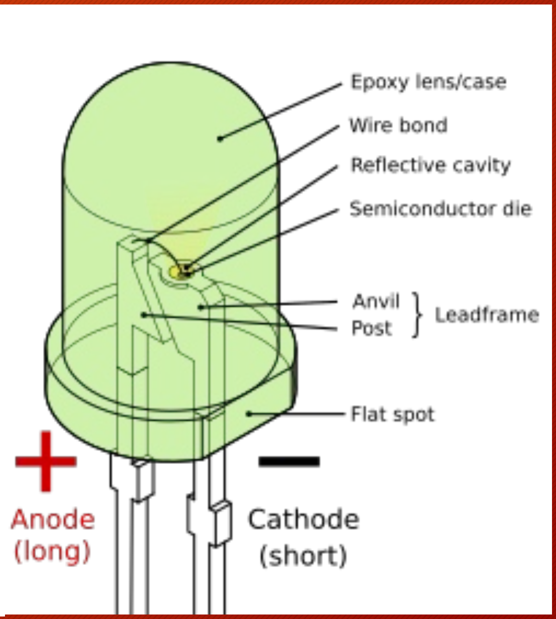


Example Zener Diodes

BZX55 Zener Diode Power Rating 500mW							
2.4V	2.7V	3.0V	3.3V	3.6V	3.9V	4.3V	4.7V
5.1V	5.6V	6.2V	6.8V	7.5V	8.2V	9.1V	10V
11V	12V	13V	15V	16V	18V	20V	22V
24V	27V	30V	33V	36V	39V	43V	47V
BZX85 Zener Diode Power Rating 1.3W							
3.3V	3.6V	3.9V	4.3V	4.7V	5.1V	5.6	6.2V
6.8V	7.5V	8.2V	9.1V	10V	11V	12V	13V
15V	16V	18V	20V	22V	24V	27V	30V
33V	36V	39V	43V	47V	51V	56V	62V

Light Emitting Diodes

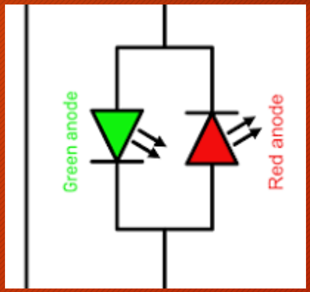
- Light emitting diodes (LED) generate light in visible, ultraviolet and infrared ranges when connected to a DC voltage
- Each "color" has a different voltage drop
- LEDs can not be put in parallel
- They can be put in series
- They come in physical different sizes



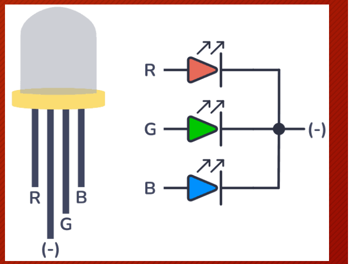
Colors and Voltage drop

Color	Wavelength (nm)	Voltage drop
White	all	$2.7 < \Delta V < 3.5$ volts
Infrared	$\lambda > 760$	$\Delta V < 1.9$ volts
Red	$610 < \lambda < 760$	$1.63 < \Delta V < 2.03$ volts
Orange	$590 < \lambda < 610$	$2.03 < \Delta V < 2.10$ volts
Yellow	$570 < \lambda < 590$	$2.1 < \Delta V < 2.18$ volts
Green	$500 < \lambda < 570$	$1.9 < \Delta V < 4$ volts
Blue	$450 < \lambda < 500$	$1.63 < \Delta V < 2.03$ volts
Violet	$400 < \lambda < 450$	$2.76 < \Delta V < 4.0$ volts
Purple	mixture of LEDs	$2.48 < \Delta V < 3.7$ volts
Ultraviolet	$\lambda < 400$	$3.1 < \Delta V < 4.4$ volts

Other types of LEDs



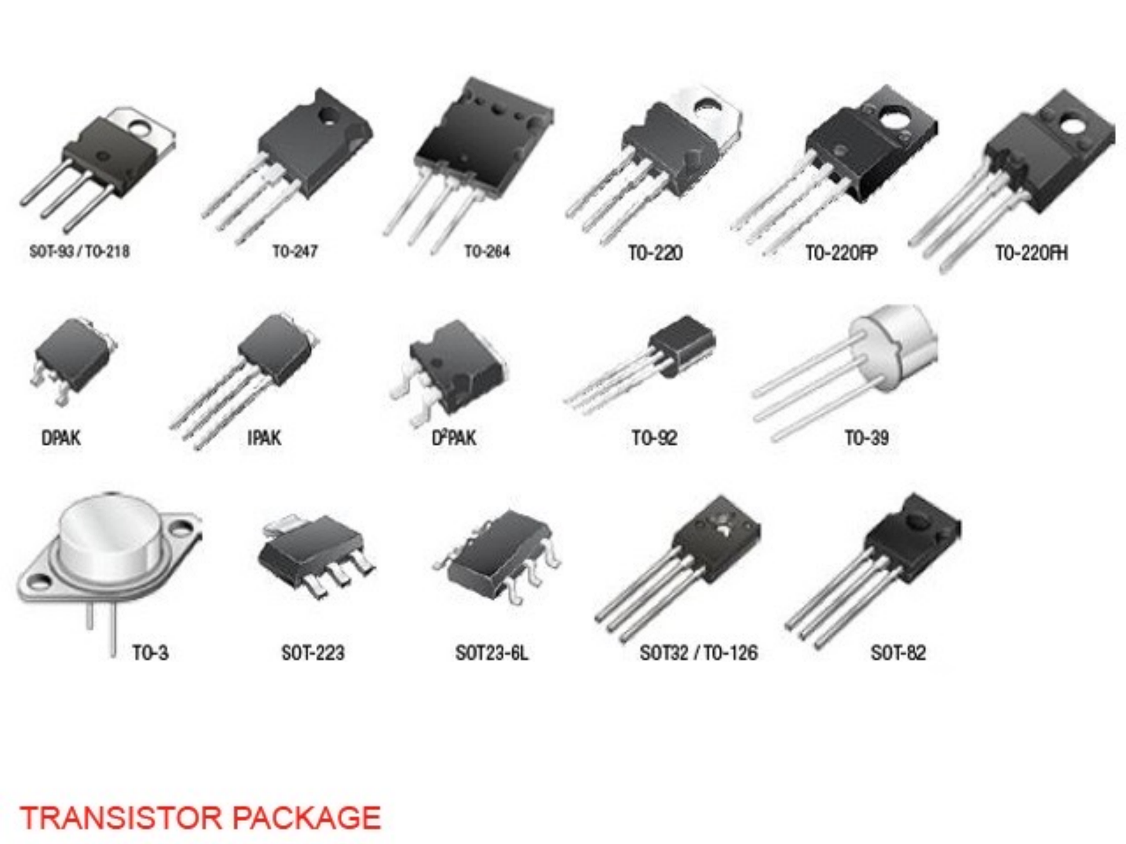
- Red/Green LEDs
  - A Red LED and a Green LED are put in parallel
  - Current in one direction lights the Red LED
  - Current in the other direction lights the Green LED
- Red/Green/Blue LEDs
  - There are 3 LEDs (Red, Green, Blue) close to each other
  - The color is then a combination of the three color LEDs
  - Some are special in that there is a chip inside the LED
  - The chip decodes an address and a value of brightness for each LED
  - They are often found in long strips with each LED having a different address
  - They are controlled by microprocessors



Transistors

- Unlike vacuum tubes, where a tube part is very similar to other tubes of the same part number,
- Transistors have a wide range of specifications for the same part number
- Designs of transistor circuits must account for the range
- Types of Transistors
  - BiPolar PNP and NPN Transistors
  - Field Effect Transistors (FET)
  - Gallium Arsenide Transistors (GAs-FET)
  - Darlington pairs
  - Opto isolators

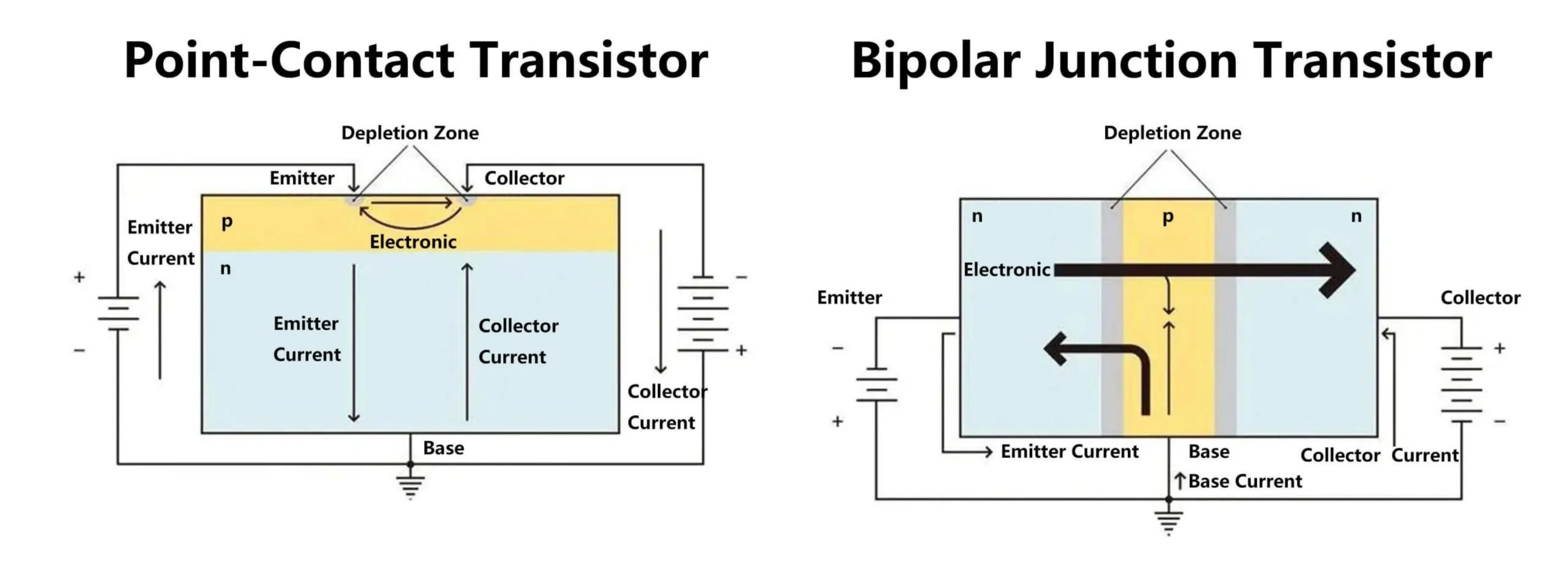
Transistor Packages



Germanium and Silicon Transistors

- The transistor was invented by Walter Brattain, John Bardeen and William Shockley,
  - at Bell Telephone Laboratories in Murray Hill, NJ,
  - on December 23, 1947
- They later shared the Nobel Prize in Physics for the breakthrough they achieved
- Bell Labs folk lore has it that the team was told to stop development on this worthless project.
  - They did not listen
  - This became the mantra of employees when working on new projects

Two Types of Transistors

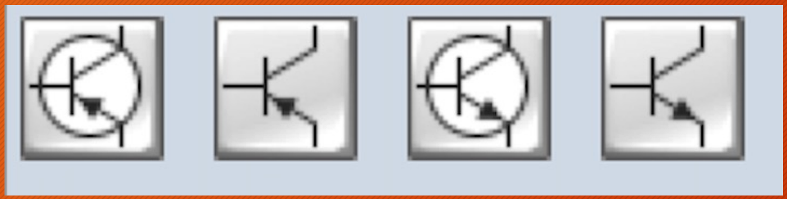


https://spectrum.ieee.org/transistor-history

Common bipolar transistors

- Small signal NPN
  - 2N2222
  - 2N2904
- Small Signal PNP
  - 2N3906

PNP NPN



Bipolar Transistor

Transistor Data Sheet example - 1

https://cdn.sparkfun.com/assets/7/9/2/7/6/2N3904.pdf

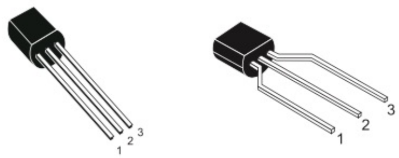
2N3904

SMALL SIGNAL NPN TRANSISTOR

PRELIMINARY DATA

Ordering Code	Marking	Package / Shipment
2N3904	2N3904	TO-92 / Bulk
2N3904-AP	2N3904	TO-92 / Ammopack

- SILICON EPITAXIAL PLANAR NPN TRANSISTOR
- TO-92 PACKAGE SUITABLE FOR THROUGH-HOLE PCB ASSEMBLY
- THE PNP COMPLEMENTARY TYPE IS 2N3906



TO-92 Bulk **TO-92 Ammopack**

APPLICATIONS

- WELL SUITABLE FOR TV AND HOME APPLIANCE EQUIPMENT
- SMALL LOAD SWITCH TRANSISTOR WITH HIGH GAIN AND LOW SATURATION VOLTAGE

Transistor Data Sheet example - 2

THERMAL DATA

$R_{thj\text{-}amb}$ •	Thermal Resistance Junction-Ambient	Max	200	°C/W
$R_{thj\text{-}case}$ •	Thermal Resistance Junction-Case	Max	83.3	°C/W

ELECTRICAL CHARACTERISTICS (T_{case} = 25 °C unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I_{CEX}	Collector Cut-off Current (V_{BE} = -3 V)	V_{CE} = 30 V			50	nA
I_{BEX}	Base Cut-off Current (V_{BE} = -3 V)	V_{CE} = 30 V			50	nA
$V_{(BR)CEO}$*	Collector-Emitter Breakdown Voltage (I_B = 0)	I_C = 1 mA	40			V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage (I_E = 0)	I_C = 10 μA	60			V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage (I_C = 0)	I_E = 10 μA	6			V
$V_{CE(sat)}$*	Collector-Emitter Saturation Voltage	I_C = 10 mA I_B = 1 mA I_C = 50 mA I_B = 5 mA			0.2 0.2	V V
$V_{BE(sat)}$*	Base-Emitter Saturation Voltage	I_C = 10 mA I_B = 1 mA I_C = 50 mA I_B = 5 mA	 0.65		0.85 0.95	V V
h_{FE}*	DC Current Gain	I_C = 0.1 mA V_{CE} = 1 V I_C = 1 mA V_{CE} = 1 V I_C = 10 mA V_{CE} = 1 V I_C = 50 mA V_{CE} = 1 V I_C = 100 mA V_{CE} = 1 V	60 80 100 60 30		 300	
f_T	Transition Frequency	I_C = 10 mA V_{CE} = 20 V f = 100 MHz	250	270		MHz
C_{CBO}	Collector-Base Capacitance	I_E = 0 V_{CB} = 10 V f = 1 MHz		4		pF
C_{EBO}	Emitter-Base Capacitance	I_C = 0 V_{EB} = 0.5 V f = 1 MHz		18		pF
NF	Noise Figure	V_{CE} = 5 V I_C = 0.1 mA f = 10 Hz to 15.7 KHz R_G = 1 KΩ		5		dB
t_d t_r	Delay Time Rise Time	I_C = 10 mA I_B = 1 mA V_{CC} = 30 V			35 35	ns ns
t_s t_f	Storage Time Fall Time	I_C = 10 mA I_{B1} = $-I_{B2}$ = 1 mA V_{CC} = 30 V			200 50	ns ns

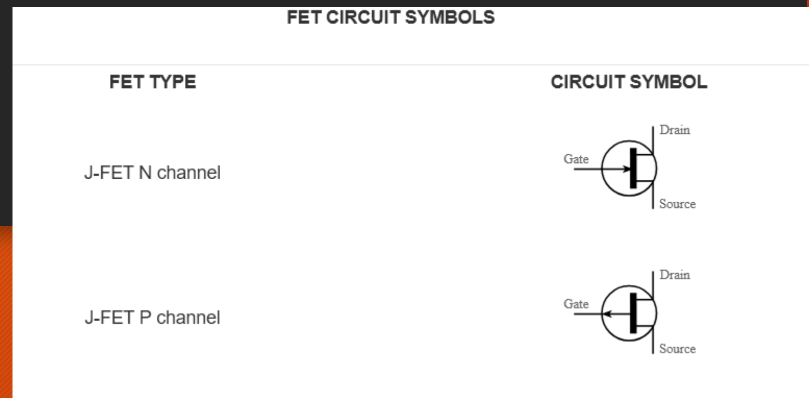
∗ Pulsed: Pulse duration = 300 μs, duty cycle ≤ 2 %

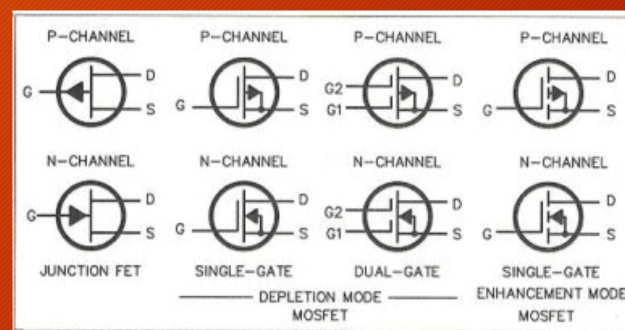
Gain

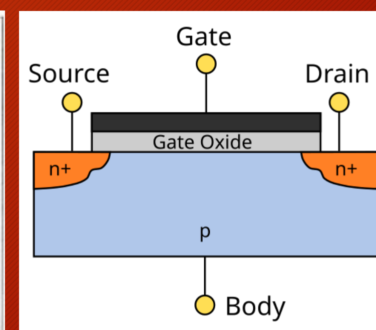
Approximate Maximum Frequency

Capacitance

Field Effect Transistors







- Bipolar Transistors have low impedance and work on current
- Field Effect Transistors work on voltage and have a high impedance
- There are two main types
  - J-FET
  - MOS-FET
- J-FET are used for small signals
- MOS-FET range from small signals to very high power circuitry

Some Commonly used FETs

- J-FET: MPF102, J310
- MOSFET:
  - small signal: 3N200
  - power: *IRF9540*

Gallium Arsenide FET (GaAsFET)

- Used in microwave circuits
- Have very low noise
- Specialty part that needs to be picked for the design frequency

Darlington Transistor

- Some transistors do not have enough gain
- So by connecting the emitter of one transistor to the base of a second one, and
- Connecting the collectors of both together
- A Darlington Transistor is created
- Some times circuits will be created with two transistors
- There are also Darlington Transistor parts with everything inside the package

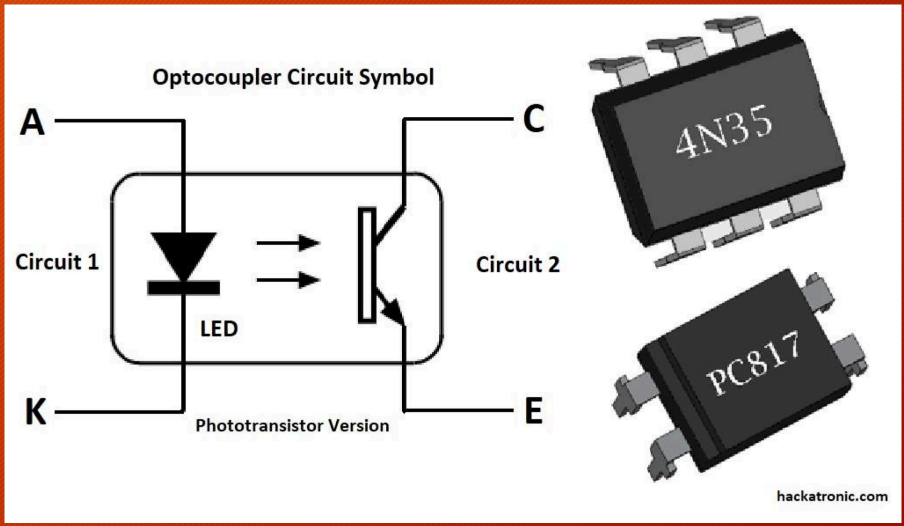
Light Sensitive Transistors

- Some materials can be sensitive to light; this is called the photo-electric effect
- When light hits a transistor, current will flow
- In the late 19th century, and early 20th century scientists could not explain this effect
- The German physicist Max Planck suggested that a beam of light is not a wave propagating through space, but has discrete energy packets, which were later called photons
- Albert Einstein published a paper advancing the hypothesis that light energy is carried in discrete quantized packets to explain experimental data from the photoelectric effect.
- Einstein was awarded the 1921 Nobel Prize in Physics for "his discovery of the law of the photoelectric effect"

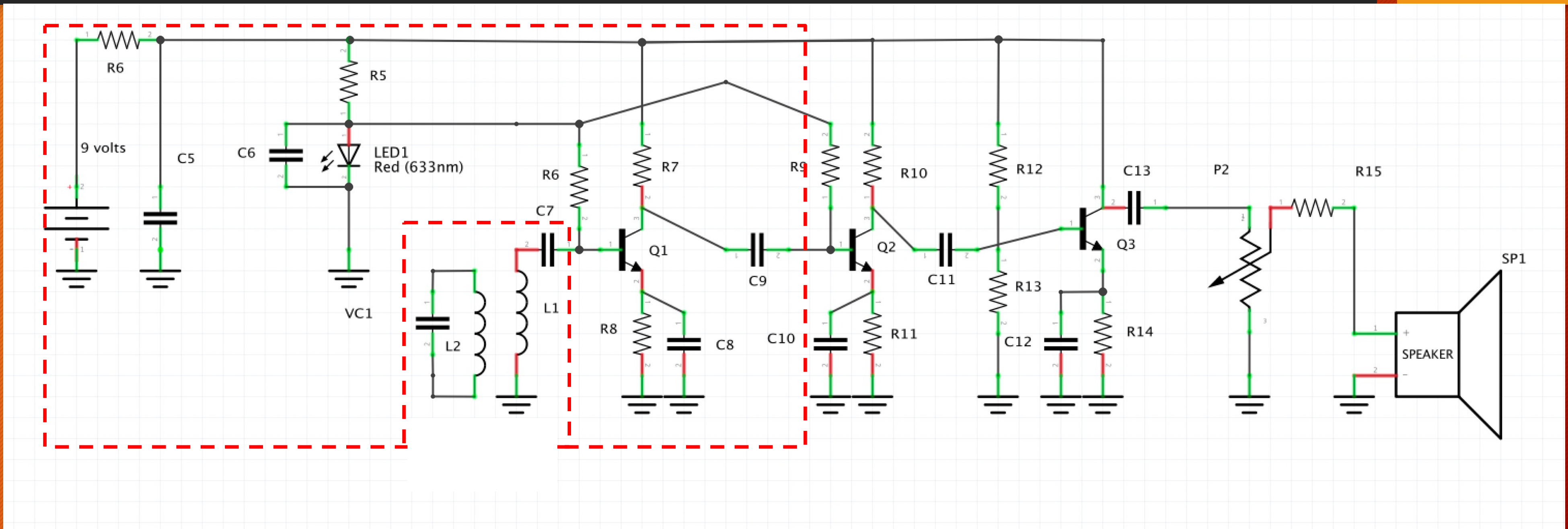
https://en.wikipedia.org/wiki/Photoelectric_effect

Optoisolators

- When it is necessary to isolate part of a circuit from another part of the circuit, an optoisolator is used.
- An LED is put in the same package as a transistor that is light sensitive.
- An example is connecting two devices in different racks where it is necessary to isolate the grounds from each other.
- Optoisolators are digital devices
  - When the LED is on, the C to E resistance is very low
  - When the LED if off, the C to E resistance is very high

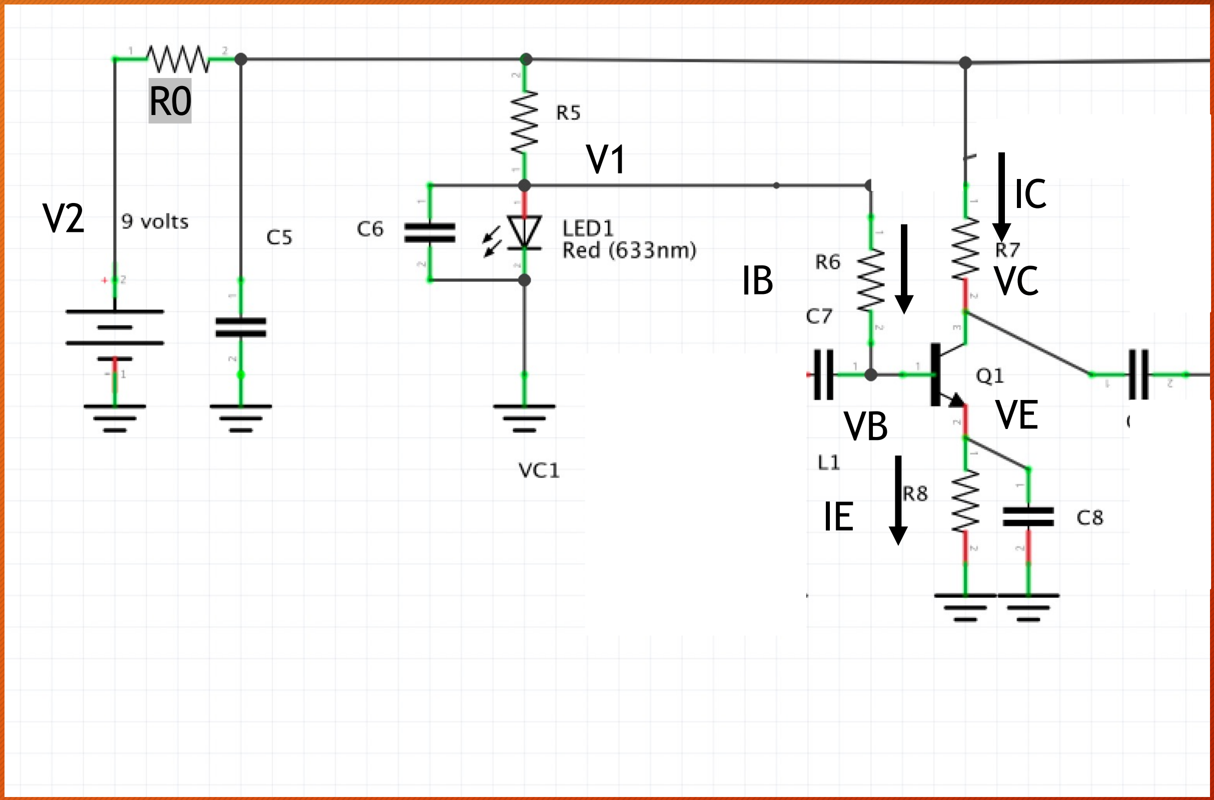


Example: Simple AM Receiver



We are going to analyze the circuit inside the dotted box

Analysis of NPN Transistor Amplifier



R8 = 2200 ohms = 2.2 k ohms
R6 = 6.8 k ohms
R7 = 4.7 k ohms
V1 = 1.6 volts (drop of red LED)
V2 = 9 volts (battery)

Equations

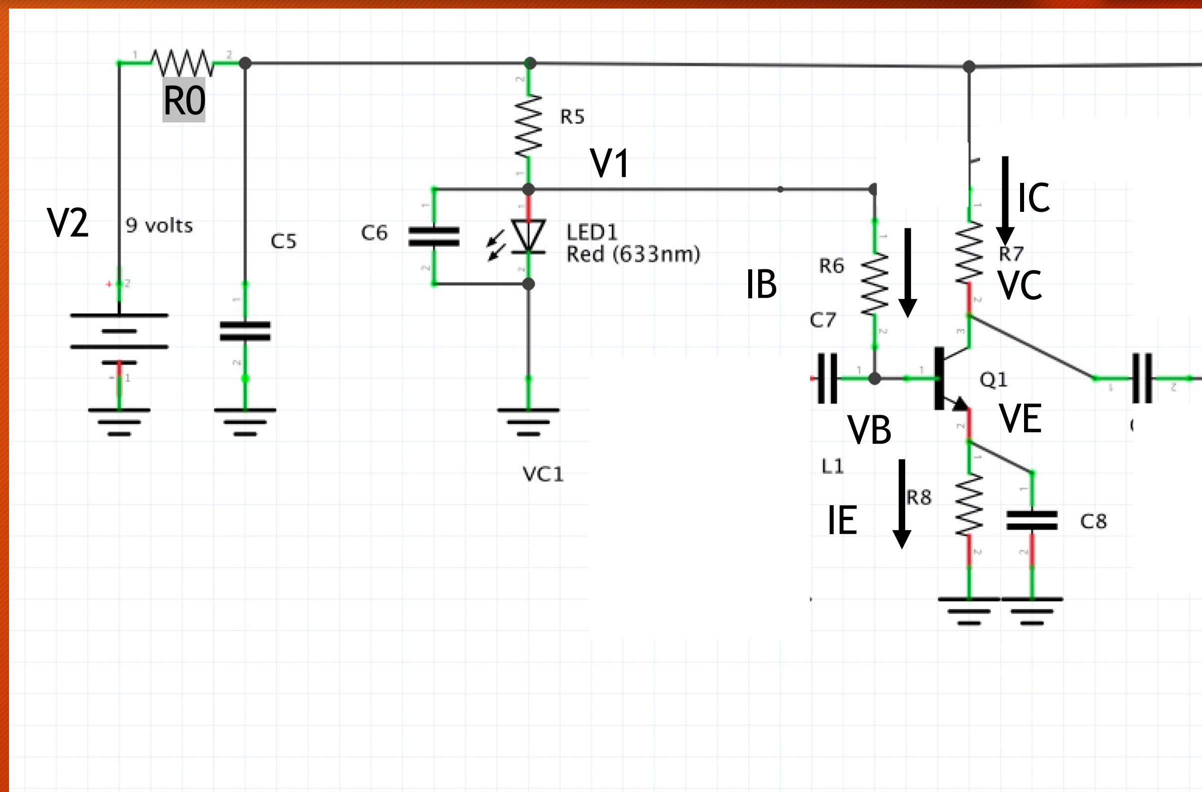
VE = R8*IE=R8*(IB+IC)
VB = VE+0.7
VC= V2-IC*R7

IE= VE/R8
IB = (V1-0.7-VE)/R6
IC = G*IB

G - Gain of transistor = IC/IB

Solving for IB gives:

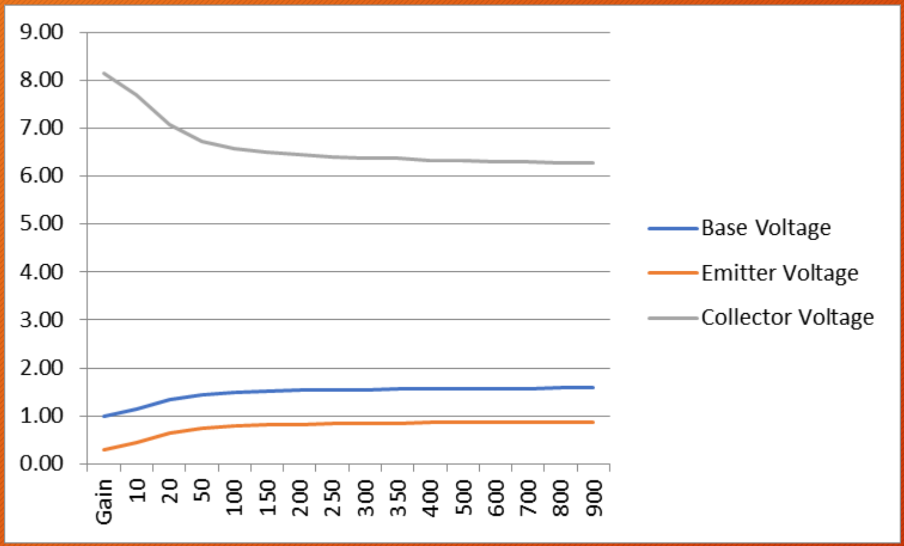
IB = (1.6-0.7)/(R6+(G+1)*R8)



Spread sheet Analysis

R8	2.2							
R6	6.8							
R7	47							
V1	1.6							
V2	9							
		G	IB	IE	IC	VB	VE	VC
		Gain	Base Current	Emitter Current	Collector Current	Base Voltage	Emitter Voltage	Collector Voltage
		10	0.0126	0.1390	0.1264	1.01	0.31	8.14
		20	0.0097	0.2028	0.1931	1.15	0.45	7.69
		50	0.0057	0.2883	0.2827	1.33	0.63	7.08
		100	0.0033	0.3377	0.3343	1.44	0.74	6.73
		150	0.0024	0.3584	0.3560	1.49	0.79	6.58
		200	0.0018	0.3698	0.3679	1.51	0.81	6.50
		250	0.0015	0.3770	0.3755	1.53	0.83	6.45
		300	0.0013	0.3820	0.3807	1.54	0.84	6.41
		350	0.0011	0.3856	0.3845	1.55	0.85	6.39
		400	0.0010	0.3884	0.3874	1.55	0.85	6.37
		500	0.0008	0.3924	0.3916	1.56	0.86	6.34
		600	0.0007	0.3950	0.3944	1.57	0.87	6.32
		700	0.0006	0.3970	0.3964	1.57	0.87	6.30
		800	0.0005	0.3985	0.3980	1.58	0.88	6.29
		900	0.0004	0.3996	0.3992	1.58	0.88	6.29
		1000	0.0004	0.4005	0.4001	1.58	0.88	6.28

Voltages vs gain of transistor



- The beauty of this design is that the voltages are almost independent of the gain of the transistor once the gain is at least 100.
- Thus, you can change transistors without changing the circuit design.

Questions

References

- Radio Amateur's Handbook, ARRL, Newington CT
  - https://www.amazon.com/ARRL-Handbook-Radio-Communications-101st/dp/1625952074
- https://www.elenco.com/wp-content/uploads/2017/10/ECK-10_REV-O-2.pdf
- https://www.infobooks.org/free-pdf-books/physics/electronics/