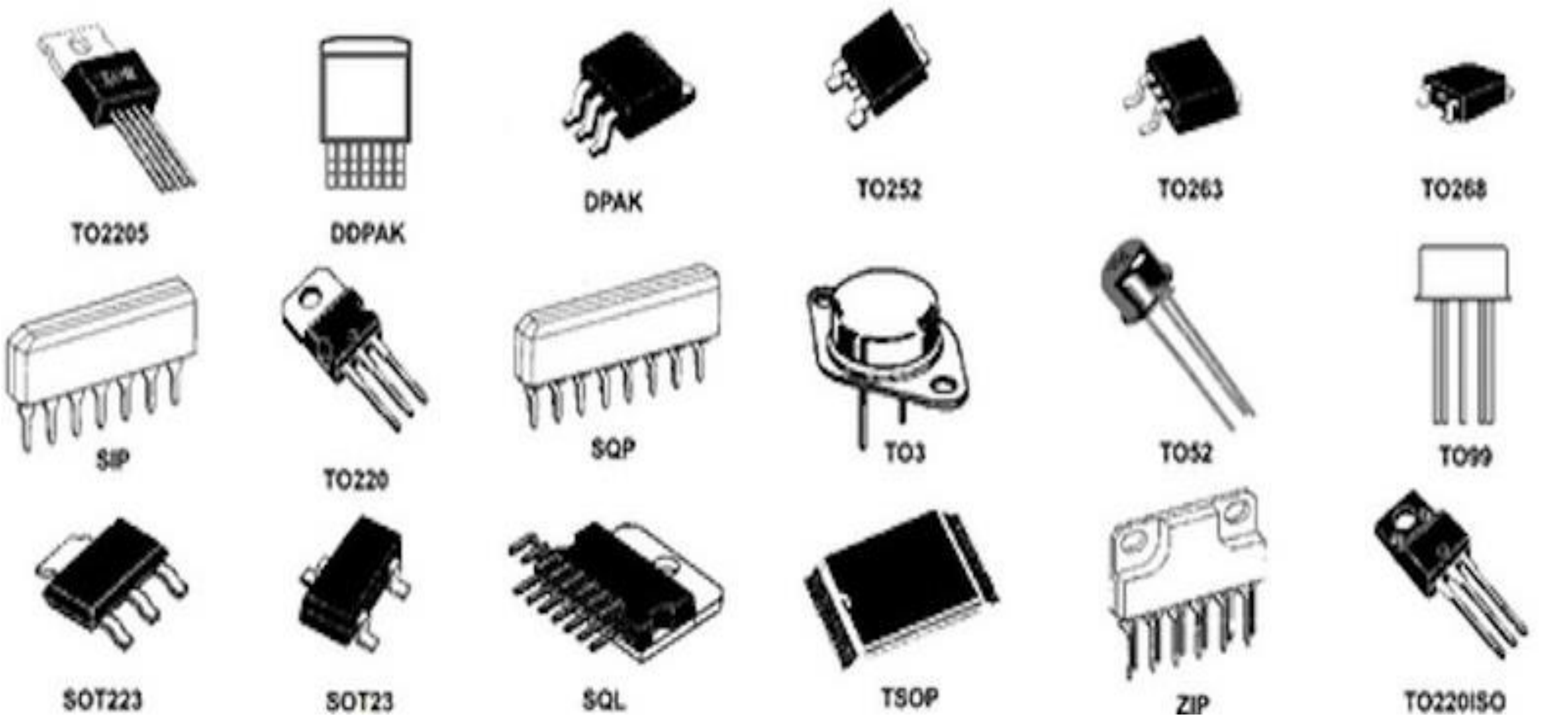

DISCRETE COMPONENTS

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OUTLINE

- Discrete Component Overview
- Passive Electrical Components (Resistors, Capacitors, Inductors)
- Semiconductor Components (Diodes, Transistors)
- Other Electrical Components (Oscillators, Transformers)
- Mechanical Components (Connectors, Mounting)
- Where to Get Components

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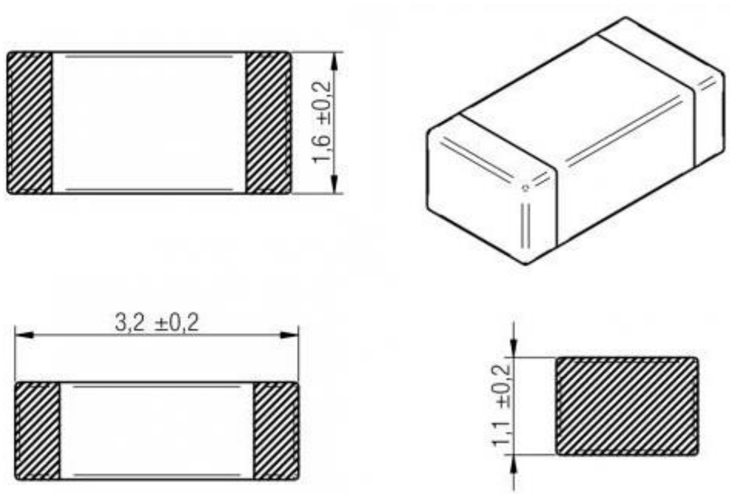
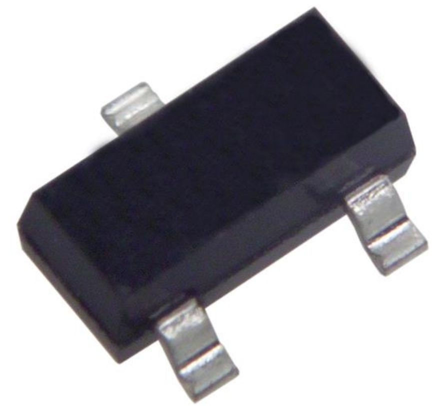
DISCRETE COMPONENTS

Considerations

Common [discrete electrical component packages]:

- Two terminal (1210, 1206, 0805, 0603, 0402)
- Three terminal (SOT-23, SOT-223)
- Five terminal (SOT-23-5, SOT-23-6)





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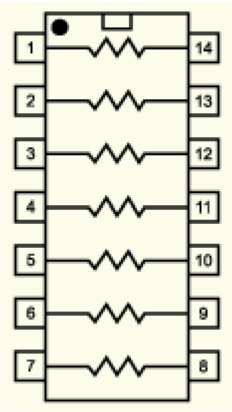
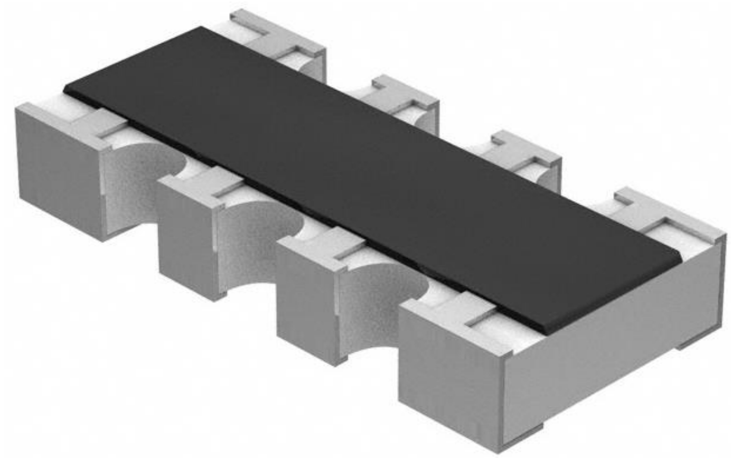
DISCRETE COMPONENTS

Considerations 2

- Depending on your needs, networks and arrays of components are available
- Choice of component package impacts the amount of power that component can handle (example: 1206 resistors often rated for 0.125W whereas the same component in an 0603 package is only rated for 0.0625W)





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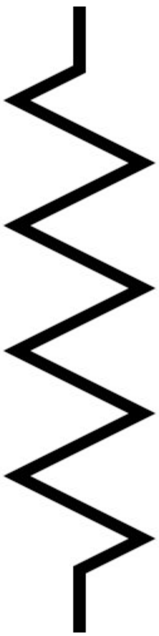
RESISTORS

Resistor Considerations

- Resistance: Resistance value in (m/k/M)Ω
- Tolerance: % error from expressed resistance value
- Power/Voltage: Component rations, in W and V
- Durability/Lifetime: How reliable the part is and how long it will last
- Temp. Coefficient: How the resistance of the device changes as a function of temperature



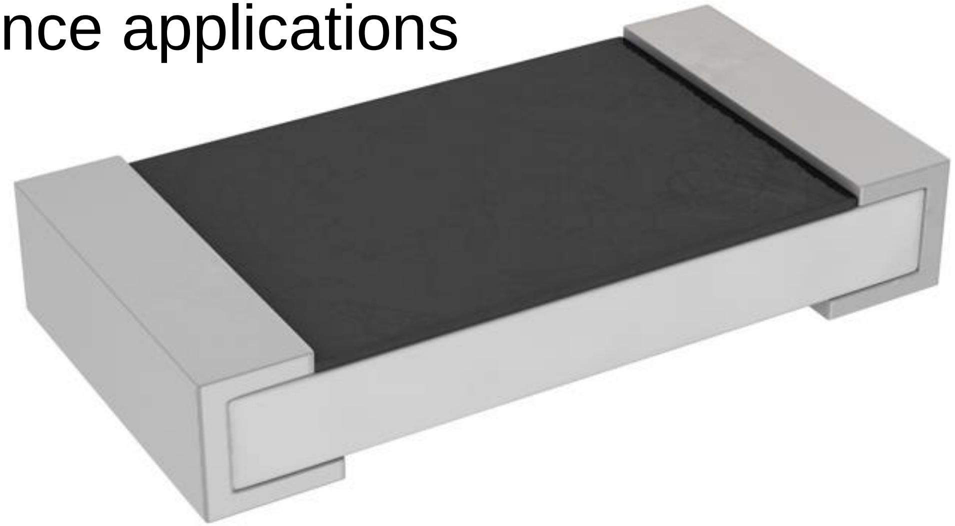
$$R = \frac{\rho L}{A}$$

$$\rho = \text{Resistivity}$$
$$L = \text{Length}$$
$$A = \text{Cross-sectional area}$$

RESISTORS

Resistor Types – Carbon Film

- Most common type for SMD and axial-lead resistors
- Carbon film (resisting material) is applied to a substrate
- Two varieties: “thick film” (looser tolerance, cheaper) and “thin film” (better performance, higher cost)
- Thin film similar to thick film; laser trimmed for thinner films and improved properties
- Useful in general resistance applications



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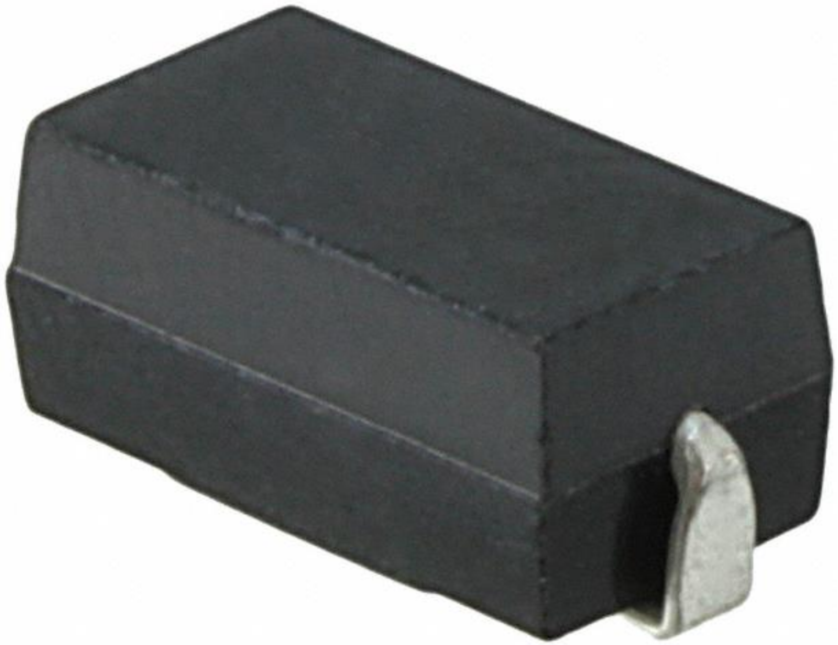
RESISTORS

Resistor Types – Metal/Metal Oxide Film

- Similar to carbon film resistors, but uses a metallic alloy instead of carbon as the resistive element
- Possess excellent linearity, temperature characteristics, power characteristics, and durability
- Metallic alloy film can be replaced by a metal oxide for higher temperature operation, stability, and reliability



RESISTORS

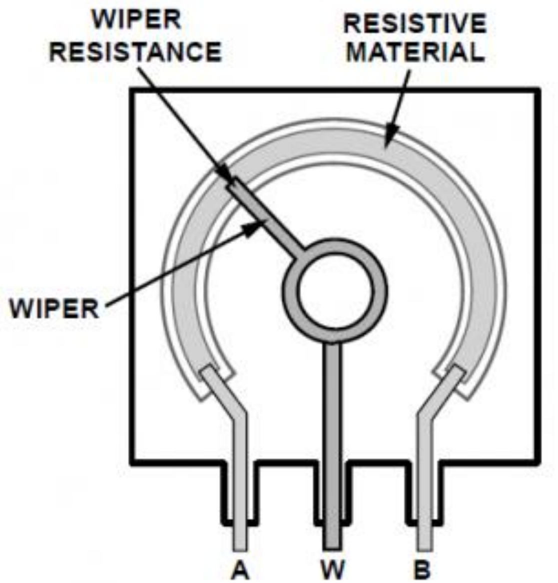
Resistor Types – Wire Wound

- Resistance achieved through use of a coil of resistive wire
- Due to coil, wire wound resistors contain more parasitic inductance than other resistor types
- Frequently used in high-power applications (resistors above 1W often referred to as “power resistors”)

RESISTORS

Resistor Types – Potentiometer

- Slider/wiper used to change effective resistance value
- Digitally-controlled potentiometers also available (resistance controlled via PWM, I2C, SPI, etc.)
- Used in variable resistance applications



RESISTORS

Resistor Type Summary

- Thick Film Carbon: Cheap, looser tolerances
- Thin Film Carbon: Improved tolerances, higher cost
- Metal Film: Good thermal stability, higher cost
- Metal Oxide Film: Best thermal stability, higher cost
- Wire Wound: High power ratings, good heat dissipation

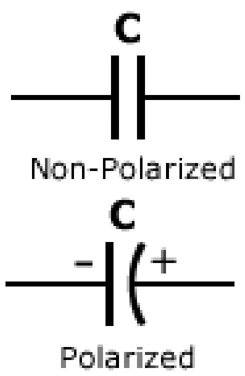
CAPACITORS

Capacitor Considerations

- Capacitance: Capacitance value in (p/n/µ/m)F
- Tolerance: %Error from stated capacitance value
- Voltage: The voltage rating for the capacitor
- Durability/Lifetime: How long the device will last
- Equivalent Series Resistance (ESR): How much resistance is introduced by the device
- Equivalent Series Inductance (ESL): How much inductance is introduced by the device

$$C = \frac{\epsilon A}{d}$$

$C =$ Capacitance (F)
$\epsilon =$ Relative permittivity of dielectric
$A =$ Area of capacitor plates(m^2)
$d =$ Distance between plates(m)



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CAPACITORS

Capacitor Types: Film Capacitor

- Foil-film and metal-film varieties
- Utilize a low-K polymer dielectric (polyester, Teflon, polypropylene, polystyrene, polycarbonate, etc.)
- Typical values < 10µF
- Superior longevity to electrolytic
- Through-hole (surface mount rare)
- Foil-film: Alternating layers of dielectric and metal foil, used in applications requiring precision
- Metal-film: Conductive film metallized directly onto dielectric, self-healing, reduced fire risk, used in high-voltage applications

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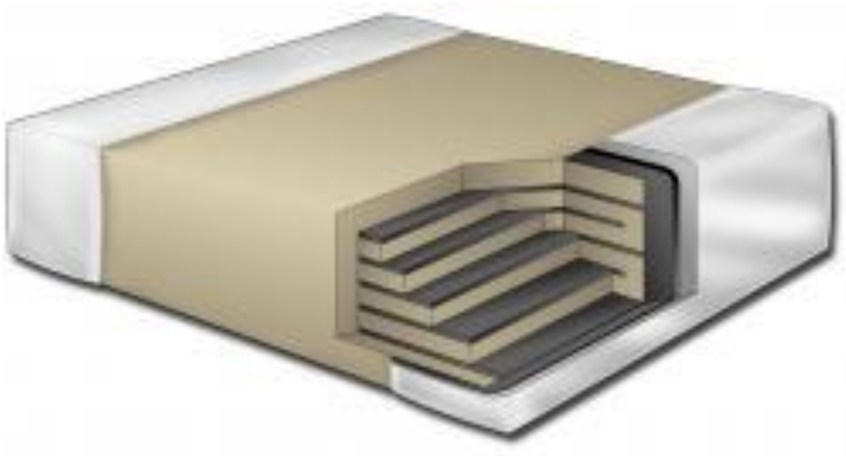
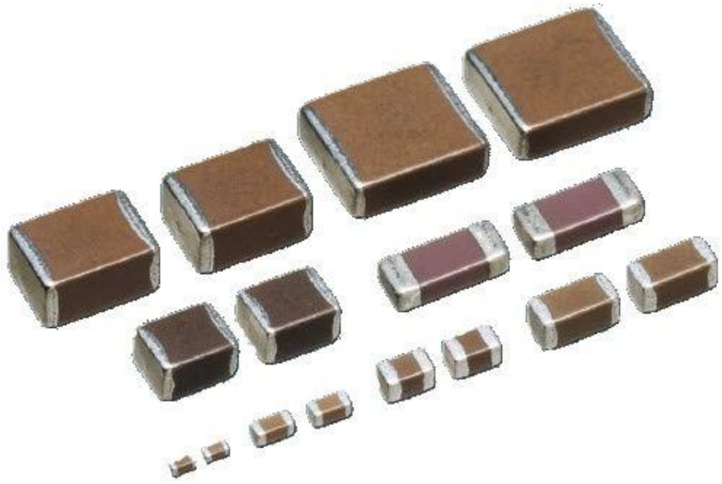
CAPACITORS

Capacitor Types: Ceramic Capacitor

- Many surface mount chip capacitors are of this variety
- Values range from ~1pF to ~1000µF
- High dielectric constant (ideal in some cases, not in others)
- Fast response times (~12ps)





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CAPACITORS

Ceramic Capacitors: Common Varieties

- A few common varieties of ceramic capacitor:
  - C0G: High-Q, lower capacities. Useful in oscillator tuning circuits and other applications requiring precise capacitances
  - X5R/X7R: Nonlinear temperature constant (looser tolerances), cheaper than C0G ceramics
  - Z5U: Lower temperature stability than X5R/X7R, space efficient, cheap, often used in bypass and decoupling capacitor applications
  - Y5V: Lowest temperature stability, smallest, cheapest, may behave undesirably when DC-biased.

CAPACITORS

Capacitor Types: Electrolytic Capacitors

- Dielectric is a very thin oxide layer grown chemically on the solid (typically aluminum) electrode
- Electrolytic capacitors use an electrolyte solution as a "wet" electrode (typically use paper soaked with solution)
- Electrolytic capacitors feature very high capacities and charge densities
- Available in polarized and non-polarized varieties
- Polarized caps can be destroyed if reverse-biased
- Wet electrode of electrolytic caps can dry out over time, giving these devices limited life

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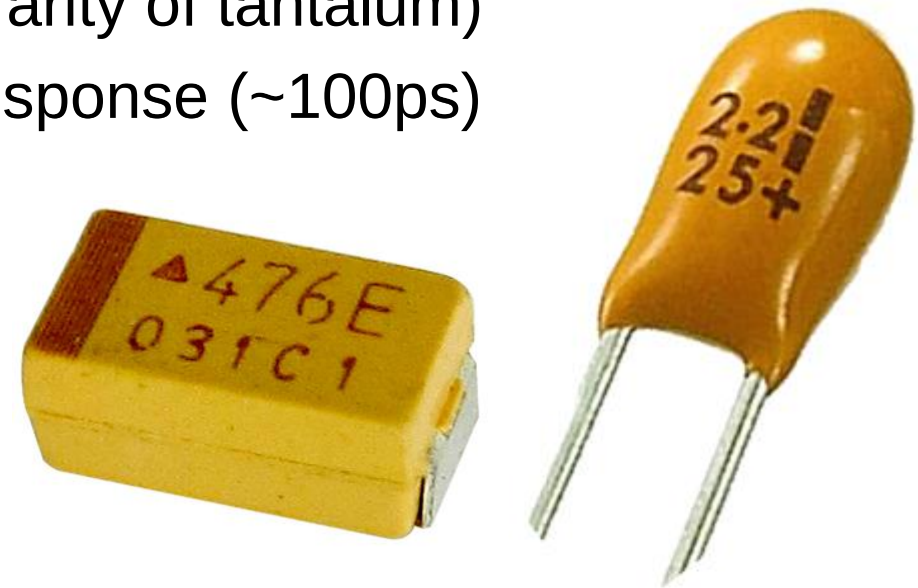
CAPACITORS

Capacitor Types: Tantalum Capacitors

- Use a dry electrolyte (increases device lifetime)
- Extremely thin dielectrics – results in higher capacitances and charge densities than aluminum electrolytics
- Lower voltage operation (50V max typical)
- Expensive (due to rarity of tantalum)
- Modest transient response (~100ps)
- High ESR typical



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CAPACITORS

Capacitor Types: Supercapacitors (Ultracapacitors)

- Hybrid capacitor device:
  - Electrostatic: Helmholtz double layer separates charge on the order of a few ångströms (0.3–0.8 nm)
  - Electrochemical: Some charge stored electrochemically, using methods similar to rechargeable batteries
- Highest energy densities of any capacitor (up to 12kF@1.2V) but deliver/accept less than half as much power (power density)
- Used for short-term storage of large amounts of energy and "burst-mode" power delivery

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CAPACITORS

Capacitor Summary

- Film Capacitors: High accuracy, high stability, poor space efficiency
- Ceramic Capacitors: Higher space efficiency, lower accuracy, lower stability
- Electrolytic Capacitors: High space efficiencies, reduced lifetimes, polarity considerations
- Tantalum Capacitors: Higher capacities, high ESR, lower max voltages
- Supercapacitors: Highest capacities, lowest max voltages, low frequency responses

INDUCTORS

Inductor Considerations

- Inductance: Inductance value in (n/μ/m)H
- Q-Factor: How ideal of an inductor is the device
- Core Type: What type of core material the inductor uses (affects permeability, saturation, and other device characteristics)
- Wire Gauge: What diameter of wire the coil uses
- Equivalent Series Resistance (ESR)
- Maximum Current Rating

$$L = \frac{N^2 \mu A}{l}$$

L = Inductance of coil in Henrys
N = Number of turns in wire coil (straight wire = 1)
μ = Permeability of core material (absolute, not relative)
A = Area of coil in square meters
l = Average length of coil in meters

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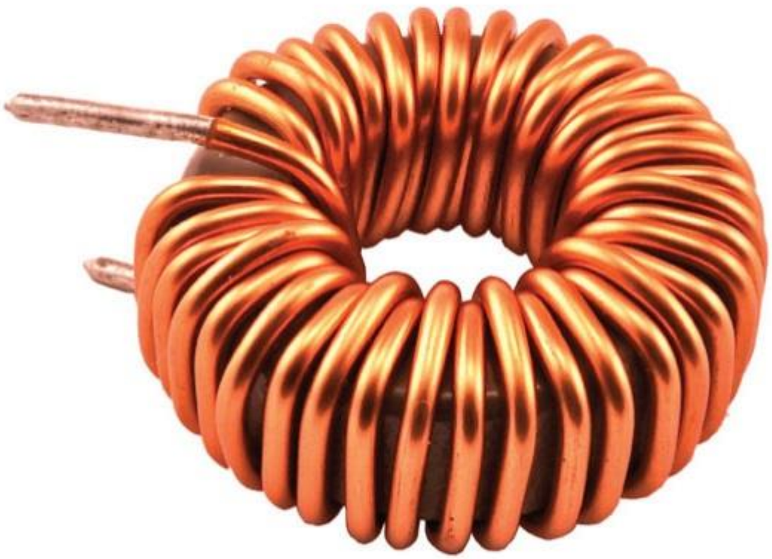
INDUCTORS

Toroidal Inductors

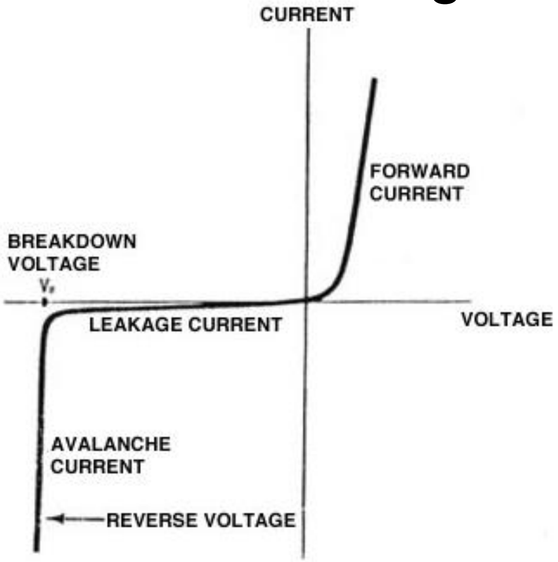
- Inductors which the coil of wire is wound around a “donut” core, or *toroid*
- The magnetic cores of toroidal inductors form closed loops, increasing the magnetic field, leading to higher inductance and Q-factor than equivalent straight-core inductors
- Toroidal designs minimize magnetic flux escaping the core (leakage flux), resulting in reduced EMI to nearby electronics



DIODES

Diode Considerations

- Forward Current: Maximum current the device can pass
- Forward Voltage: Voltage dropped across the device when conducting
- Leakage Current: Current that can pass through device when reverse-biased
- Breakdown Voltage: Maximum tolerable reverse voltage before avalanche breakdown occurs
- Recovery Time: How quickly the diode responds (related to device frequency response)



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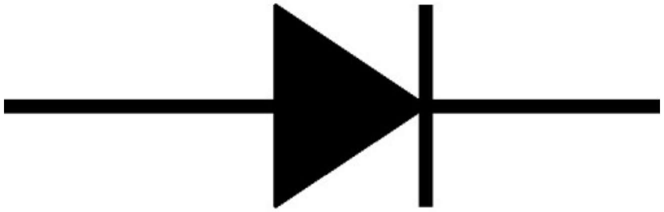
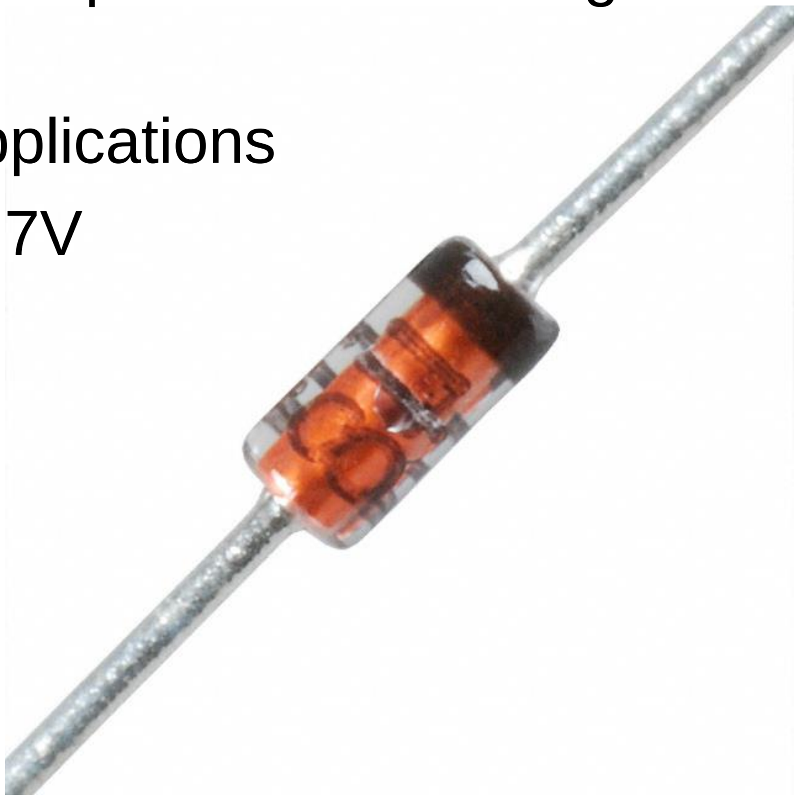
DIODES

Diode Types: PN Junction Diodes

- Formed by using the junction between two “doped” semiconductor materials (typically silicon)
- Junction capacitance reduces performance at high frequencies
- Used in general purpose applications
- Typical forward voltage: ~0.7V





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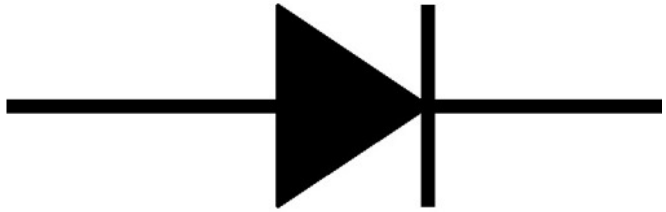
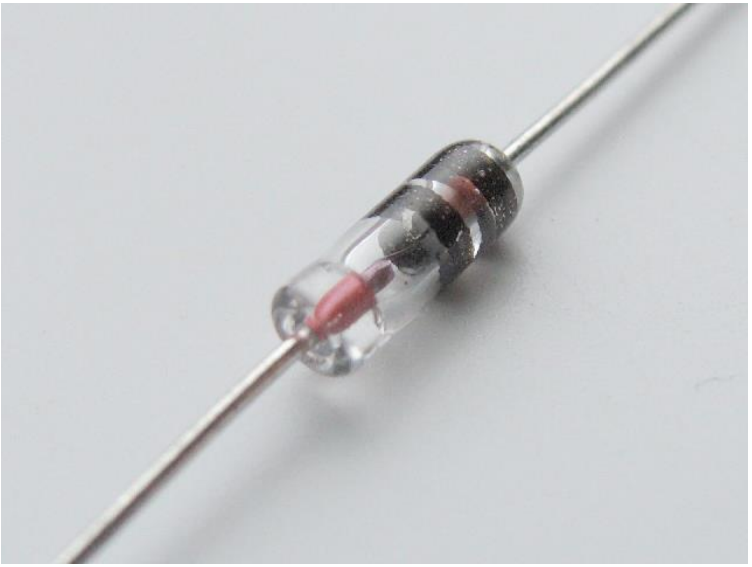
DIODES

Diode Types: Germanium Diodes

- Similar to silicon diodes, but germanium is used instead
- Germanium properties allow for improved response characteristics and high-frequency operation
- Often used in RF and radio applications
- Typical forward voltage: ~0.3V





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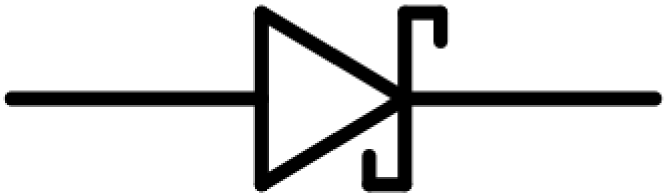
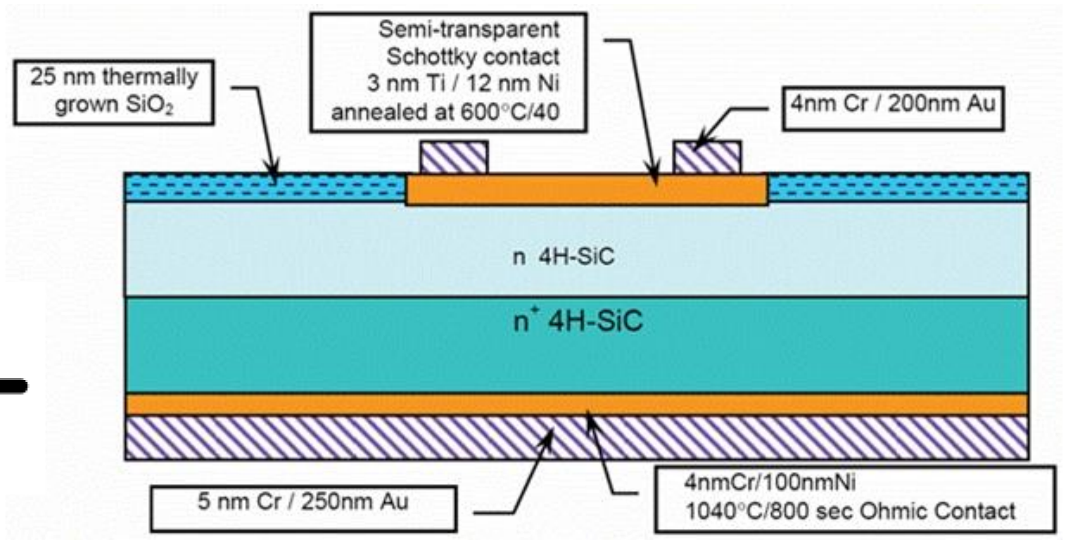
DIODES

Diode Types: Schottky Diode

- Similar to silicon diode, but one of the silicon junction materials is replaced with a metal
- Use of a metal reduces junction capacitance, improving frequency response at higher frequencies
- Higher leakage currents than silicon junction diodes
- Often used in high speed applications
- Typical forward voltage: 0.4V – 0.5V





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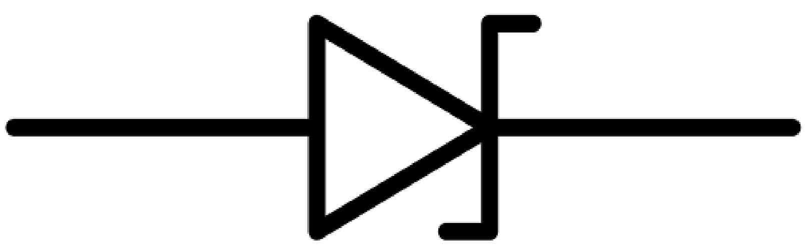
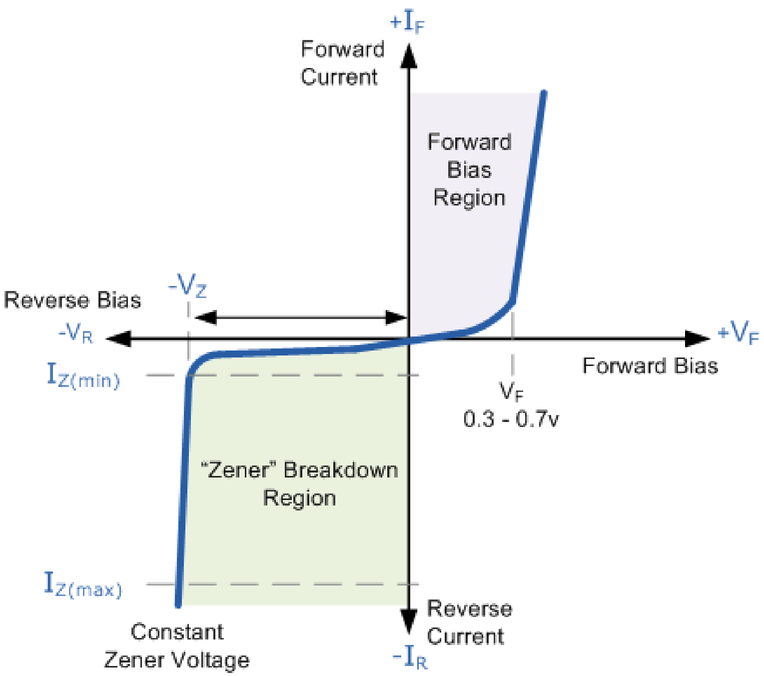
DIODES

Diode Types: Zener Diode

- Diode specially designed to operate in the breakdown voltage range (other diodes can be damaged when operating in breakdown)
- Provides a fixed voltage across a wide range of currents
- Commonly used as a voltage reference
- Available in many breakdown voltages (2.7V, 3.3V, 5.6V, etc.)





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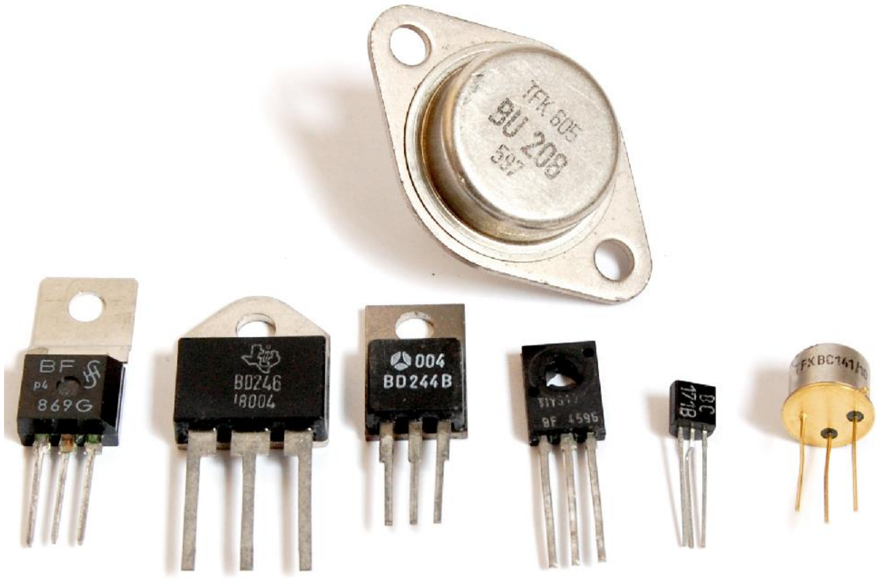
Diode Summary

- PN Junction Diode: General purpose operation, slower response times, ~0.7V forward voltage
- Germanium Diode: High speed operation, often used in RF applications, ~0.3V forward voltage
- Schottky Diode: Higher speed operation, higher leakage current, 0.4-0.5V forward voltage
- Zener Diode: Designed for operation in breakdown region, often used to provide fixed voltage reference

TRANSISTORS

Transistor Considerations

- <u>Voltage:</u> Voltage at which the device operates (in W)
- <u>Power:</u> Maximum rated power dissipation (in W)
- <u>Frequency:</u> Max frequency at which the device can switch
- <u>Amplification:</u> The gain from the base/gate
- <u>Current:</u> Maximum allowable current through the device



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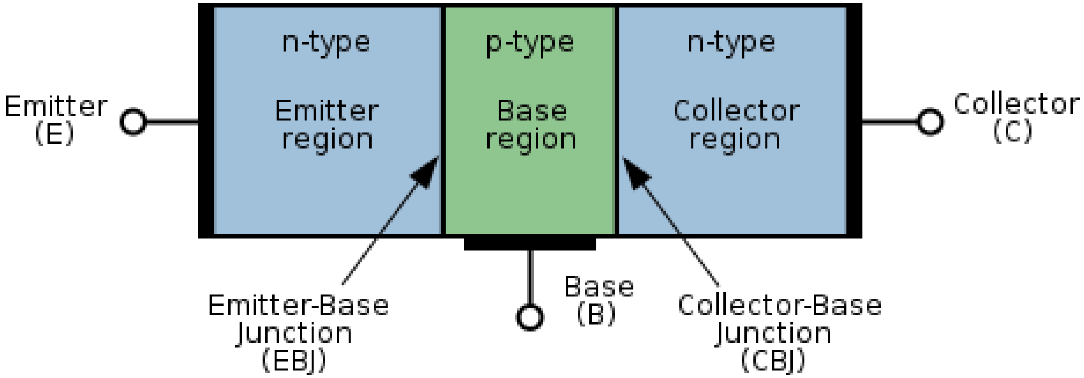
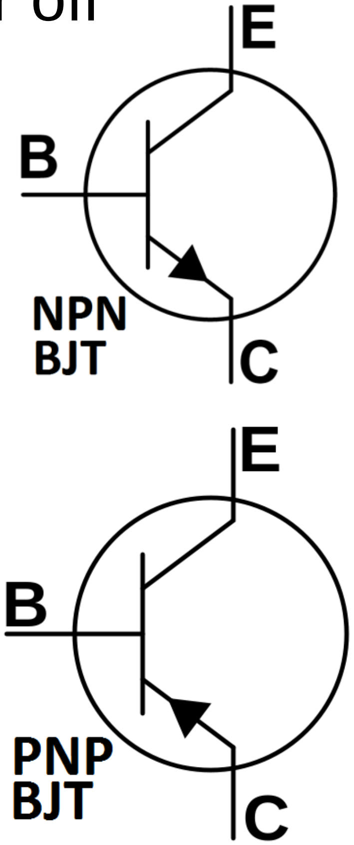
TRANSISTORS

Transistor Types - BJTs

- Formed through a combination of two junction diodes
- 3 terminals – base, emitter, and collector
- Require base current to be switched on or off
- β - current gain from base to collector
- Two types – npn and pnp
- Cheap to produce but more susceptible to damage





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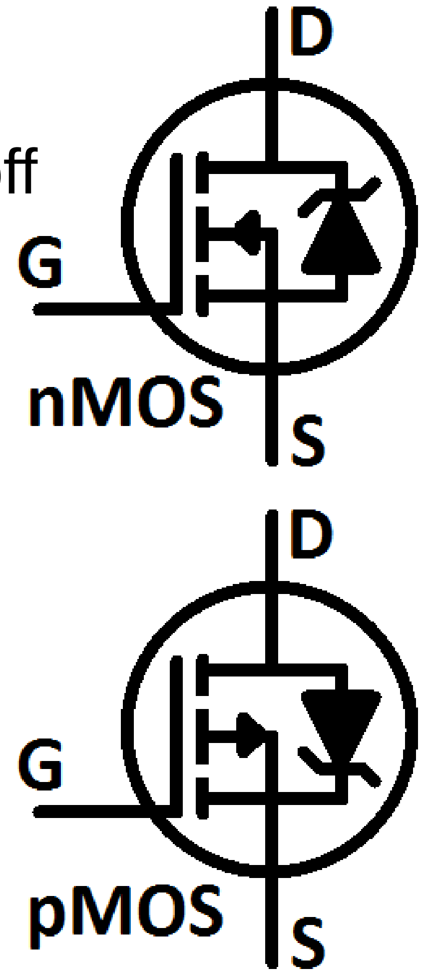
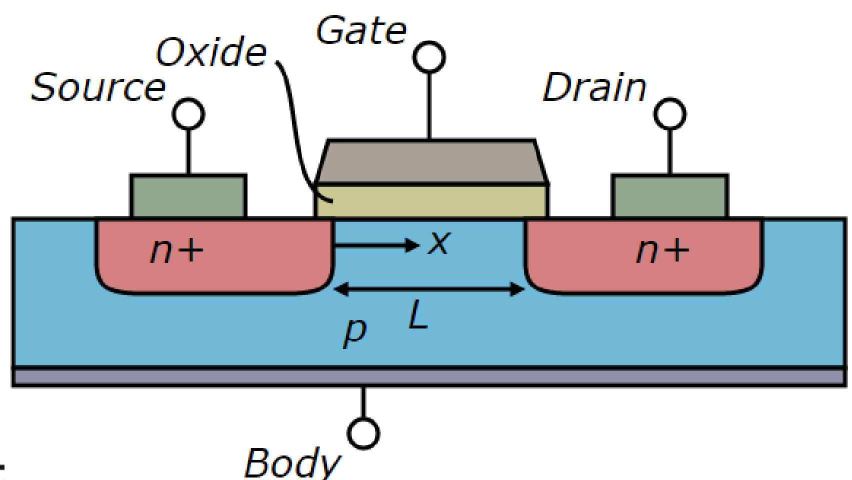
TRANSISTORS

Transistor Types - MOSFETs

- Can operate as a voltage-controlled switch
- 3 terminals – gate, source, and drain
- Require gate voltage to be switched on or off
- h_{FE} – Transistor gain
- nMOS and pMOS varieties available
- Feature integrated diodes (body diodes)





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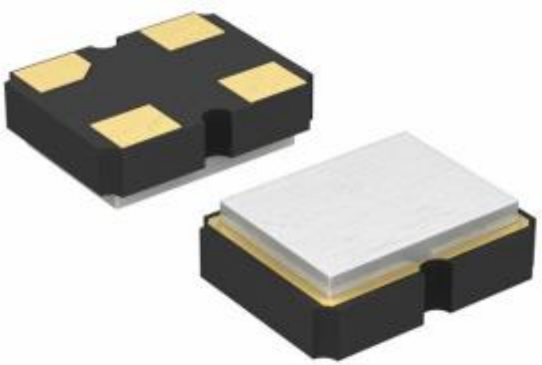
CLOCK SOURCES

- Crystals and Resonators (XTAL):
  - Vibrate when an electrical signal is applied
  - Crystals use piezoelectric lattices (quartz) while resonators use ceramic elements
  - Require external support components (typically capacitors)
- Oscillator:
  - Generally an oscillator element (crystals typical) with integrated support components



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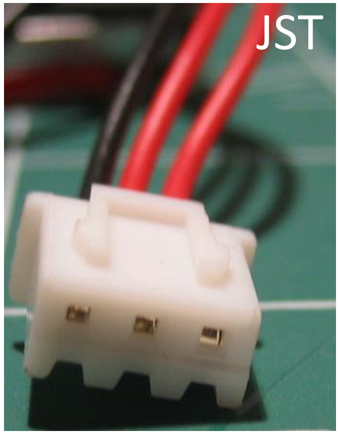
MECHANICAL COMPONENTS

Connectors

- Used to effectively and “cleanly” connect boards together (often used in conjunction with ribbon cables)
- Considerations:
  - Physical Layout (width, height, pin array dimensions)
  - Voltage/Current/Power ratings
  - Ease of crimping and availability of tools

Barrel Jack

IDC



MTA100

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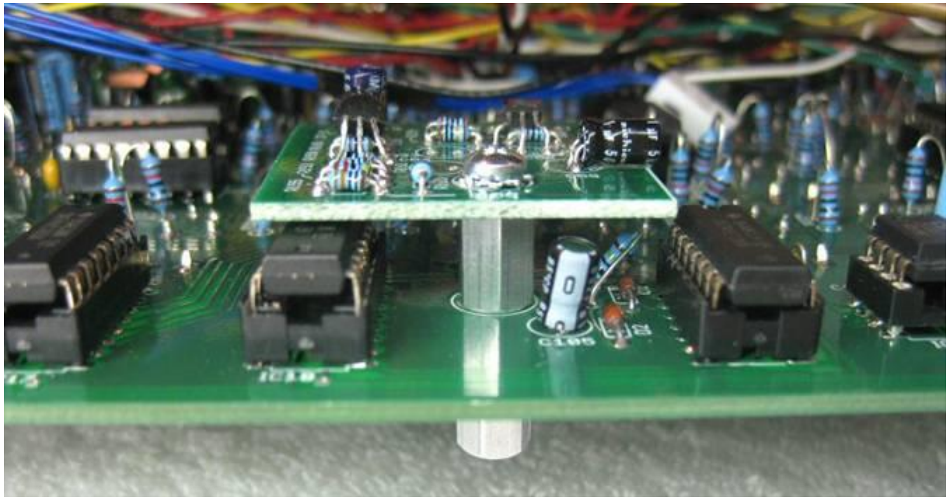
MECHANICAL COMPONENTS

Standoffs

- One method for physically mounting circuit boards to chasses
- Require use of drilled mounting holes (need to be included in PCB layout)
- Can enable stacked PCB designs (see below)



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OBTAINING PARTS

Vendors

- Where do I get parts?
  - DigiKey, Mouser, Newark, Futurlec, McMaster Carr, etc.: Reputable online vendors, competitive prices
  - Sparkfun, Adafruit, etc.: Sell components at substantial markup. Recommend as last resort if a part is need online
  - EE Instrument Room, Lafayette Electronic Supply: Local component sources (Lafayette, IN specific)
  - Radioshack: When you need parts TODAY. $$$$$$$$$$$$$$
- Other considerations for parts:
  - Source as many parts from a single vendor as possible (reduces shipping costs)
  - Purchase parts from reputable vendors if possible (beware of shady vendors and parts with poor documentation/support)

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OBTAINING PARTS

Part Search Engines

- Octopart: https://octopart.com
- Findchips: http://www.findchips.com
- Parts.io: https://parts.io/
- Allow users to search multiple vendors and compare prices, availability, cost breakpoints, etc. on components

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OBTAINING PARTS

Sampling Parts

- In addition to normal electronics channels, some vendors generously offer free samples of some parts for engineers to test to determine their validity in end product designs
- Before ordering a part for prototyping purposes, it may be beneficial to see if samples can be procured
- Sample parts programs behave somewhat on an honors system, and benefit the engineering community at large. Therefore, don't abuse them.

OBTAINING PARTS

Tips for Procuring Parts

To maximize your experience procuring parts:

1. Order parts that are currently available and in production. DO NOT rely on parts that are going to be in future production, parts that are EOL and not recommended for new designs, or any parts that cannot be found in stock
2. Order parts with good documentation and community support
3. Order parts that can be shipped in a reasonable timeframe (2 weeks or less recommended)
4. Order spare parts (at least 2 copies of most parts is highly recommended; 3-5 is even better)
5. Order parts from established vendors to minimize risks of counterfeit parts and shady practices.

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OBTAINING PARTS

Amazon, eBay, Alibaba

- Occasionally you may find parts selling for less than retail value on market sites such as Amazon, eBay, or Alibaba
- Buyer Beware
- eBay, Alibaba, etc. often suffer from significant problems, including:
  - Lack of reliable documentation: Vital for designs involving the products or components at hand
  - Increased likelihood of counterfeit parts: Which may not work as well as advertised, or at all
- All of this leads to increased risk, so:
  - Always check the seller rating, documentation, and community support for parts AND
  - Proceed with caution

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OBTAINING PARTS

Counterfeit Parts

- A globalized economy, outsourced manufacturing/supply chains, and economic incentives have lead to significant increases in counterfeit chips and components in recent years
- For an excellent case study in counterfeit electronics, see this post regarding the Chumby (open source hardware project) and issues faced from counterfeit ICs

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Questions?