Electronic Fundamentals - Not Obvious

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Electronic fundamentals that every EE student should know when they graduate from college.

Capacitors are one of the most important electronic components on a PCB.

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1) All capacitors have ESR (Equivalent Series Resistance).

- Ceramic capacitors have a low ESR.
  - They can filter high-frequency electronic noise.
  - They cannot filter low frequency electronic noise.
  - They have the longest life span.

- Non-ceramic capacitors have a high ESR
  - They can filter low frequency electronic noise.
  - They cannot filter high frequency electronic noise.

- Ceramic capacitors (such as 2.2 µF) and non-ceramic capacitors (such as a Tantalum 47 µF) are needed for an "external power input" rail.

- Digital components and switching voltage regulators create digital electronic noise on the PCB voltage rail.
  - Digital fast rising edges and fast falling edges affect the PCB voltage planes and ground planes.
  - A ceramic 0.1 µF capacitor should be on the voltage input of "every" IC.
    - All digital ICs and analog ICs.
    - This reduces digital electronic noise which can affect analog signals.

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2) Overrate every capacitor by a factor of two. The exception is the tantalum capacitor which needs to be overrated by a factor of three.

- Some years ago, a control panel for an IBM computer caught fire in an electronic assembly plant.
  - A 6.8 V tantalum capacitor was on a 5 V rail.
  - There should have been a 15 V, or higher, voltage rating on that tantalum capacitor.
  - IBM was fortunate this happened in an electronic assembly plant, not at a customer's site.

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3) “Bifilar Choke” are two inductors wrapped in parallel.

- “Bifilar Choke” current “out” will always equal the current “in”.

- A “Bifilar Choke” filters undesired “electronic noise” from entering the PCB.
  - It also filters “electronic noise” from exiting the PCB.
  - This may be necessary for meeting EMC requirements.

- With a “Bifilar Choke”:
  - “Communication” is possible because the “current in” equals the “current out”.

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4) Multilayer PCBs are important.

- One PCB inner layer should be a ground layer. Another PCB inner layer should be a voltage layer (commonly layer 2 and layer 5) for a 6-layer PCB.
  - This helps mitigate digital electronic noise from affecting other electronic components on the PCB.

- When a motor is used, place a common mode inductor between the motor PCB ground / voltage plane and the electronic PCB ground / voltage plane.
  - For a common mode inductor, the current "in" must equal the current "out".
    - This eliminates almost all motor electronic noise from affecting the analog circuitry.

- Multilayer PCBs make it easier to meet EMC requirements.

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5) Voltage regulators convert a DC voltage into different DC voltage.

- There are three types of voltage regulators. Linear voltage regulators, switching voltage regulators, and LDO (low dropout regulators).
  - The common output of “all” 3 V voltage regulators:
    - When V_{in} = 5 V
      - › V_{out} = 3 V.
    - When V_{in} = 12 V
      - › V_{out} = 3 V.
  - V_{out} remains at 3 V regardless of the V_{in} voltage.

- For linear voltage regulators:
  - V_{in} must always be a higher voltage than V_{out}.
  - I_{in} “always” equals I_{out}.

- A linear voltage regulator is "not" power efficient ($P_{efficiency} = P_{out} / P_{in}$).
- A 3 V linear voltage regulator example:
  - V_{in} = 6 V and I_{in} = 30 mA … V_{out} = 3 V and I_{out} = 30 mA.
    - P_{in} = 6 V * 30 mA = 180 mW.
    - P_{out} = 3 V * 30 mA = 90 mW.
    - $P_{efficiency}$ = 90 mW / 180 mW = 50%.
  - V_{in} = 12 V and I_{in} = 30 mA … V_{out} = 3 V and I_{out} = 30 mA.
    - P_{in} = 12 V * 30 mA = 360 mW.
    - P_{out} = 3 V * 30 mA = 90 mW.
    - $P_{efficiency}$ = 90 mW / 360 mW = 25%.
- Linear voltage regulators do not create electronic noise.

- For switching voltage regulators:
  - V_{in} can be a higher voltage than V_{out}.
    - And V_{in} can be a lower voltage than V_{out}.
  - I_{out} "can be larger" than I_{in}.
  - A switching voltage regulator "is" power efficient.
  - A 3 V switching voltage regulator example:
    - When a switching voltage regulator has 80% power efficiency:
      - P_{out} = 3 V * 30 mA = 90 mW
        - P_{in} = 90 mW / 80% = 113 mW.
      - When V_{in} = 6 V
        - I_{in} = 113 mW / 6 V = 18.8 mA.
      - When V_{in} = 12 V.
        - I_{in} = 113 mW / 12 V = 9.4 mA
      - A larger V_{in} requires less I_{in}.
    - When a switching voltage regulator has 90% power efficiency:
      - P_{out} = 3 V * 30 mA = 90 mW.
        - P_{in} = 90 mW / 90% = 100 mW.
      - When V_{in} = 12 V.
        - I_{in} = 100 mW / 12 V = 8.3 mA.
      - Higher $P_{efficiency}$ requires less $I_{in.}$
        - Batteries last longer.
  - Switching regulators are essential for low input power requirements.
    - They do require more electronic components.
    - They do generate electronic noise.

- LDO's (low dropout regulators) allow a small voltage difference between V_{in} and V_{out}.
  - V_{in} = 3.6 V is commonly acceptable for V_{out} = 3 V.
  - Linear voltage regulators and switching voltage regulators:
    - Commonly require a larger voltage difference between V_{in} and V_{out}.
    - Datasheets provide those details.

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6) FRAM is like RAM, except FRAM does not lose the FRAM contents when powered down.

- When powered on, the FRAM contains the same contents as before loss of power.
- A FRAM cell can be rewritten, one cell at a time.
  - With FLASH, it is not possible to re-write only one cell.
    - With FLASH, an entire segment must be erased, and then rewritten.
- FLASH can wear out after being erased and rewritten about 24,000 times.
  - A FRAM, when rewritten every 250 nsec, will last more than 75 years.
- FRAM is larger, and slightly more expensive. But in some cases, it is necessary.

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7) Amplifying an electronic signal can amplify electronic noise.

- Instrumentation Amps:
  - Minimize “electronic noise” amplification.
  - CMRR (common mode rejection ratio) specifies level of electronic noise reduction.
    - When CMRR equals 100 dB, the electronic noise is reduced ($10^{(100\ dB\ /\ 20\ dB)}$) equals 100,000.
      - The common mode electronic noise is reduced 100,000 times.
  - Instrumentation Amps require close to zero current into the Instrumentation Amp inputs.

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8) When the op amp “inputs”, or the op amp “outputs”, approach the “voltage rail”, V_{out} can become inaccurate.

- Some rail-to-rail op amps allow V_{out} to approach voltage rails with minimal effect.
- Some rail-to-rail op amps allow V_{in} to approach voltage rails with minimal effect.
- Datasheets provide these parameters.
  - Rail-to-rail descriptions may not be completely accurate as rail-to-rail can mean to within a few hundred mV.

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9) Digital potentiometers can change resistor values electronically.

- For example, a 100 k Ω, 8 bit digital potentiometer resistor value can be changed electronically.

    - Changed with a minimum of 0 Ω to a maximum of 100 k Ω in increments of 256 values.
- A digital potentiometer can change an op amp gain
    - While the op amp is powered.
- Ditto for an op amp offset.

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10) Tin Whiskers have become a problem.

- The European Union (RoHS) banned the use of lead in solder.
    - Solder had, in the past, been a combination of tin and lead.
    - Without the addition of lead, tin whiskers grow from tin over time.
    - Tin whiskers “short” electronic circuits which results in failure.
        - This has led to early electronics failures
        - Two satellites fell out of the sky because of tin whiskers.
        - Lead is allowed for airplane electronics.
            - Tin whiskers can still occur as electronic components also have no lead.

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11) Some years ago, multilayer PCBs started failing, months after installed at a customer site

- The culprit was dendrite growth between PCB traces in the inner layers of a multilayer PCB.
    - Dendrite growth occurs over a length of time.
        - Dendrite growth is metallic which can eventually short PCB internal traces.
    - The internal PCB layers must be cleaned properly before they are stacked together.
        - This inhibits dendrite growth.

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12) Optoisolators (optocouplers or photocouplers) contain an LED and a phototransistor.

- Current through an LED, results in light from the LED.
- The LED light is detected by a phototransistor.
    - Results in current through phototransistor.
- More current through the LED results in a higher intensity light.
    - Results in more current through the phototransistor.
- Optoisolators provide galvanic isolation.
    - Zero current flow between the input current and the output current.
- Commercially available optoisolators.

  - Can withstand up to 10,000 V between the input voltage and output voltage.

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13) Hall Sensors detect a magnet that is stationary.

- Prior to Hall Sensors, the only way to detect a magnet is by moving a coil of wire near a magnet or moving a magnet near a coil of wire.
- Hall Sensors can determine magnetic field strength while stationary or while moving.
- Hall Sensors can be used for:
  - Printers (doors left open)
  - Factory automation (robotics, conveyor belts)
  - Industrial controls (energize motor windings at correct time)
  - Vehicles (wheel speed, anti-lock brake, traction control, engine ignition timing).

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14) Crystals generate precise frequencies.

- Crystal frequencies change very little with temperature changes.
  - Precise frequencies are needed for:
    - Computers, cell phones, satellites, and many other devices.
  - Crystals range from kilohertz to hundreds of megahertz.
  - Crystals provide only microamps of current.
    - It is common to place a crystal in close proximity to an IC.
    - They need to be connected to an IC high input impedance.
  - It is common to place small value capacitors in the close proximity to the crystal.
    - Commonly between 5 pF and 22 pF.
- A crystal alternative is a resonator.
  - A resonator provides a fairly constant frequency.
    - Less accurate than a crystal.
  - A resonator is lower cost.
    - Unfortunately, the frequency can change with temperature changes.
- Another crystal alternative is oscillators.
  - An oscillator provides a constant frequency (the same as a crystal).
  - Oscillators provide more current than crystals.
    - Useful when multiple components need a constant frequency.
    - Can be located long distances (inches) from components.
  - Oscillators are higher cost, consume more real estate, and consume more power.

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15) Electronic “impedance”

- Impedances are:
  - Capacitors
    - Are resistant to voltage changes (AC).
    - There are phase changes.
  - Inductors
    - Are resistant to current changes (AC).
    - There are phase changes.
  - Resistors
    - Are not resistant to voltage changes or current changes.
    - There are no phase changes.
  - The letter "Z" denotes impedance.

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16) "Every" electronic product must meet EMC (Electromagnetic Compatibility) requirements.

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17) SPICE electronic models predict “end results”.

- Bench top testing can be difficult.
  - Changing “every” component, one at a time, is time consuming.

- Micro-Cap is the best SPICE model I've ever used (over a span of 20 years).
  - Other SPICE programs do not perform as well as Micro-Cap.
    - TINI-TI (Texas Instruments) ... LTspice (Linear Technology) .... MATLAB ... etc. .
      None of them are even close to Micro-Cap capability
  - Micro-Cap is easy to use.

- SPICE models allow varying component tolerances such as:
  - Changing temperatures.
  - Estimating worst case values.

- All EE's at Emerson used Micro-Cap
  - Even though it cost $4,500 each.
  - Micro-Cap is now free.
    - Andy Thompson, owner of Spectrum Software, has retired.

- See the website **Electronics.FoxPing.com** for a Micro-Cap demo and examples.
  - 6.1 Electronic Datasheets, Micro-Cap

||| Micro-Cap Download & Examples |||

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Electronic Fundamentals at https://electronics.foxping.com/ has links to YouTube video clips.