Lecture 1

Henry Lau (2021)
v1.0

Introduction

Topics in training

Resistors, Inductors, Capacitors, Diodes, Relay, MOSFETS, Power and Safety, Buck converter, Basic schematic and PCB layout in Altium Designer

Currently planned 4 set of slides with 1 set of self study altium designer guide

Topic

Basic electronics/electrical knowledge learnt in DSE.

Passive components

Resistors, Inductors, Capacitors considerations and usage

Basic wiring and connectors

PGND and SGND in system

DSE and Extra Background

Commonly Used Terms

Voltage: The energy of the electrons

Current: Rate of electrons flow

Power: Energy that the component can provide of consume.

Resistance: The real part of impedance.

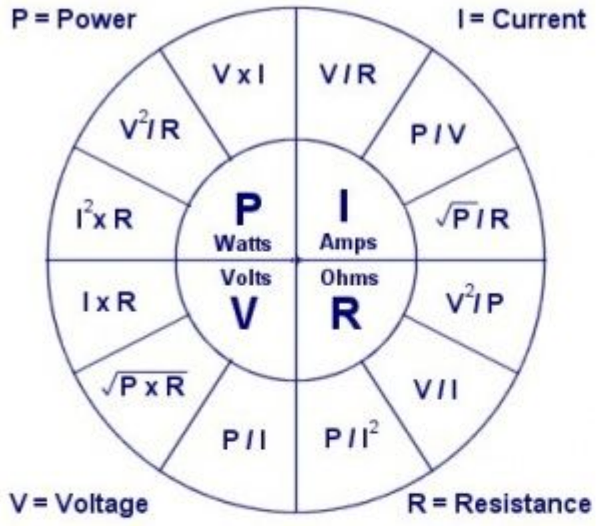
Reactance: The imaginary part of impedance.

AC and DC: Alternate Current and Direct Current.

Formula

V=IR: voltage equals to current times resistance.

P=VI: power equals to voltage times current.



Formula

Physical meaning:

$V = IR$:

1. If there is potential difference across any resistance, current will flow through.
2. If you inject current through a resistor, there will be potential difference across the resistor.

Formula

Physical meaning

P=VI:

1. The power that a source can provide = the max voltage * max current that it could provide.
2. The power that an electrical component consumes = Potential difference * max current.

Useful courses in electronics in HKU

ELEC2346 => basic circuit analysis and RLC circuit

ELEC3143 => power electronics, mainly learn more about DC-DC converters

ELEC3350 => semiconductor devices (old code 3346)

Good stuff

EEVBlog Fundamental Friday

Louis Rossmann   Soldering skills

PDFs/videos from big companies, since they cannot sell you their products if you don’t know how to use them

Examples:

This Texas Instruments playlists about tons of stuff

This Vishay playlist about diodes in different packages

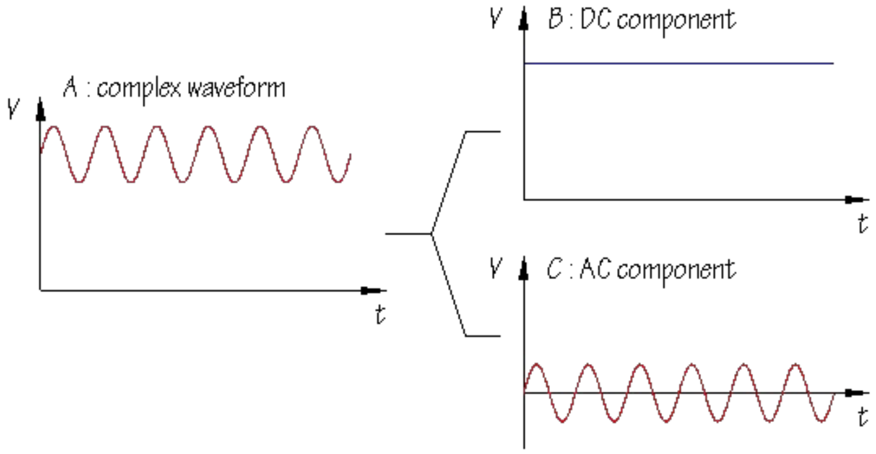
This Infineon PDF about reverse voltage protection

Mouser / Digikey newsletter to know new electronic components released

Superimpose

Signal could be split into DC and AC component superimposed on each other.

We will come back to this when talking about noise and filtering



Passive Components

Definition

The strict definition is not well defined, please refer to wikipedia

https://en.wikipedia.org/wiki/Passivity_(engineering)

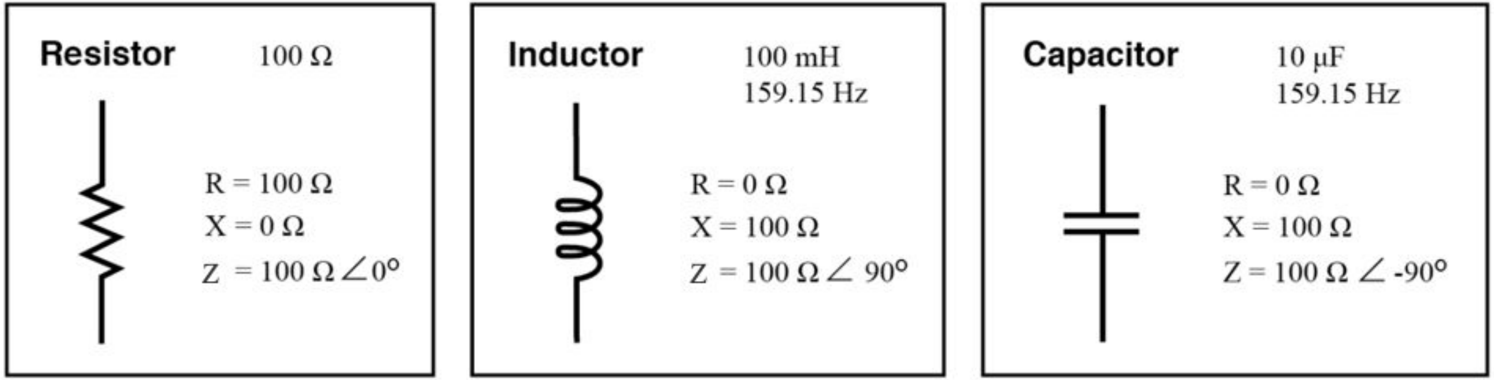
Under both definitions, resistors, inductors, capacitors and diodes are defined as passive components.

Concepts

Impedance (Z) : Z = R + jX

R: Resistance (Real), which shows the inability of current flow in the circuit.

X: Reactance (Imaginary), which is the opposition of current change in the circuit.



Resistor

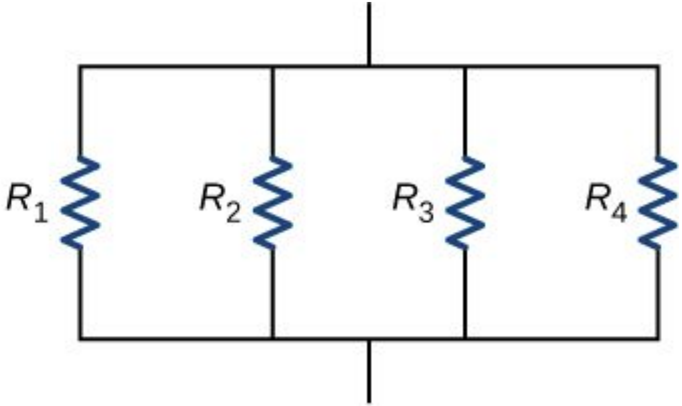
Resistor

In ideal condition, resistor contains its listed resistance and has no reactance, it could also dissipate unlimited power.

As it has no reactance, the impedance doesn’t change in relationship to the frequency of voltage across it.

Resistor

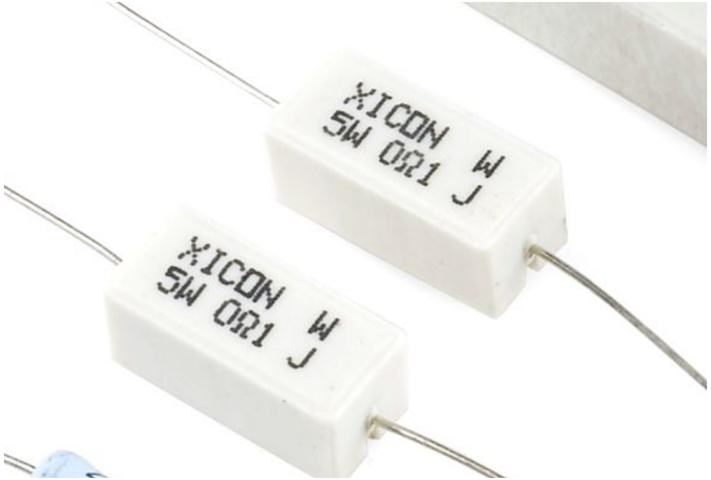
(a) Resistors connected in series



(b) Resistors connected in parallel

Power Rating of Resistor

Every resistor has a power rating. The power rating of it shows the maximum power (power loss) that it could dissipate before it breaks down. Like the resistor shown in the picture has 0.1 ohm with power rating of 5W.



Max current is around 7A before it breaks down

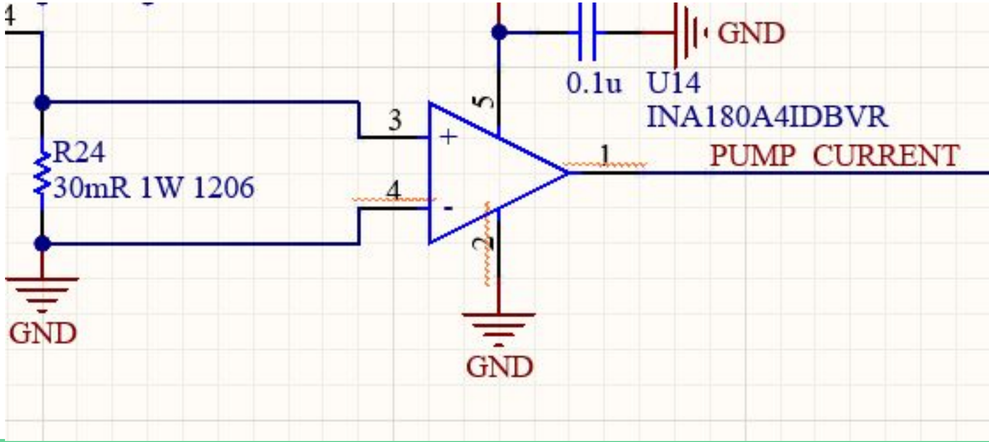
(How to calculate 7A?)

Power Rating of Resistor

In this schematic, a shunt resistor is used to measure the current of a water pump.

The expected maximum current flowing through the resistor is 3A, so the power loss is 0.27W

If we use a resistor with a power rating lower than 0.27W, there will a risk of burning

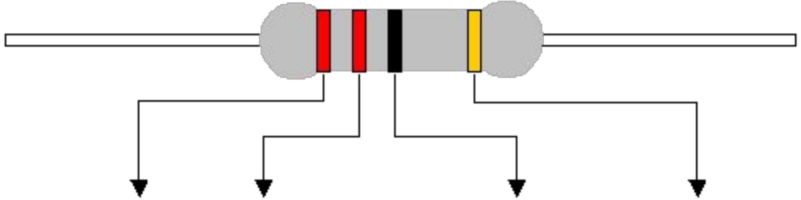


Tolerance and color code

Due to manufacturing constraints, there are tolerance in the resistance.

In the figure, the 4th color band represents the tolerance of the resistor. For example, if the color band is gold, the tolerance is 5%

(e.g. 1K Ohm resistor @5% tolerance could range from 950 Ohm to 1050 Ohm)



COLOR	1ST BAND	2ND BAND	3TH BAND	MULTIPLIER	TOLERANCE	
BLACK	0	0	0	1		
BROWN	1	1	1	10	± 1%	F
RED	2	2	2	100	± 2%	G
ORANGE	3	3	3	1K		
YELLOW	4	4	4	10K		
GREEN	5	5	5	100K	± 0.5%	D
BLUE	6	6	6	1M	± 0.25%	C
VIOLET	7	7	7	10M	± 0.10%	B
GREY	8	8	8		± 0.05%	A
WHITE	9	9	9			
GOLD				0.1	± 5%	J
SILVER				0.01	± 10%	K
PLAIN					± 20%	M

Choosing resistors

When choosing resistors, first choose the correct value that is required, always calculate the power that it needs to dissipate. If it is higher than the rated power, it will meltdown deal to excessive heat. Resistors with higher power rating will need a larger physical size.

The requirement of tolerance in a resistor depends on different application. You may want resistor with better tolerance rating when you are building RF circuits or analog circuits. Keep in mind resistors with better tolerance ratings usually costs more.

Inductor

Inductor

An inductor is composed of a coil of wires winded around a core. The unit of inductance is Henry (H).

Formula: Z = 2(pi)(f)(L)(j)

Physical meaning: the impedance of inductors are proportional to frequency. It resists the change of current

It stores electrical energy in form of magnetic flux. (magnetic field)

Energy = 0.5(L)(I)(I)

Energy stored in inductor is related to the current flowing through it

Inductor

In ideal situation:

Inductor doesn’t have resistance and only has positive reactance. Its inductance is also unaffected by the current.

In real situation:

Inductor has equivalent series resistance (ESR) which we need to take account of when we design circuits.

Inductors has current limit, if the current passing through it is higher than the rated current, the inductor will saturate and the inductance will decrease

Inductor

Parallel Inductances

$$\mathbf{L}_{\text{total}} = \frac{1}{\dfrac{1}{\mathbf{L}_1} + \dfrac{1}{\mathbf{L}_2} + \ \dots\ \dfrac{1}{\mathbf{L}_n}}$$

Series Inductances

$$\mathbf{L}_{\text{total}} = \mathbf{L}_1 + \mathbf{L}_2 + \dots\ \mathbf{L}_n$$

Parallel and series equation for inductor (similar to resistor)

Voltage current relationship of inductor

Voltage drop across the inductor is proportional to the rate of change of current across the inductor.

Transient current will lead to large voltage difference across the inductor

"Ohm's Law" for an inductor

$$\mathbf{v} = \mathbf{L}\,\frac{\mathbf{di}}{\mathbf{dt}}$$

Where,

$\mathbf{v}$ = Instantaneous voltage across the inductor

$\mathbf{L}$ = Inductance in Henrys

$\frac{\mathbf{di}}{\mathbf{dt}}$ = Instantaneous rate of current change (amps per second)

Tolerance

Usually power inductors have a tolerance of 20-30%

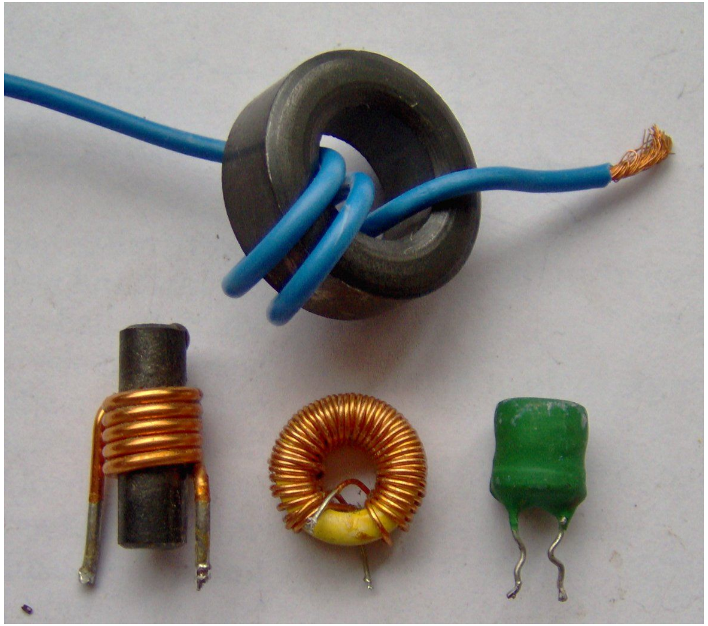
When designing the circuit (eg DC-DC converter), the tolerance need to make sure the system will function within the tolerance range.

Smaller inductor used in RF have much much better tolerance la

Inductor’s Usage

Usage of inductors:

1. Choke
2. DC to DC converters



Choke

Choke is used to block high frequency while passing DC and lower frequency.

Usage: Connect common-mode choke at the power input of the circuit board could reduce the differential mode noise entering the PCB, it also prevents the high frequency noise from leaving the PCB into the power wires

Used in tandem with bulk capacitors

DC-to-DC converter

Inductor is a common component used in buck converters

This topic will be further covered in lecture about DC-DC converters.

Choosing an inductor

Choose the correct inductance, with the tolerance that is usable in the application. The current rating of the inductor must be taken into consideration to prevent the inductor from reaching saturation (leading to drop in inductance). The ESR will will cause power loss in inductor (power loss = current * current * ESR)

Capacitor

Capacitor

A capacitor is formed by putting 2 conductive layer and an insulating layer between them. The unit of inductance is Farad (F).

Formula: Z = -j/(2(pi)(Hz)(C))

Physical meaning: the impedance of capacitors are inversely proportional to frequency. In small signal analysis, we can treat capacitor as opened in DC and closed in AC.

It stores electrical energy in form of electronic charge across the 2 plates.

Energy stored = 0.5(C)(V)^2

Capacitor

In ideal situation, capacitor doesn’t have resistance and only has negative reactance.

In real situation, a capacitor has resistance (equivalent series resistance “ESR”), which we need to take account of when designing circuits.

Capacitors has voltage limit, if the voltage across it is higher than rated voltage, the capacitor will fail.

Capacitor

Series Capacitances

$$C_{total} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \ldots \frac{1}{C_n}}$$

Parallel Capacitances

$$C_{total} = C_1 \ + \ C_2 \ + \ldots \ C_n$$

Parallel and series equation for capacitor (opposite to resistor)

Voltage current relationship of capacitor

The current passing through the capacitor is proportional to the rate of change of voltage across the capacitor.

"Ohm's Law" for a capacitor

$$i = C \frac{dv}{dt}$$

Where,

i = Instantaneous current through the capacitor

C = Capacitance in Farads

$\frac{dv}{dt}$ = Instantaneous rate of voltage change (volts per second)

Types of capacitor

3 types of capacitors: Tantalum, Electrolytic and Ceramic.

Ceramic capacitor has lowest ESR
Tantalum and electrolytic capacitor are cheaper way to obtain higher capacitance

Choosing voltage rating for different types of capacitors.
Ceramic: 20% higher
Tantalum: 50% higher
Electrolytic: 35% higher

Further reading

Capacitor

Common usage:

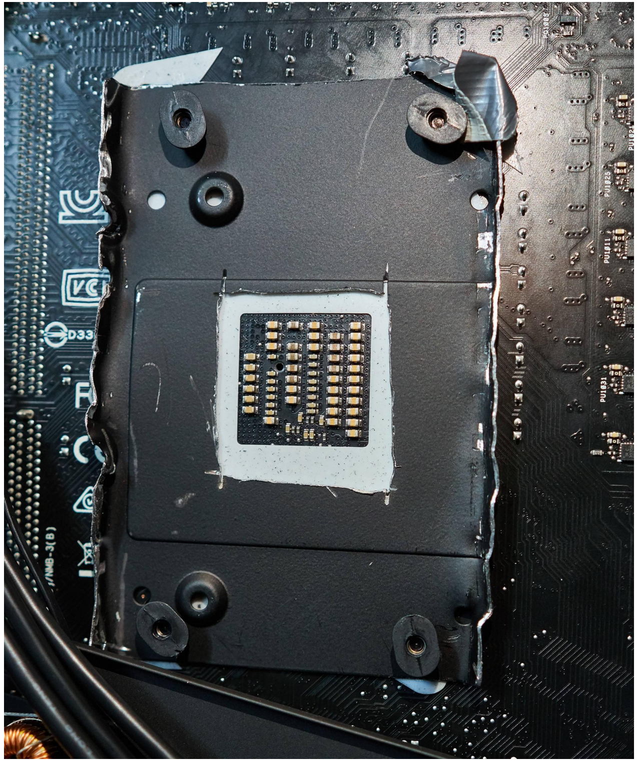
1. Decoupling/Bypass
2. Bulk capacitor
3. Filter

Decoupling/Bypass

Decoupling capacitors are added close to power pin to a device with high switching frequency to minimize the noise in power

Ceramic capacitors are usually chosen for this purpose for their low ESR

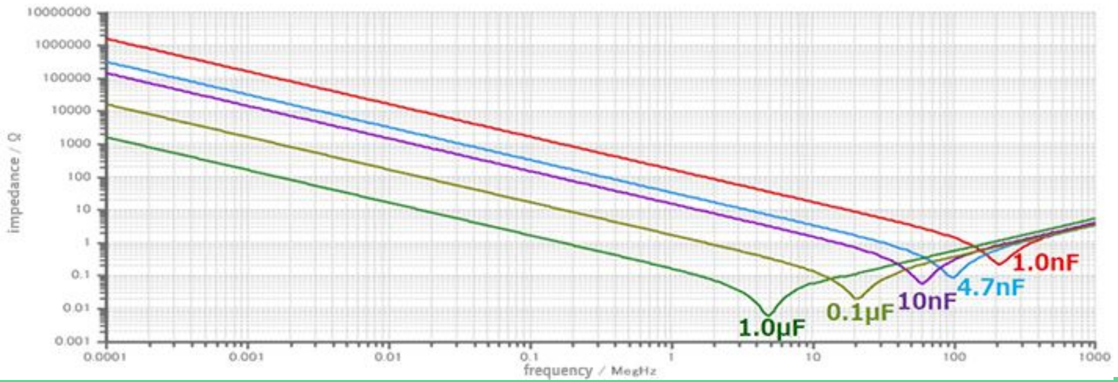
(picture showing SMD capacitors on the back side of a cpu socket)



Frequency response

Different value of capacitors to cater for different frequency

https://www.reddit.com/r/ElectricalEngineering/comments/nqmowp/i_should_probably_pursue_another_career_instead/




RodgarTallstag · 2m

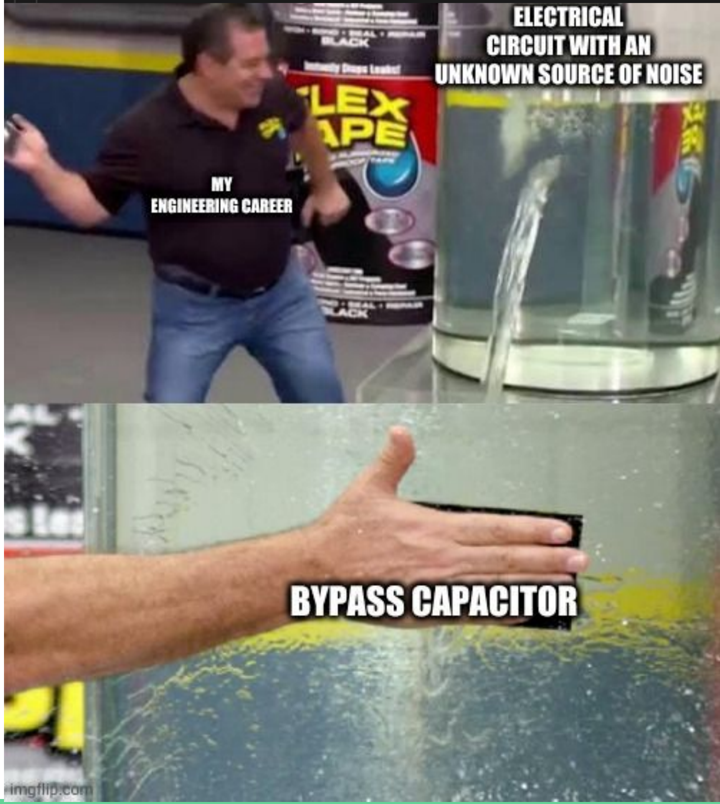
Dream team is 4.7uF + 0.1uF + 100pF for me, takes almost all the reasonable frequencies of disturbance

126 Reply Give Award Share Report Save

darkonark · 2m

saving this comment

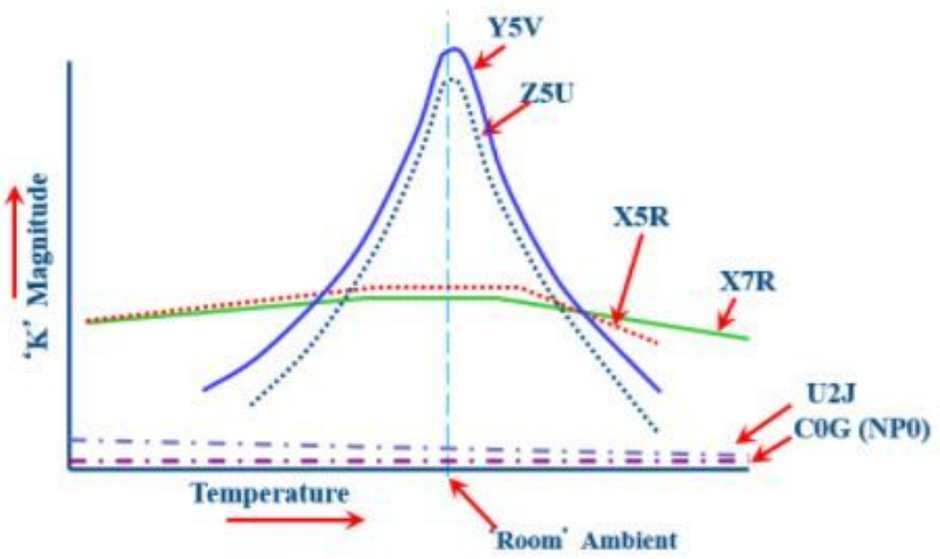
27 Reply Give Award Share Report Save



Rating of ceramic capacitors

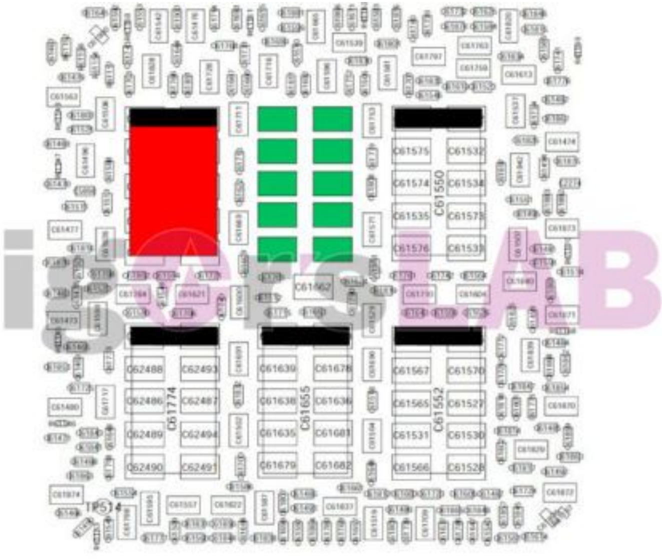
Usually capacitors are rated as X5R, X7R etc. These ratings are describing the percentage change of the capacitor in different temperature. In our team we usually use capacitors with X5R or higher.

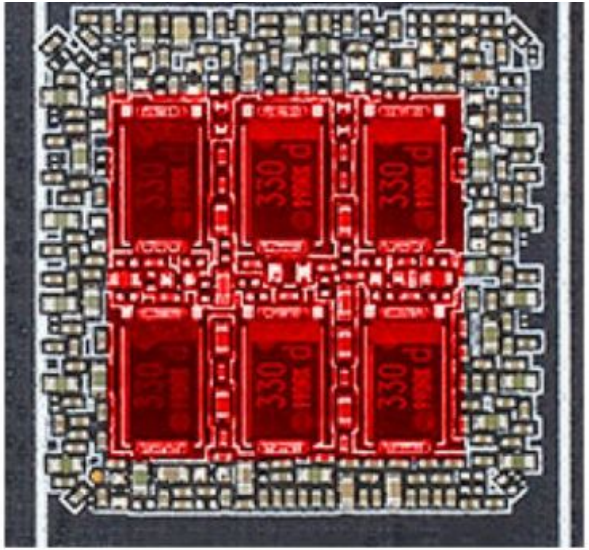
Further reading

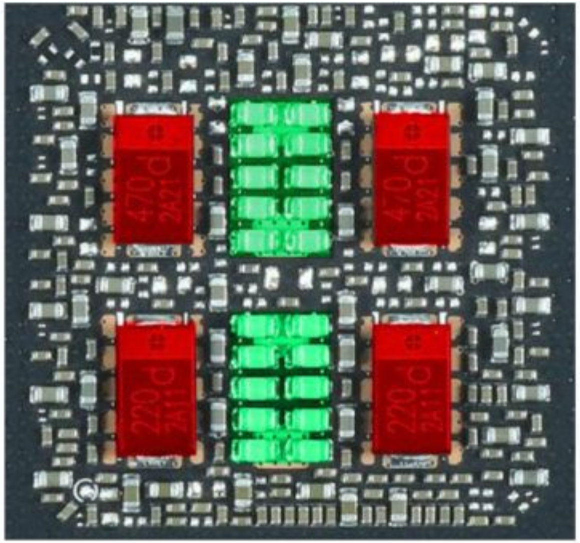


Decoupling Capacitor Issues (Novideo RTX3080)

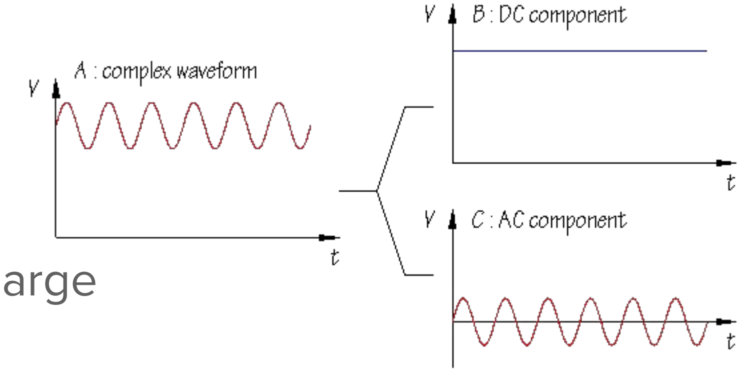
https://videocardz.com/newz/manufacturers-respond-to-geforce-rtx-3080-3090-crash-to-desktop-issues





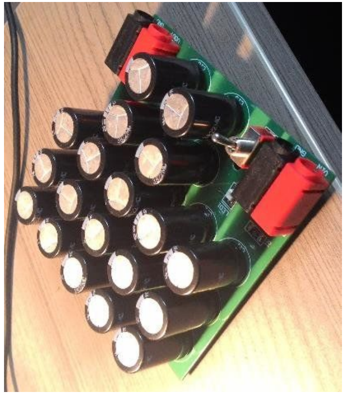


Bulk Capacitor



Bulk capacitance act as reservoir to store electric charge

Electrolytic capacitor are used as Bulk Capacitor to provide stable voltage when the supply current is unstable (low frequency noise in power cable)



Usually added at the power input of the PCB

Decoupling / Bulk Capacitor help minimize the amplitude of AC component (noise)

Electrolytic Capacitor Brand Selection

https://www.badcaps.net/forum/

Mainly focus on electrolytic capacitors (audio and power supply related)

Have a megathread for good caps, and another one for bad caps

Sometimes having a good E-cap at lower value is better than having a bad E-cap at higher value

Nichicon , NCC, Rubycon are commonly used in high-end power supplies
Panasonic is a religion

Filter

Passive high pass, low pass and bandpass filter with RLC circuit.

Examples:
Usage of low pass filter to filter high frequency noise (low pass filter and anti-aliasing filter for ADC)

If Have Enough Time

Learn how to use Mouser to find components that we needed

https://www.mouser.hk/Passive-Components/Inductors-Chokes-Coils/Fixed-Inductors/_/N-wpcz?Keyword=inductor&FS=True

Tutorial

1. What is the purpose of having color code on through hole resistors
2. What is saturation in an inductor
3. Why ferrite core is inserted into an inductor
4. Why decoupling capacitors with different values are used in parallel (hint)
5. How is the value of electrolytic capacitor affected by the time of usage / aging
6. Can we make an active low-pass filter with just RLC as its components

System power and Signal Wiring

Connectors and Wires

Link (For HKU internal use only)

Types of connector (power and signal)

Wires gauge (AWG standard)

Wire Gauge	Max amps for chassis wiring (Powerstream.com)	Applications
AWG 22	7A	transmitting signal and powering sensors
AWG 18	16A	powering actuators e.g. motors
AWG 15	28A	powering heavy duty loads e.g. duct fans
AWG 12	41A	powering heavy duty loads e.g. duct fans

Cabling and wiring of robot

Parasitics of cable

Star topology vs daisy chain

PGND and SGND (power and signal ground)

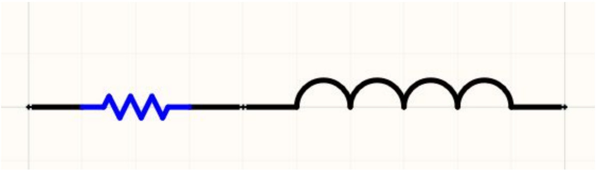
First we will talk about power in a system

Parasitics of cable

Beside from resistances, cable comes with inductance too.

When you connect motorboards to the battery with longer cable, the more voltage drop

$$v = L \frac{di}{dt}$$

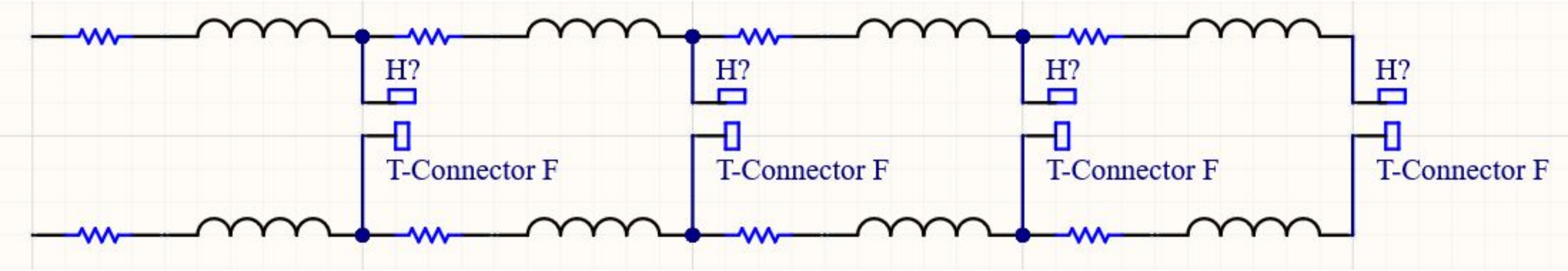


Topology

Daisy chain vs star topology

The power ground of the system will be considered for now

Why switches are placed on the higher side of the battery instead on the low side? (clue inductive current)



Daisy Chain

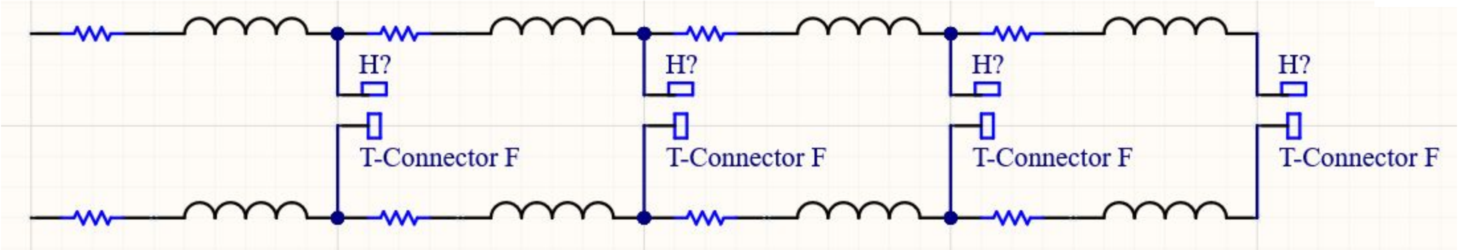
Shorter cable used in total

Power ground of each board suffers from higher variation when there is high current flow due to voltage drop.

High parasitic inductance for the load at the end of the chain => more voltage drop from transient current.

"Ohm's Law" for an inductor

$$v = L \frac{di}{dt}$$

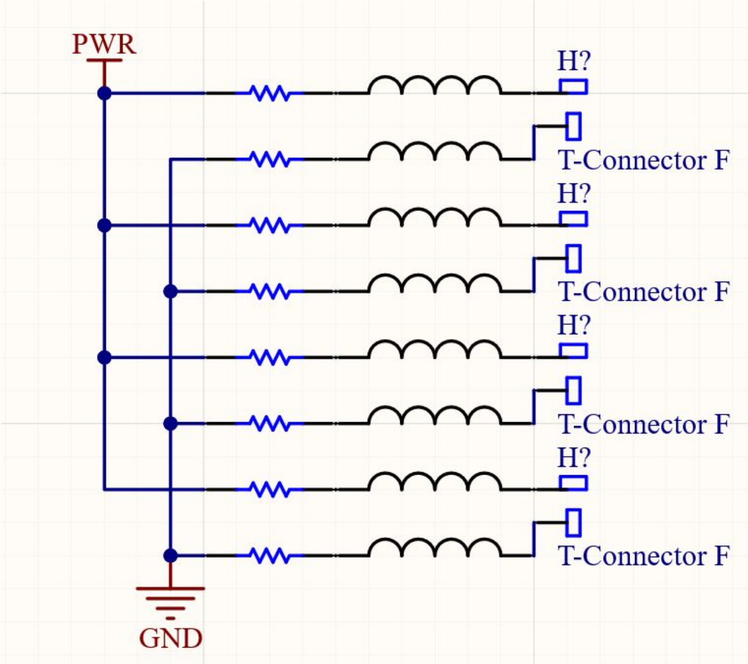


Star Topology

Increase in cable length

Better grounding between different nodes

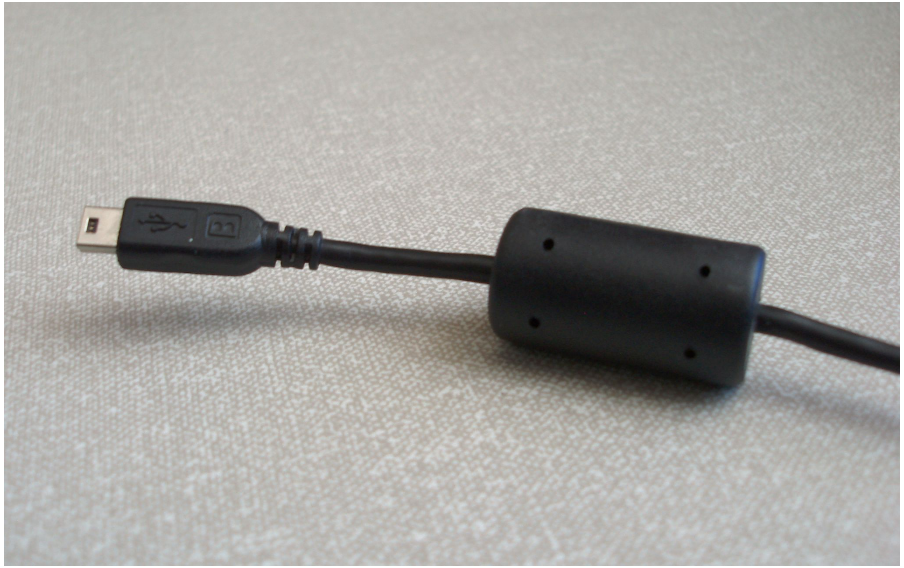
Thinner cable could be used for lesser loadings



Ferrite Bead

Ferrite bead is used to suppress high frequency electronic noise on both direction.

For example suppress high frequency noise of switching power supply from entering the device. Or vice versa



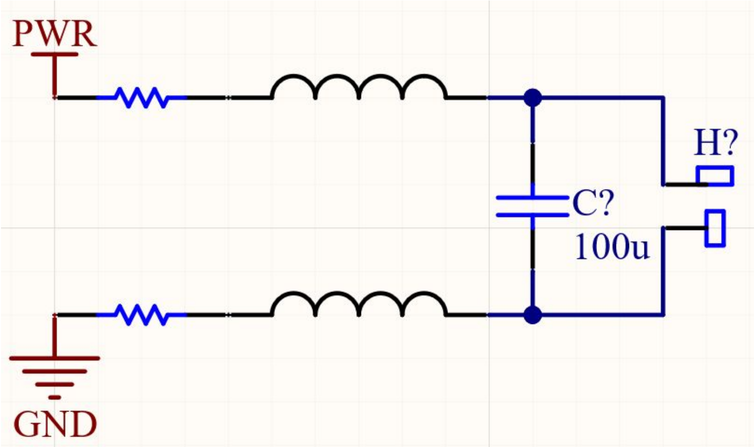
Bulk Capacitor

The parasitic inductance will affect the voltage at the PCB when there is a transient current

$$v = L \frac{di}{dt}$$

Place bulk capacitor to improve the transient response at the PCB.

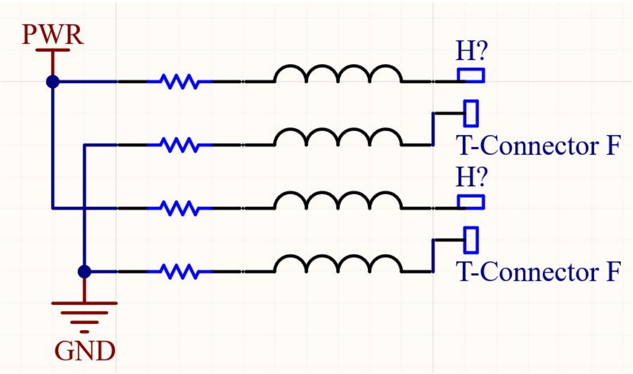
Larger bulk capacitor should be used for PCB with larger transient loading

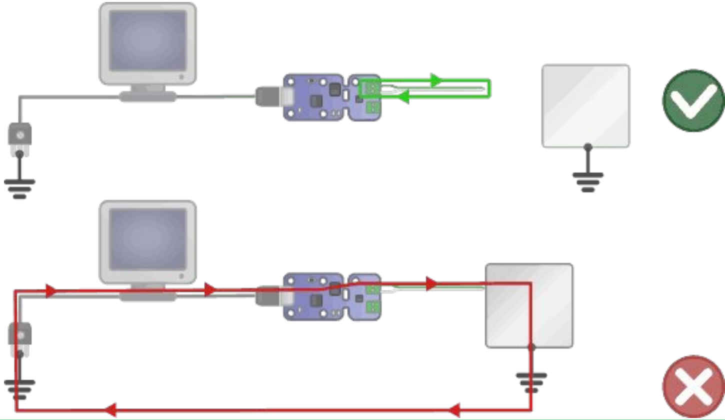


Signal in a System (Signal Ground)

When you want 2 PCBs to communicate with each other, you would need to connect their ground together

When we connect the GND pin from one PCB to another PCB. We will create sth called ground loop.

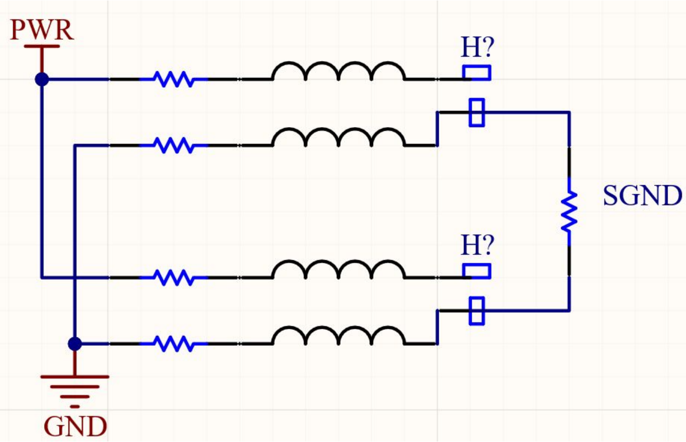




Signal Ground in star topology

With the wire trying to form a common ground for SGND. The Loadings/PCB are grounds at 2 different point (at the battery and at the signal cable connecting the ground)

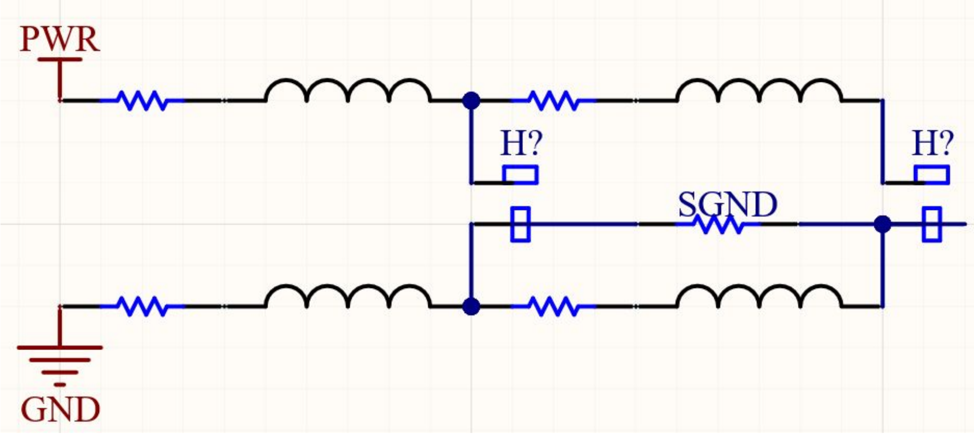
Having ground loop also means you can’t “control” how the current returns to the battery



Signal Ground in daisy chain topology

Ground loop in daisy chain topology is smaller than the ground loop in star topology

For EMC/EMI compliance testings. Having ground loop => more EM emission. It is advised to prevent having ground loop.



Potential Problems related to poor grounding

Problem:

Problem on PCB #1 but damaged PCB #2

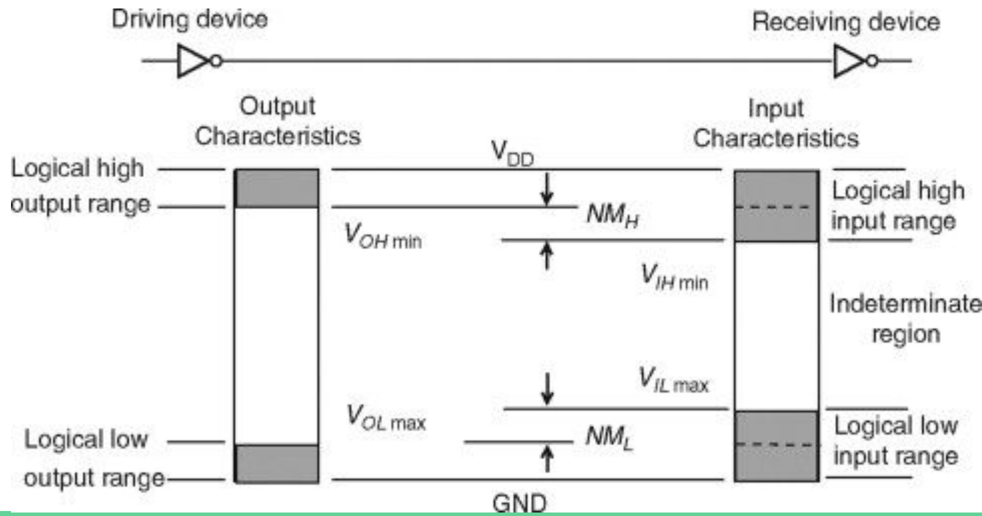
Works individually but doesn’t work when integrated into the system (communication error)

PCB burning when there is a sudden change in loading in the system

Noise Margin

Noise margin describes the difference between acceptable output voltage and input voltage

Need to check the voltage margin on both high and low.

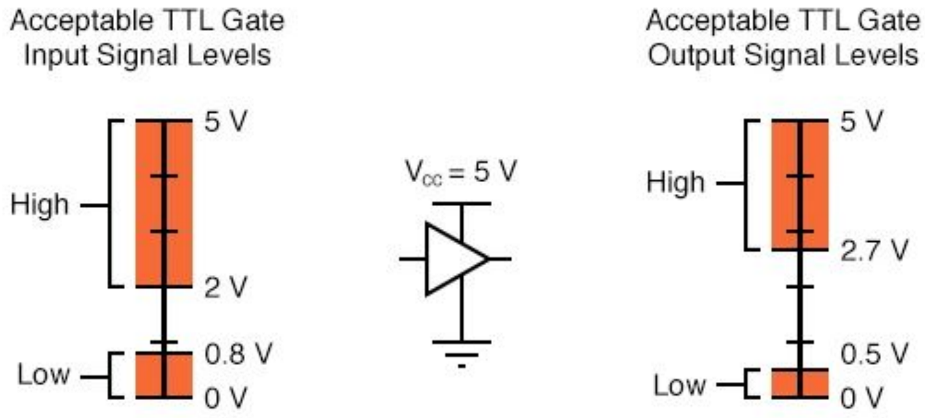


Noise Margin

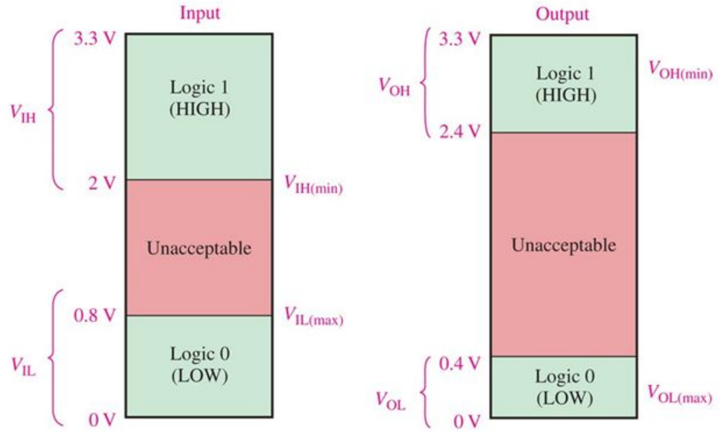
Usually signal with higher voltage level will have better noise margin

Common standards are TTL and CMOS

A moving ground plane will affect the voltage level at the receiving end



Determine the HIGH level noise margin for 3.3V CMOS, given the voltage levels below:



Signal Integrity

When doing wiring for signals, always need to consider its signal integrity

You will need to consider the signal level and its signal strength

For example you could use RS232 transceiver to boost the voltage level of the signal to improve noise margin or use RS485 transceiver to change your UART signal into differential signal

Transceivers

For example, improve signal integrity of single-ended signal by turning them into differential signal with transceiver

Changing UART to RS232 / RS485 standard

In the picture you could also observe common ground is not required for communication

MAX481/MAX483/MAX485/
MAX487–MAX491/MAX1487

Low-Power, Slew-Rate-Limited
RS-485/RS-422 Transceivers

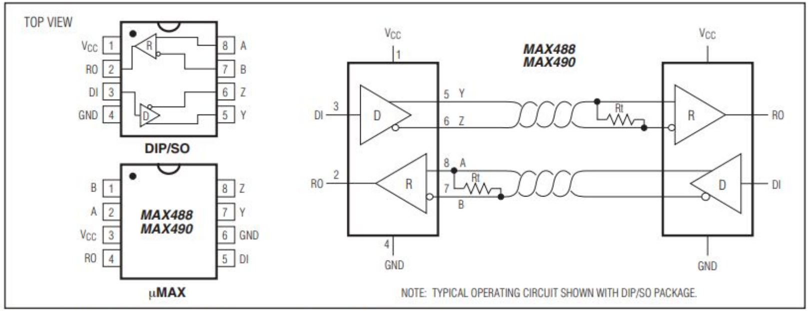


Figure 2. MAX488/MAX490 Pin Configuration and Typical Operating Circuit

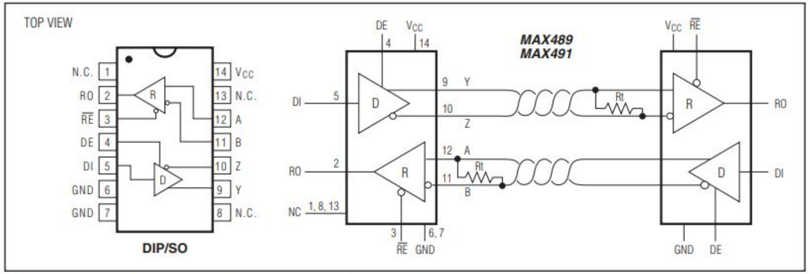
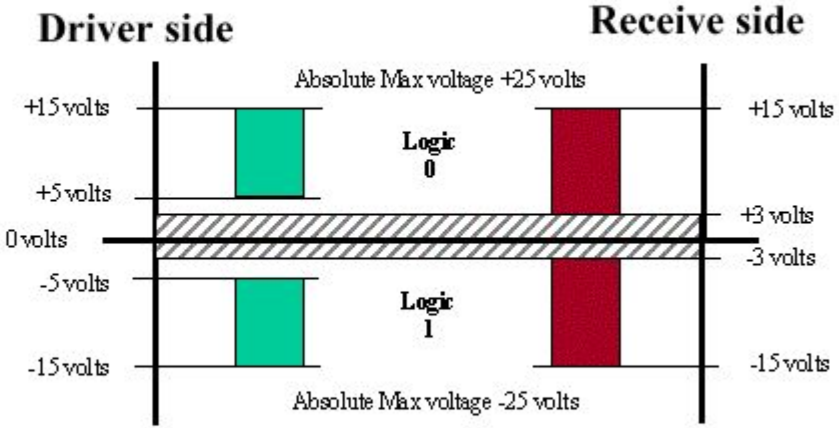


Figure 3. MAX489/MAX491 Pin Configuration and Typical Operating Circuit

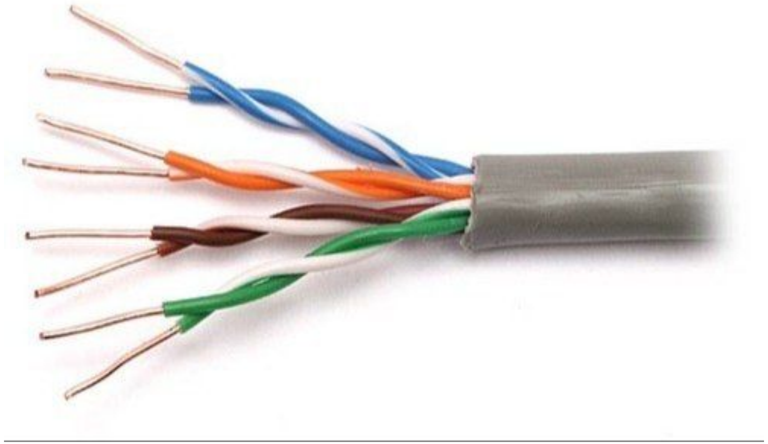
RS232

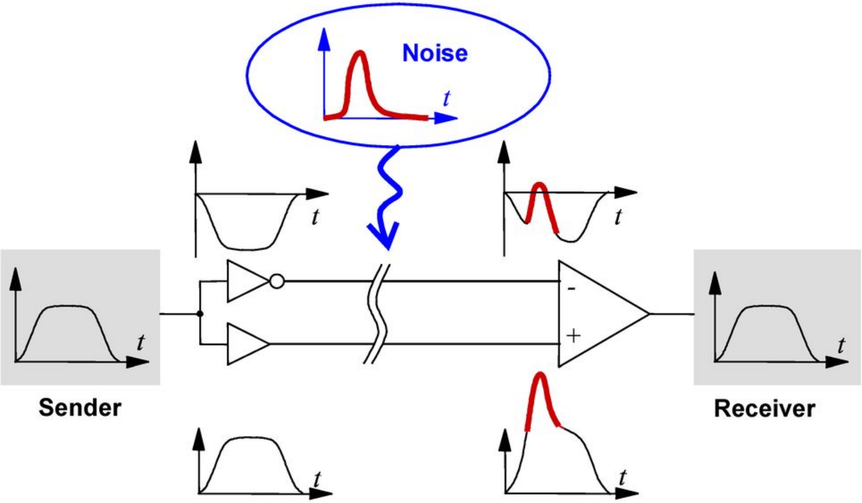
By comparing to TTL / CMOS standard, you could see the noise margin is significantly larger.



Differential Signal

Differential signal is immune to common mode noise since the noise will be cancelled out. Requires more consideration in wiring. Differential signal should be routed with twisted pair with similar/same length.





TLDR

Use more RS232/485 and CAN bus

Tutorial

1. For CAN bus connection, is daisy chain or star topology prefered
2. How does using CAN bus or RS485 resolve the ground loop issue?
3. How will transient current at the load affect the voltage at the load
4. Will adding too much capacitance at the power input have any negative effect?

Extra

https://item.taobao.com/item.htm?spm=a230r.1.14.16.2d1e7bb7Rmilga&id=532104429980&ns=1&abbucket=18#detail

Goot stuff for wiring along linear guide