The Fundamental Technical Knowledge of Passive Components

— for Windows version —

Chapter I : Capacitor

Chapter II : Inductor

Chapter III : Electro-Magnetic Compatibility (EMC)

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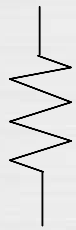
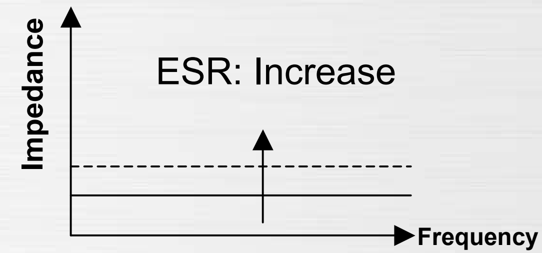
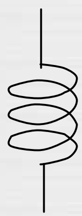
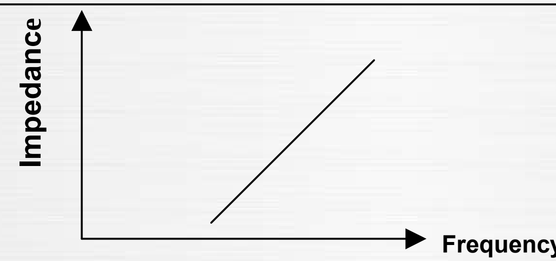
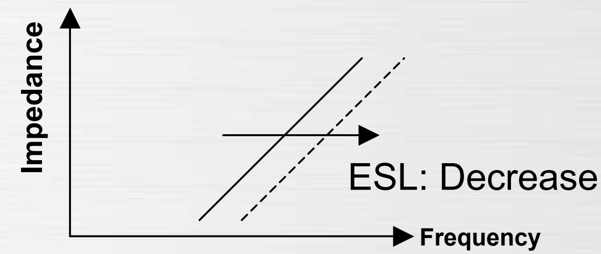
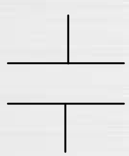
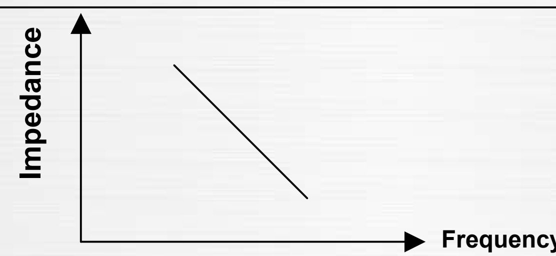
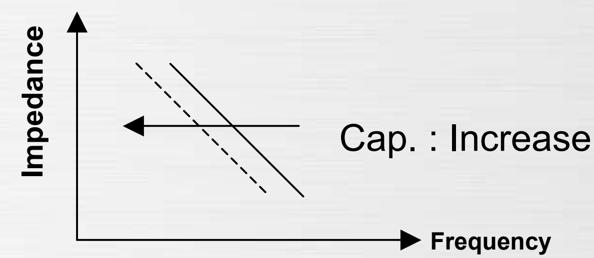
- Chapter 1-

Capacitor

Impedance Characteristics of Capacitor

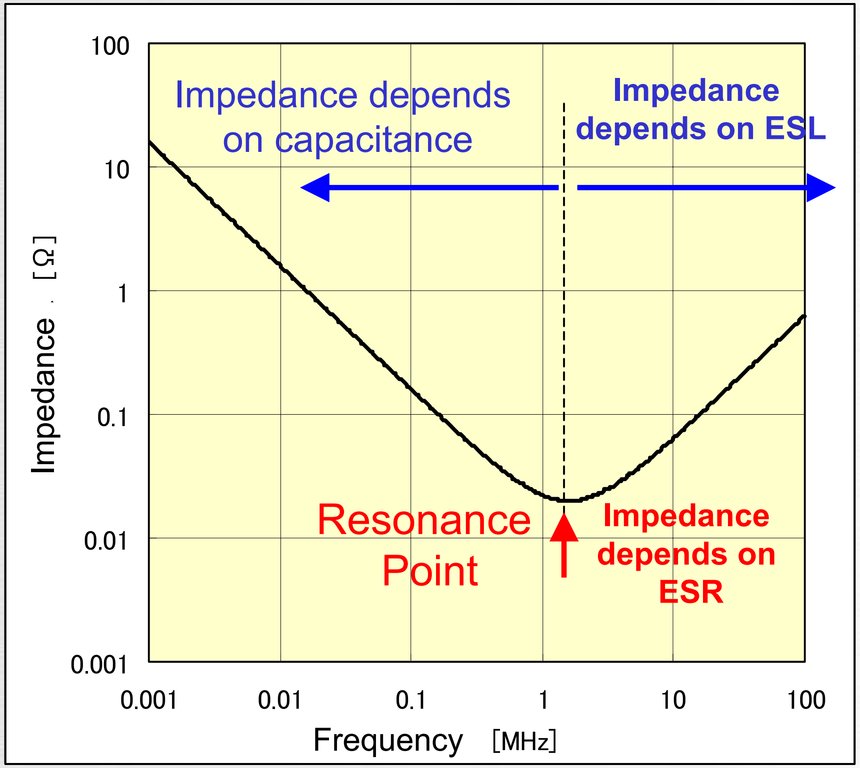
Impedance equivalent circuit with capacitor is the same as the RLC series model.

Elements in Capacitor	Changes in Frequency	Changes in Element
ESR 	 ESR is constant	
ESL 	 ESL increases	
Capacitance 	 Capacitance decreases	

What happens to the impedance level when connected in series?

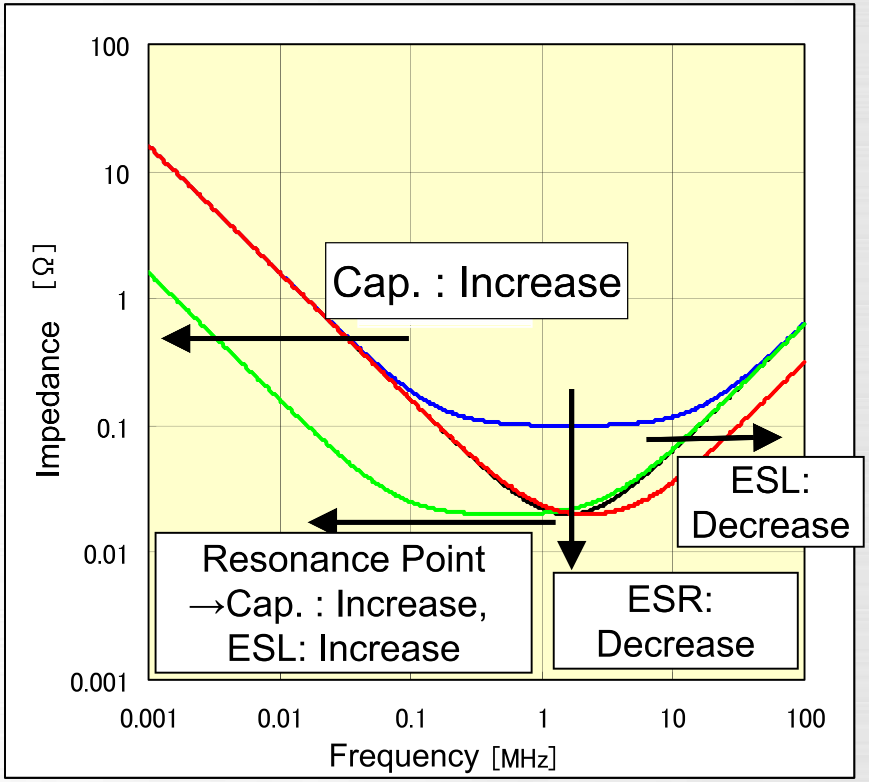
Impedance Characteristics of Capacitor

Impedance for series connection



- At resonance point, no impedance for Capacitor & ESL (Impedance for ESR only)
- The frequency at resonance point depends on Capacitor & ESL

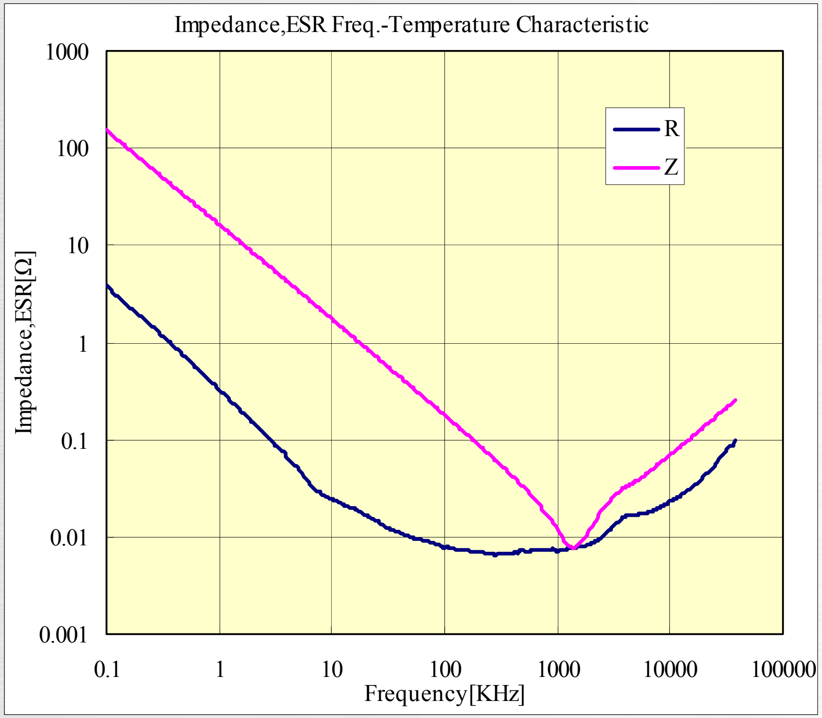
Impedance with different elements



Impedance characteristics vary depended on each element.

Impedance Characteristics of Capacitor

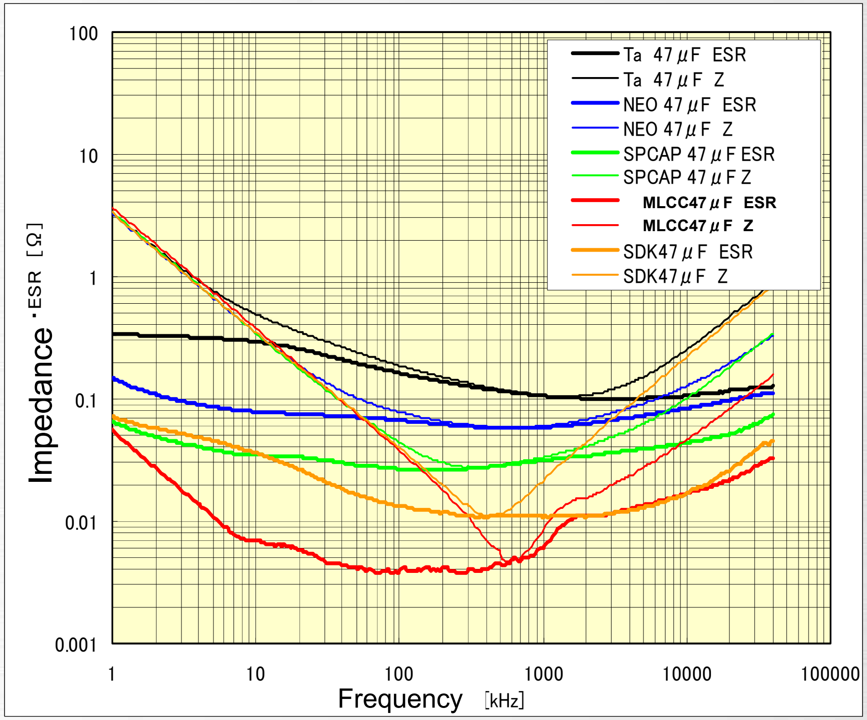
ESR varies depended on frequency



RLC Series Model→ ESR independent from frequency

ESR actually varies.

Frequency characteristics for different type of capacitors



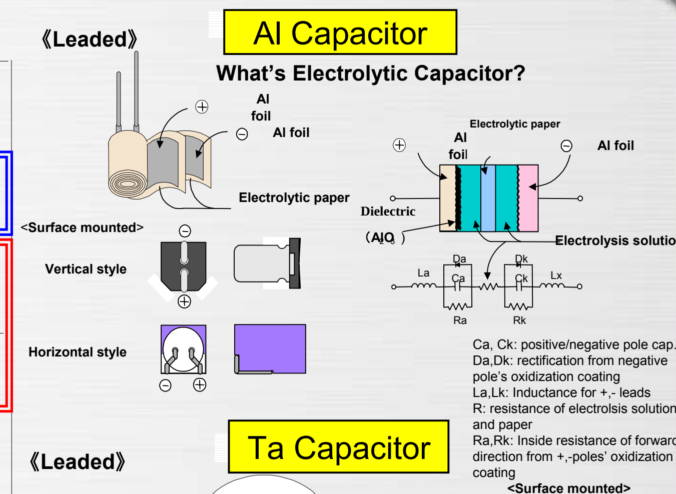
RLC varies depended on capacitor's material, structure and case size

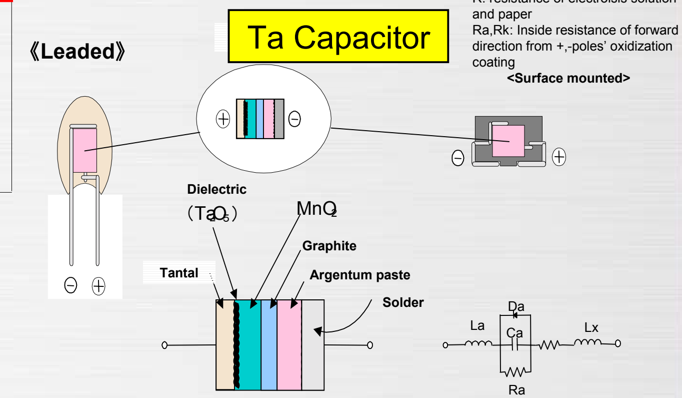
Frequency characteristic varies depended on the type of capacitor, especially on ESR.

Reliabilities of Multi-Layered Ceramic Capacitor

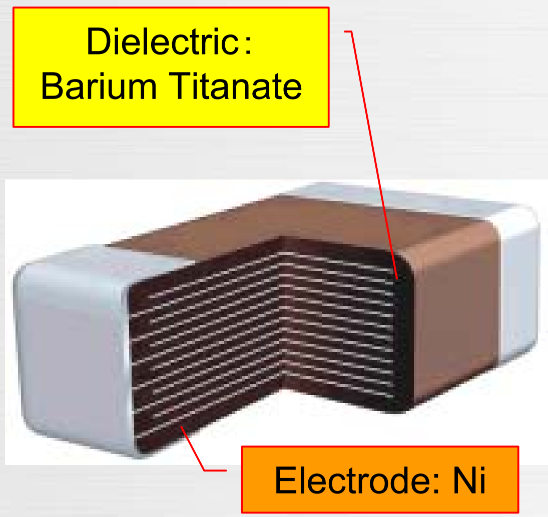
1. Operational condition comparison chart for Circuit

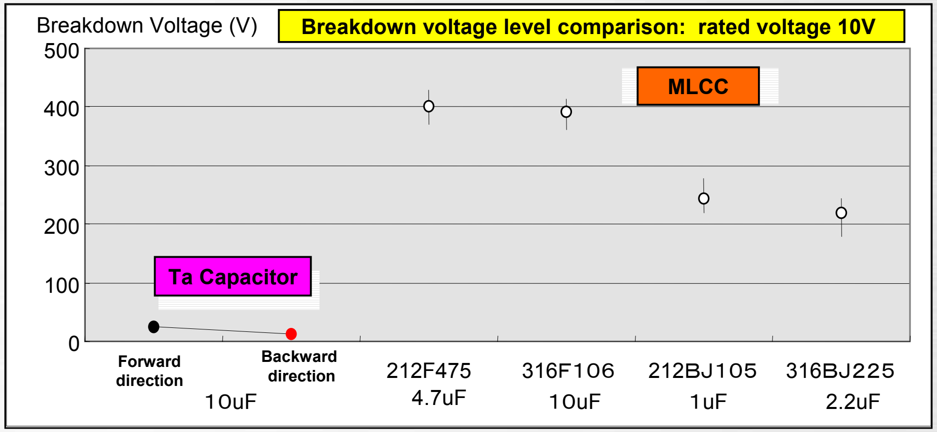
	Polarity	De-rating	Ripple CU. Limitation	Heat Resistance	Solvent Resistance	Loading Test
MLCC	No	◎	◎	◎	◎	◎
Ta Cap.	Yes	×	△	×	△	×
Al Cap.	Yes	×	×	△	×	△
Application Problems	*Layout *Polarity exam When mounting *Reverse voltage Consideration	*Operational limitation for rated voltage (70～50%level)	*Have margin capacity for ripple current *Less reliable associated from self heating	*Limitation for reflow molding and degrading advancement	*Liquid solution flooding except block structure MLCC	*Al capacitor: decreasing in capacitance from electrolysis loss *Ta capacitor: diffusion of Ag, short circuit from degrading of insulating layer





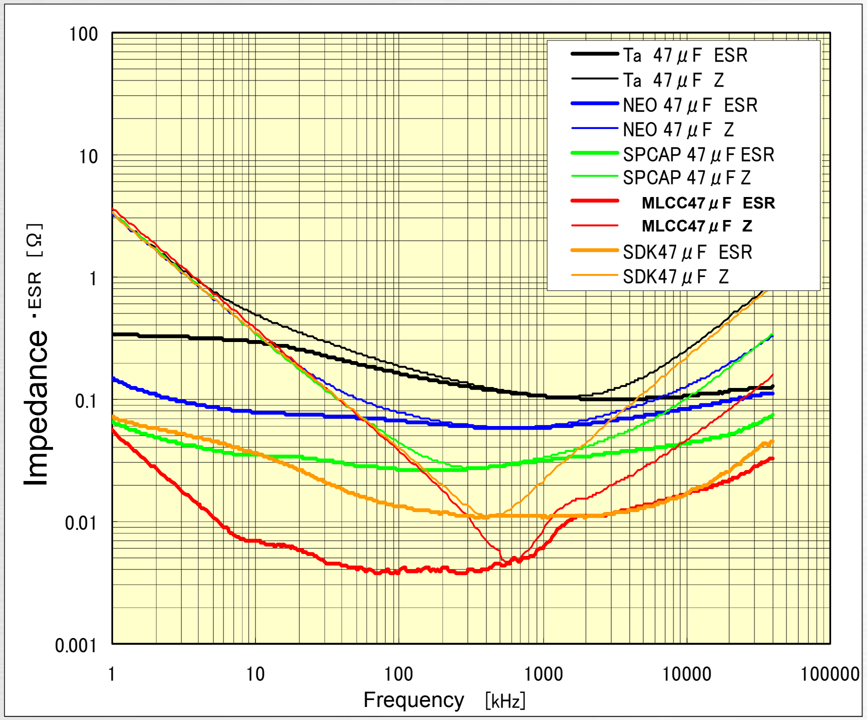
Ceramic Capacitor





Characteristics Comparison for the Different Type of Capacitors

Frequency Characteristics



ESR varies greatly depended on each type of capacitors.

Al>Ta>Functional Ta>Functional Al>ML

The lower ESR becomes, the lower the impedance for high frequency gets.

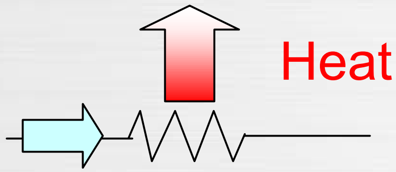
Al>Ta>Functional Ta>Functional Al>ML

MLCC has superior frequency characteristics.

The most competitive merit

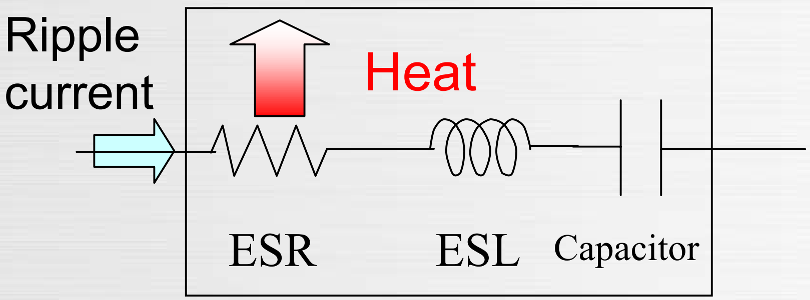
Characteristics Comparison for the Different Type of Capacitors

Ripple Current Characteristics



Electrical energy is converted to heat when current goes through resistance.

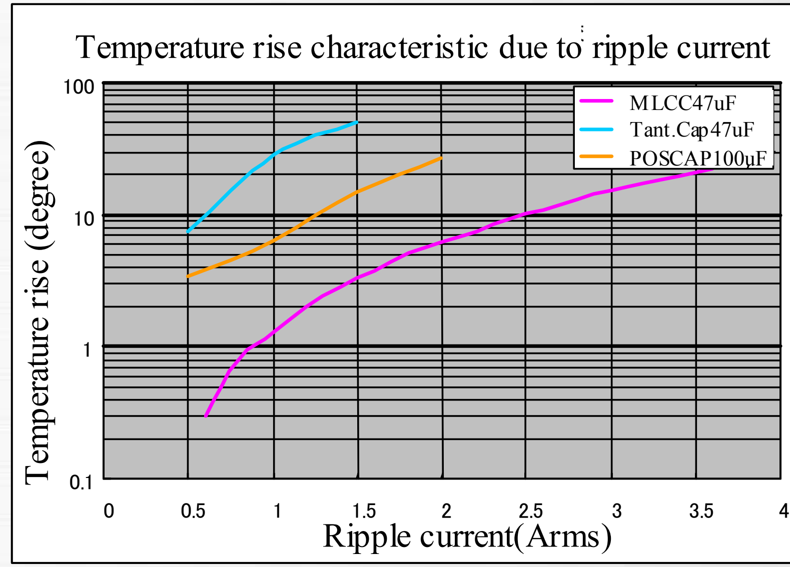
Capacitor



Electrical energy is converted to heat when ripple current (AC) goes through capacitor. (DC does not go through it)

Heat shortens capacitor's durability.

Ripple current characteristics for the different type of capacitors



Given the same amount of calorific power, ripple current goes through MLCC the most because of its low ESR.

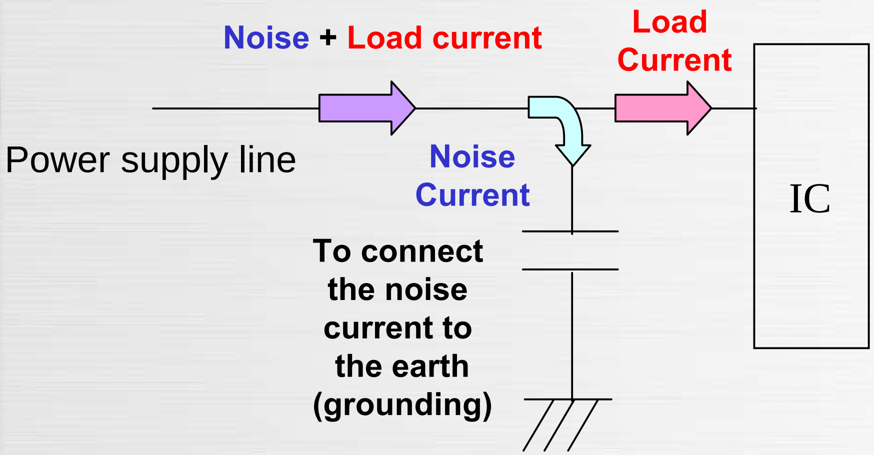
Operational recommendation of heat release value for MLCC is within 10℃.
There is no limitation of allowed ripple current for MLCC.

Operational recommendation of heat release value for electrolytic capacitor is within 5℃.
Allowed ripple current is regulated by makers.

The Basic Knowledge of Circuits

The Functions of Bypass (decoupling) Capacitor

The Role of Bypass Capacitor



The principle of operation for Bypass Capacitor

DC does not go through the capacitor (Impedance:∞)

⇨ DC is supplied directly to IC

AC (noise) does go through the capacitor

⇨ AC (noise) is grounded

Noise Suppression → Stabilize IC operation

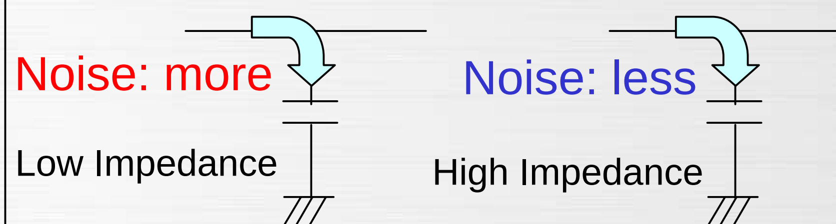
Necessary Characteristics for Bypass Capacitor

It has low impedance.
(low prevention of an electric current)

It electrifies an electric current well.

It efficiently grounds the noise current.

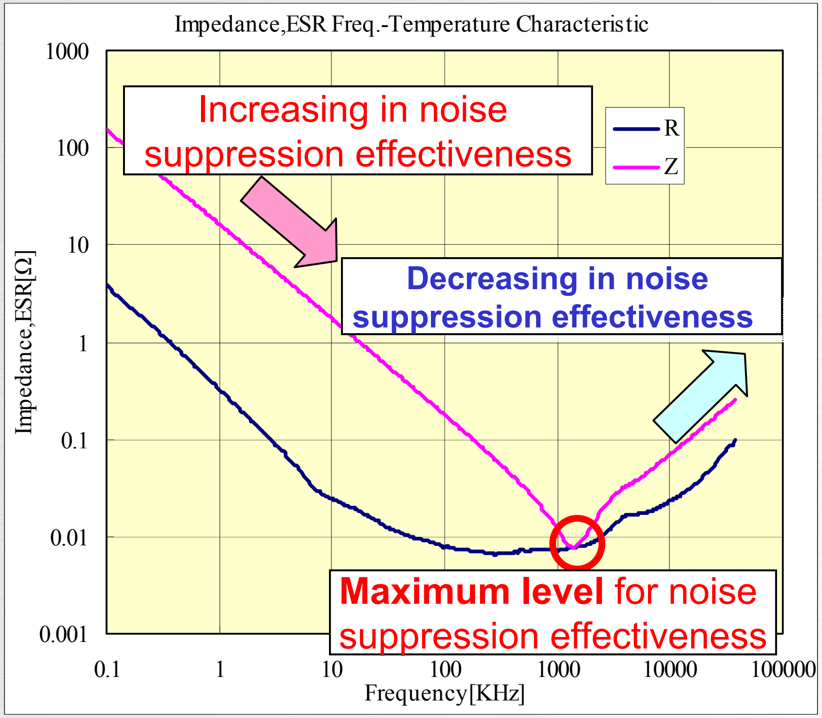
It effectively decreases the noise current.



Impedance	Low ⇔ High
Noise effect of decreasing	More effective ⇔ Less effective

The Functions of Bypass (decoupling) Capacitor

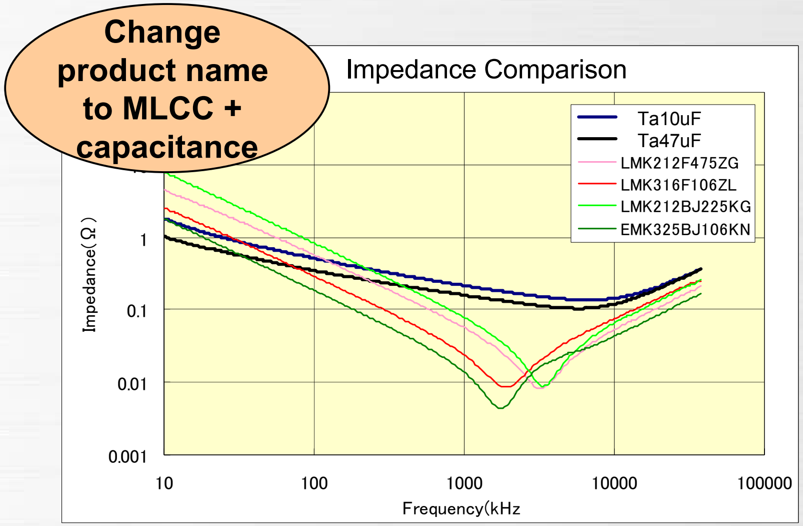
Selection Criteria for Capacitor



Several kinds of Noise Frequencies

Select a Capacitor based on noise frequency needs to be eliminated

Replacement of Ta capacitor by Bypass Capacitor



When the frequency is over 10kHz, the impedance of MLCC is lower than that of Ta capacitor.

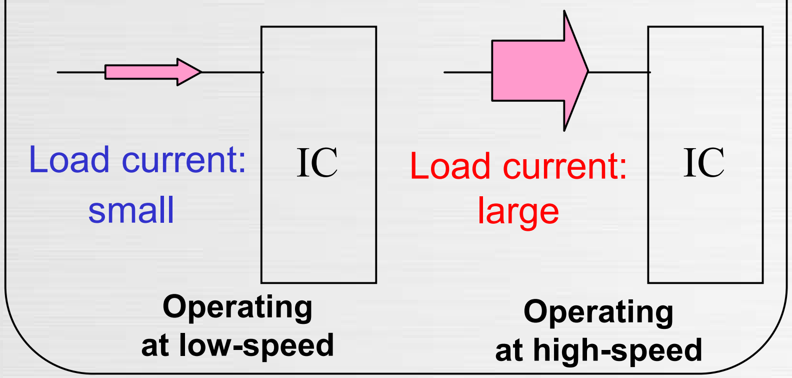
Effectiveness of reduction in high frequency noise for MLCC is more superior than that of Ta capacitor.

It enables to replace Ta capacitor with a smaller value of MLCC.

The Functions of Backup Capacitor

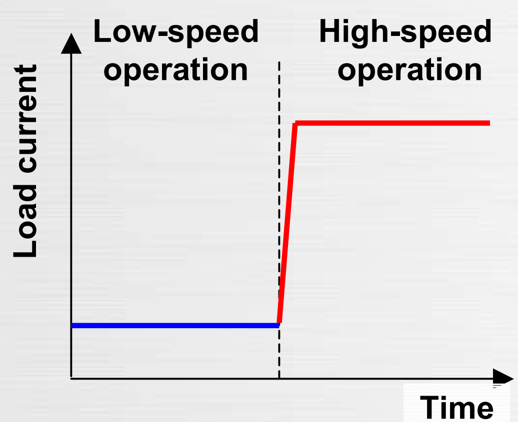
Load current to IC

Load current doesn't stay constant.

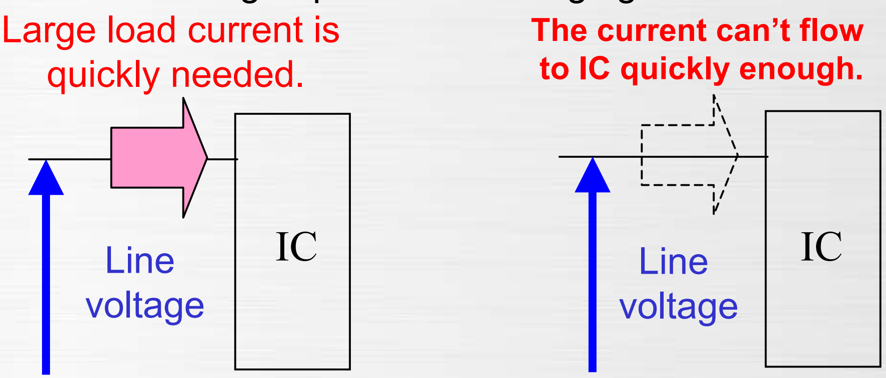


High-speed load change

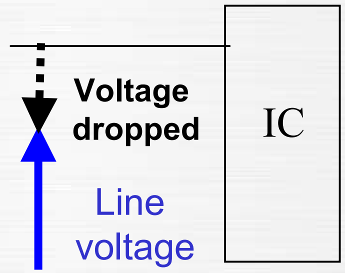
When IC's operational speed changes rapidly, large load current is quickly needed.

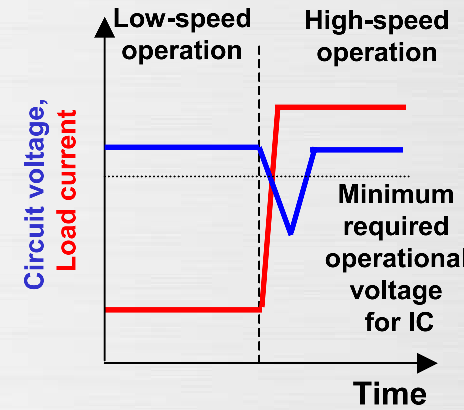


Power line for high-speed load changing



Line voltage can't be maintained, therefore voltage is dropped.



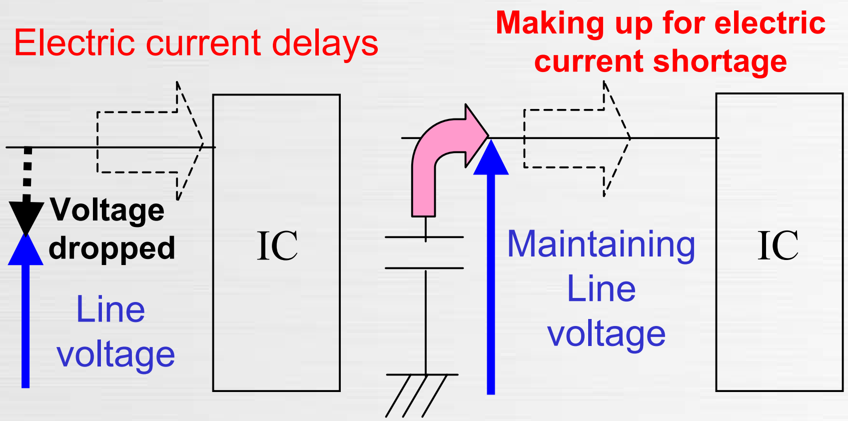


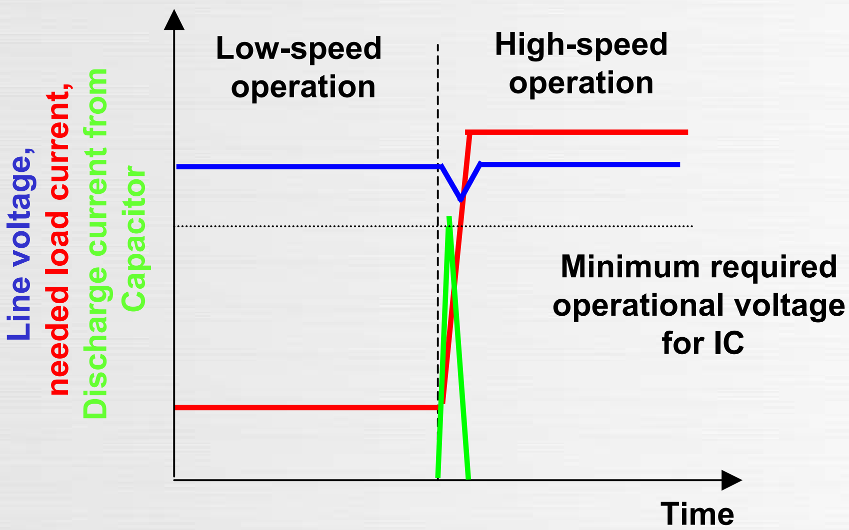
Line voltage decreases below the required operational voltage for IC.

The IC stops its operation.

The Functions of Backup Capacitor

The Role of Backup Capacitor

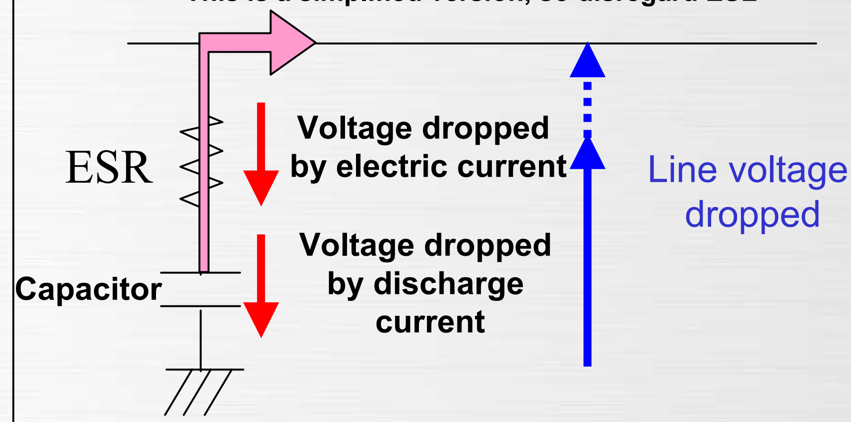




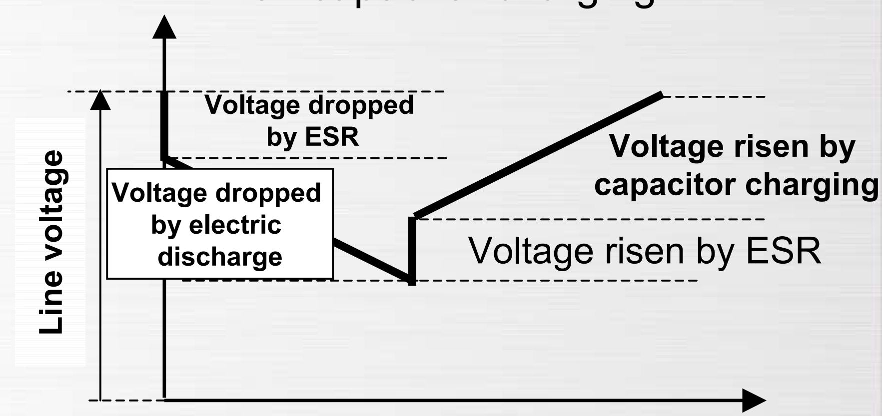
Keeping the minimum required operational voltage for IC ⇨ Maintaining stable operation

Capacitor's actual (considering equivalent circuit)

*This is a simplified version, so disregard ESL

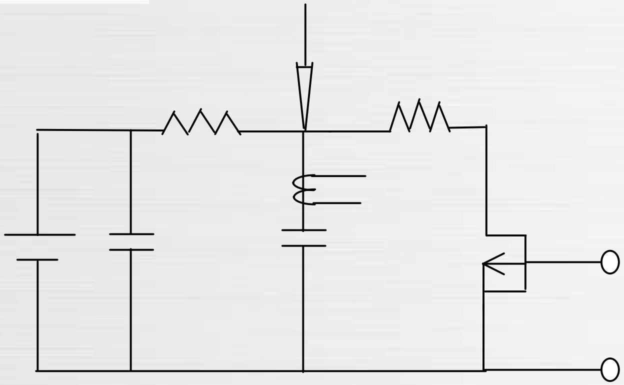


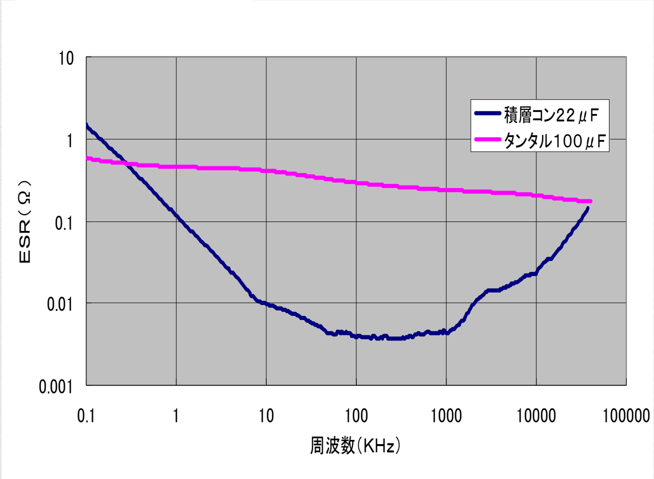
Voltage fluctuation occurs when capacitor charging



Capacitor and ESR decide the amount of voltage dropped

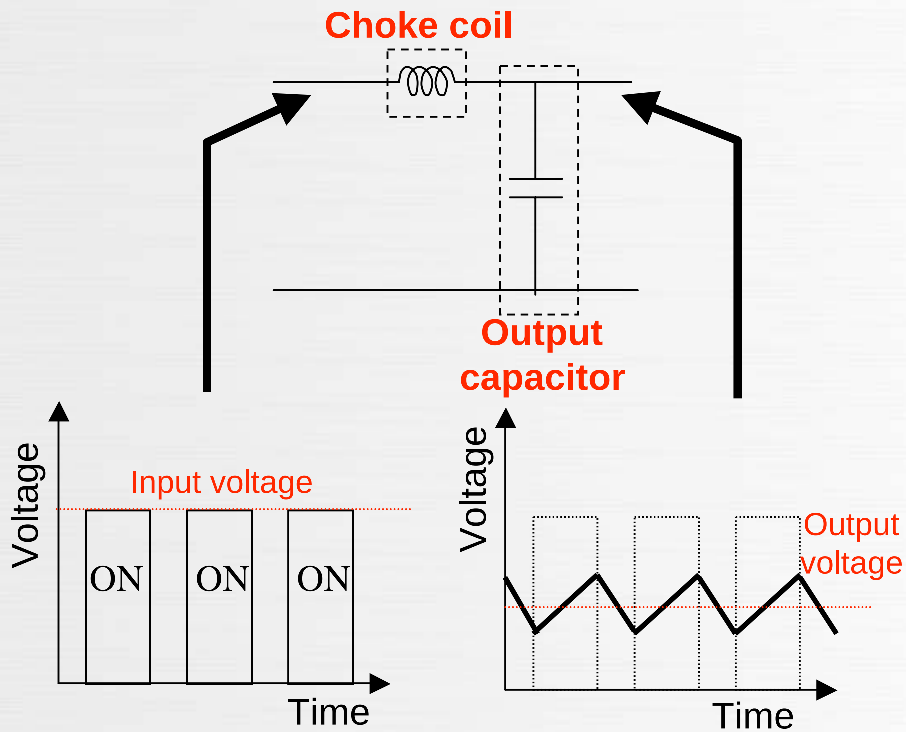
The Functions of Backup Capacitor





Step-Down Converter

Output side operation



Input voltage is controlled by an on-off switching.

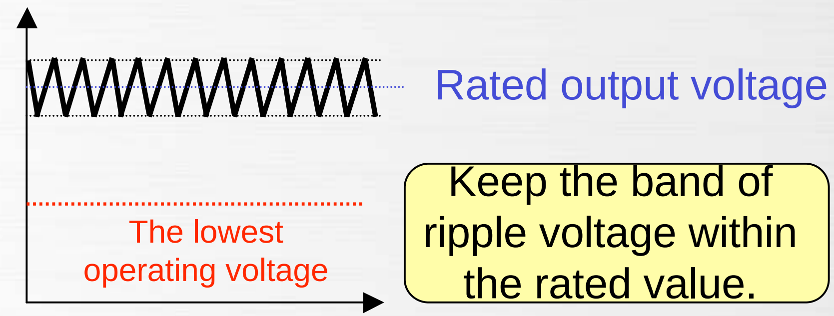
It is smoothed with a choke coil and an output capacitor.

Ripple voltage is included.

Points of output voltage to remember

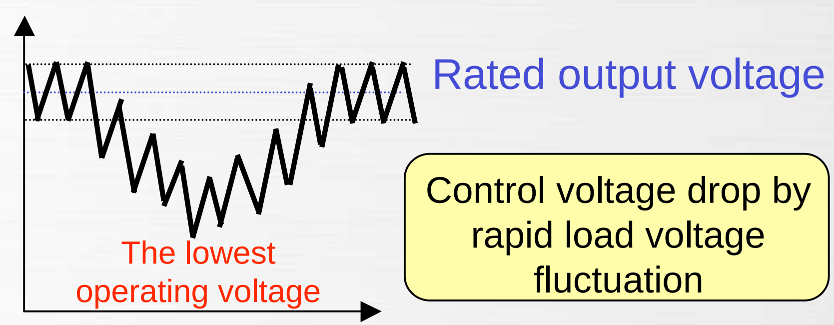
Keeping higher voltage than the lowest operating voltage of load IC.

Ripple voltage



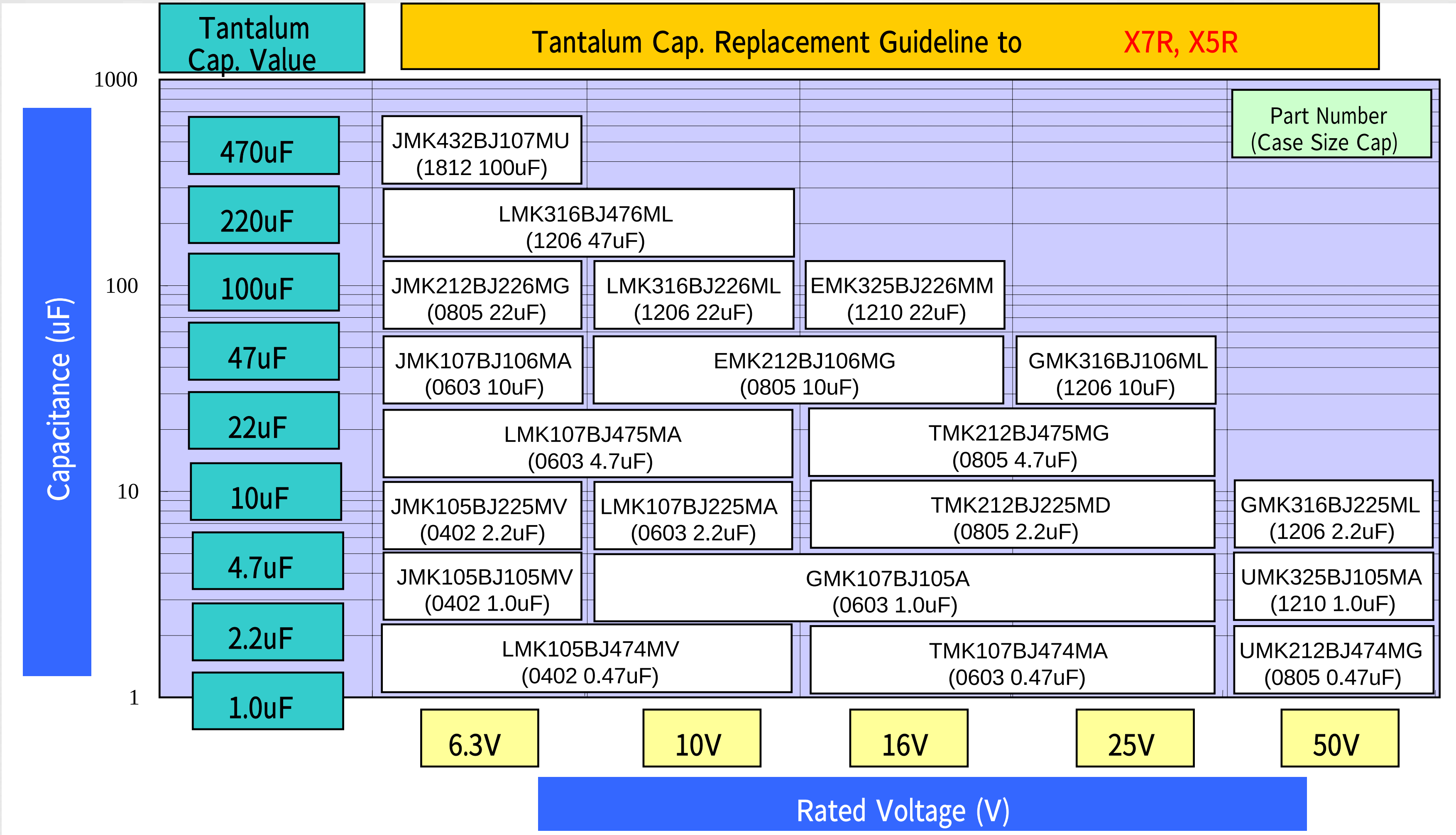
Keep the band of ripple voltage within the rated value.

Rapid load voltage fluctuation



Control voltage drop by rapid load voltage fluctuation

Ta cap & Al cap replacement guideline to MLCC X7R, X5R



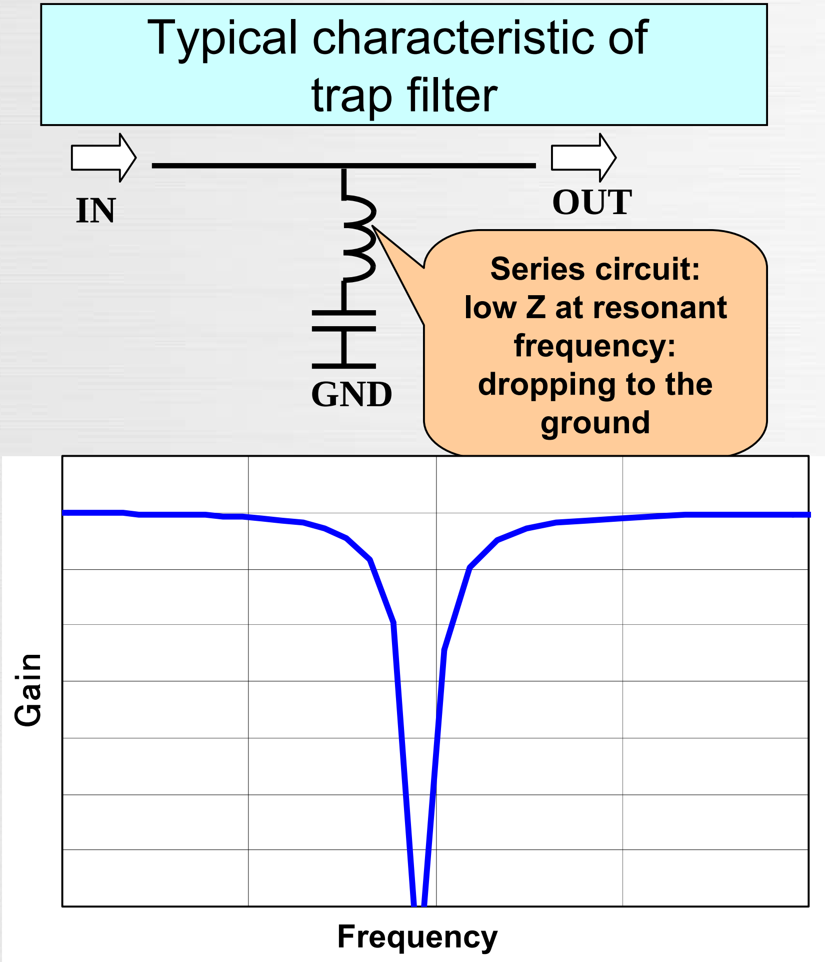
Note: Suggested capacitance value of MLCC may be changed depending on the frequency level of noise.

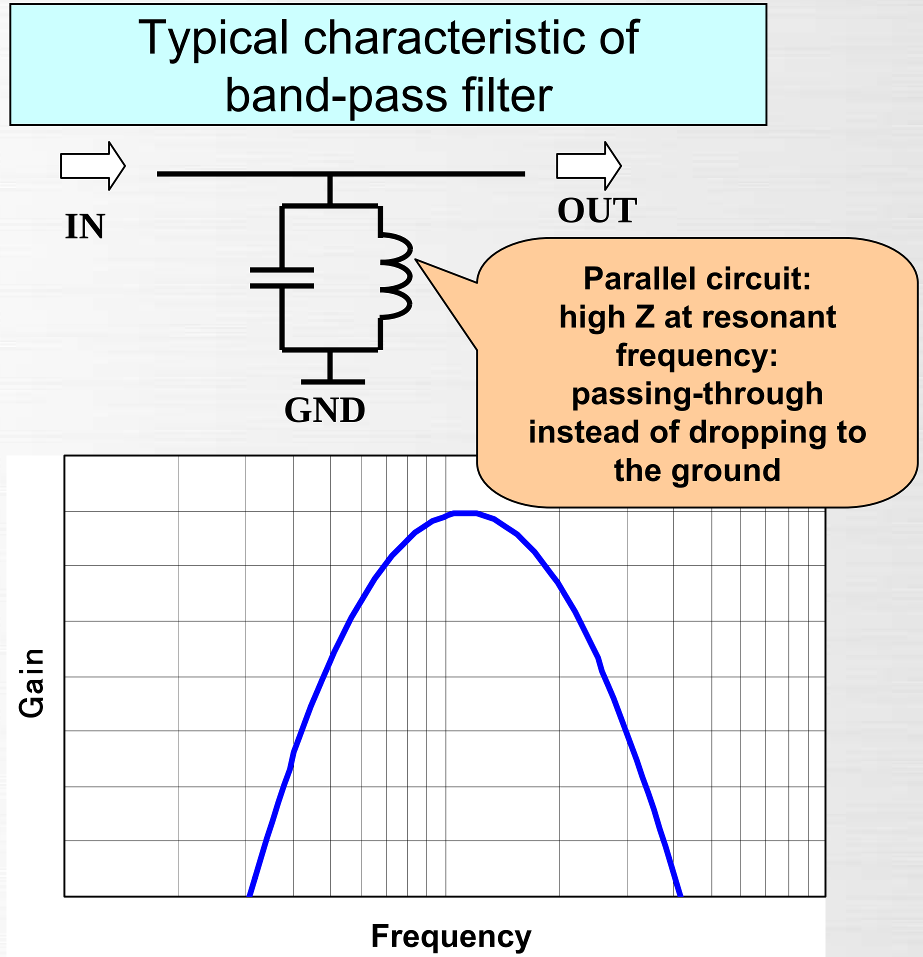
Note: As derating is not required for MLCCs,use the actual voltage of the circuit when selecting MLCC for replacement.

It requires as much as 1/5 to 1/20 of Al capacitor’s capacitance to replace.

Application of Inductor and Capacitor "Band-pass Filter and Trap Filter"

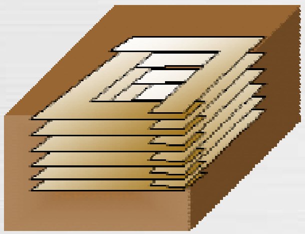
Impedance of series circuit: Lowest at frequency resonance point
Impedance of parallel circuit: Highest at frequency resonance point

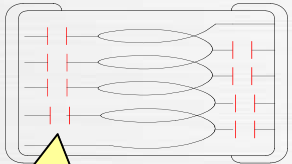




Real Characteristics of Inductor “Self-Resonance Point Characteristic”

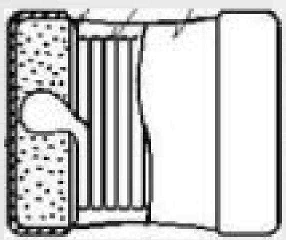
Multilayer inductor

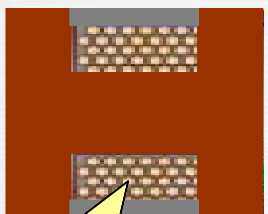




Ex) Stray capacitance existed between internal and external electrode

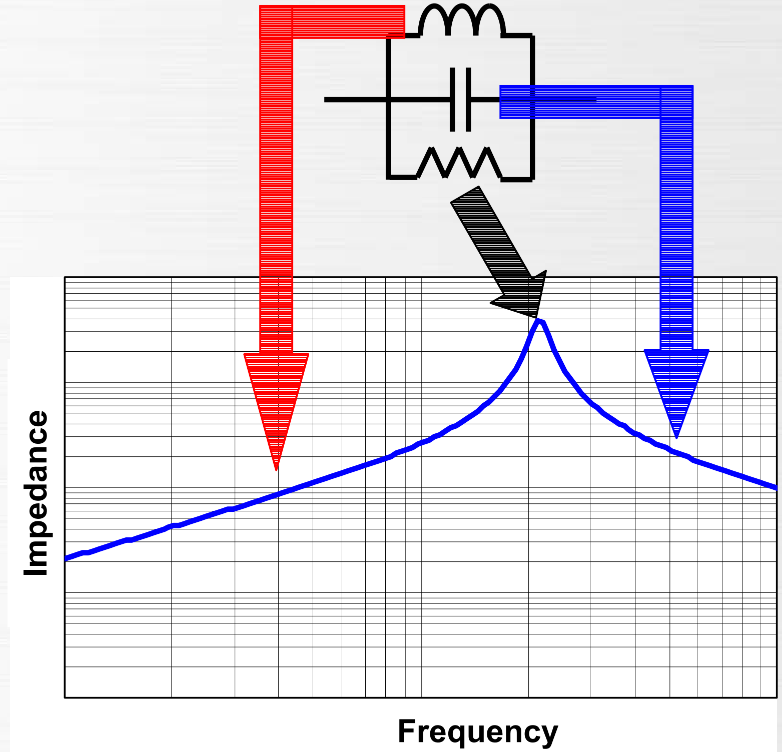
Wound chip inductor





Ex) Stray capacitance existed between winding wires

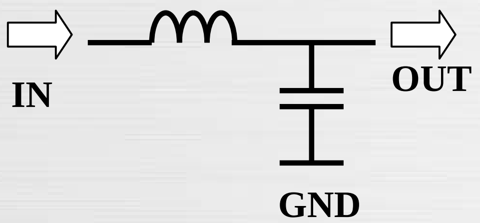
Typical impedance characteristic of existing inductor
~similar to the typical impedance characteristic of LCR parallel circuit~



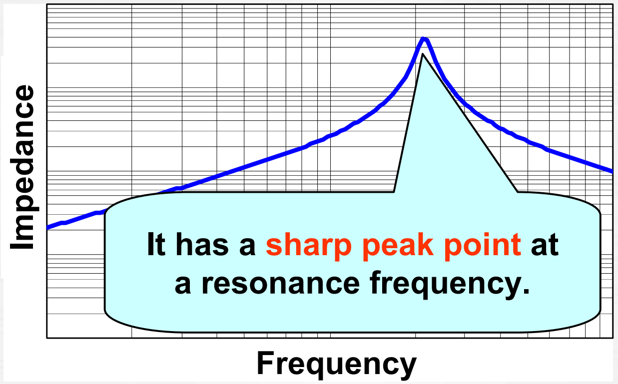
Inductor for the low frequency side, capacitor for the high frequency side and at resonance point, impedance is limited.

Application Ex. using Self-Resonance Characteristic of Inductor “Trapping Formulation by Low-pass Filter”

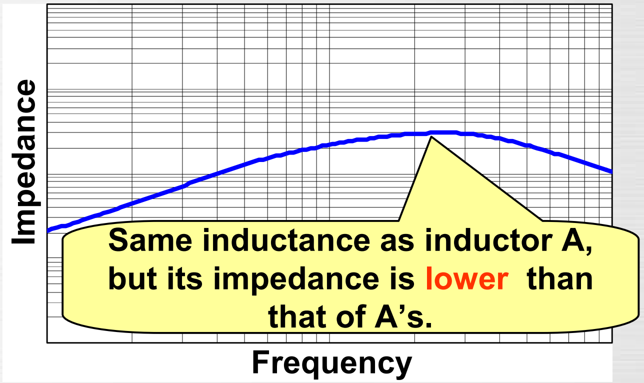
Example of Low-pass filter



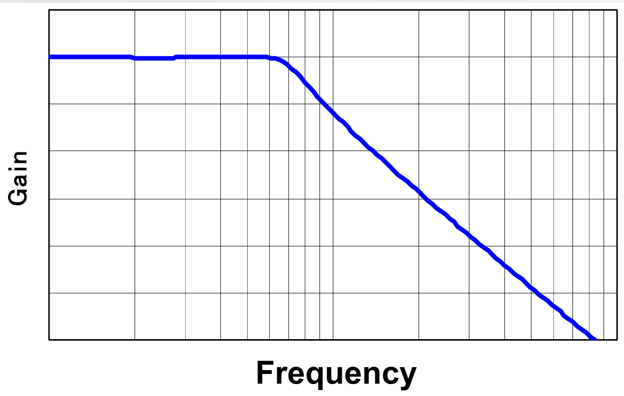
Inductor A: impedance characteristic



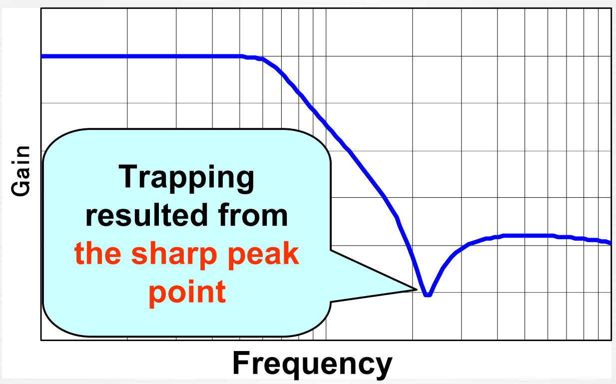
Inductor B: impedance characteristic



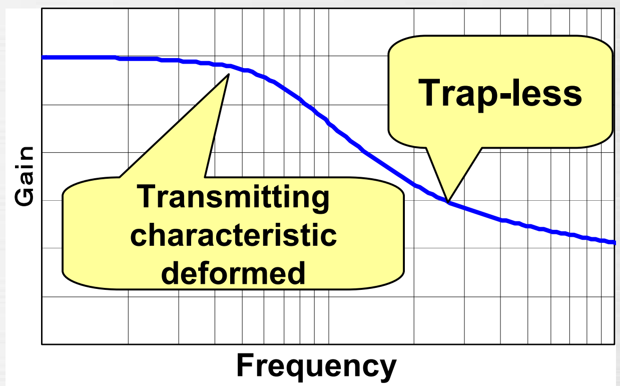
Filter characteristic of pure inductor



Inductor A in use



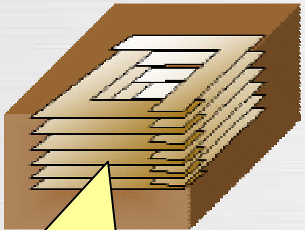
Inductor B in use



This self-resonance characteristic is proactively implemented for a filter circuit application, and therefore this unique characteristic needs to be considered for both replacement and downsizing applications.

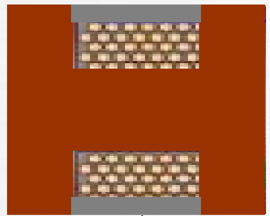
Real Characteristics of Inductor “Lost Elements and Q Characteristic”

ML inductor



Print internal electrode on sheet made of core material

Wound chip inductor

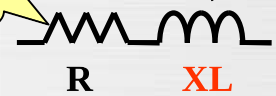


Wind up wire around core

Inductor’s Q factor

Impedance of pure inductor:
Inductive reactance

Resistance elements
(Summation of loss)



$$Q = \frac{\left|\text{Inductive reactance}\right|}{\text{Resistance elements}}$$

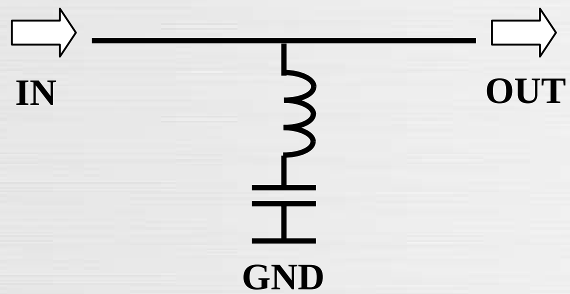
<u>Core materials:</u>
Hysterisis loss, Eddy current loss, dielectric material loss and more …
<u>Internal electrode:</u>
DCR, resistance loss in high frequency zone originated from skin effect and more…
Pure inductor has no loss at all.

Q factor is an approximation value which expresses how close an inductor is to be a pure inductor.
The larger the Q factor an inductor has, the purer the inductor becomes on circuit.

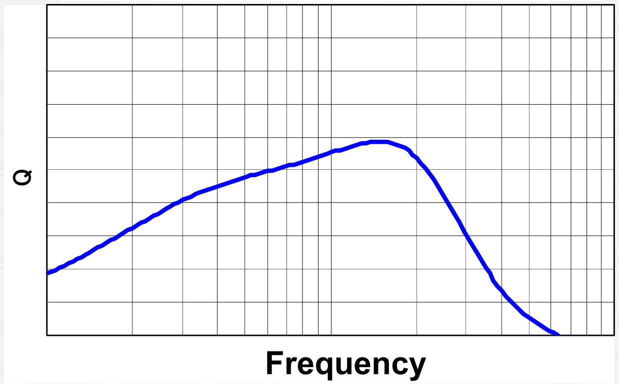
Q Factor and Filter Characteristics of Inductor "Example of How the Difference in Q Factor Influences Trap-Filter Characteristic"

Example of trap filter

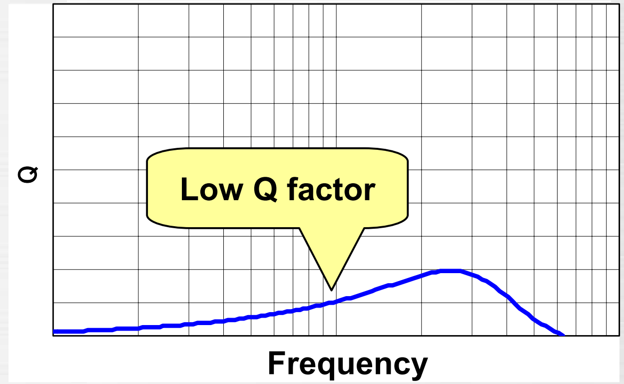
Series resonance of inductor and capacitor



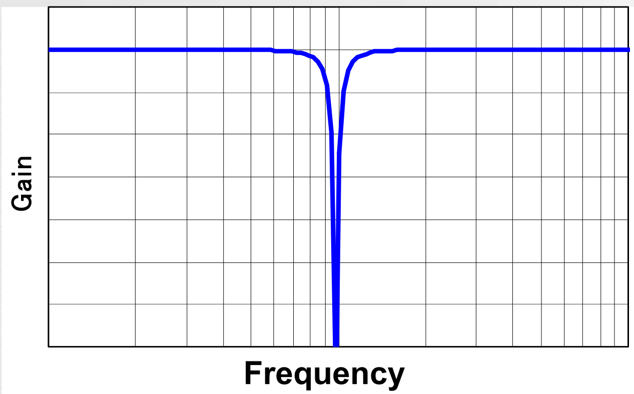
Inductor A: Q factor characteristic



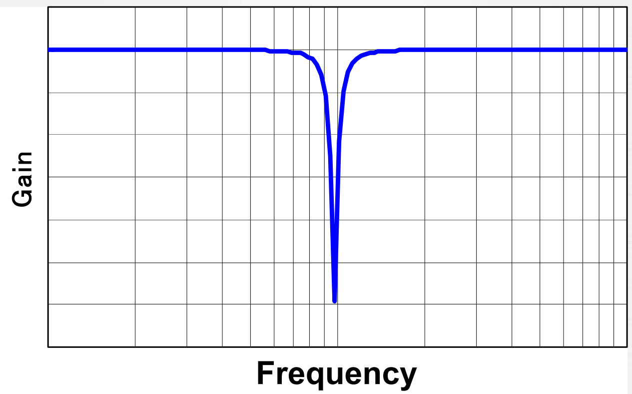
Inductor B: Q factor characteristic



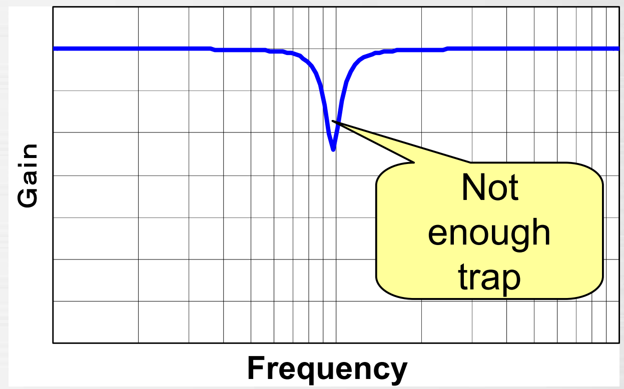
Filter characteristic example of pure inductor



Inductor A in use

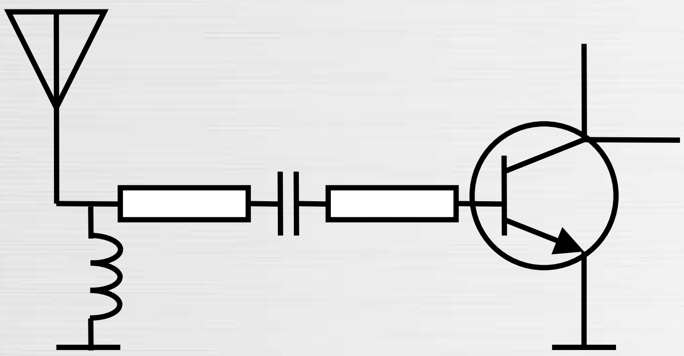


Inductor B in use

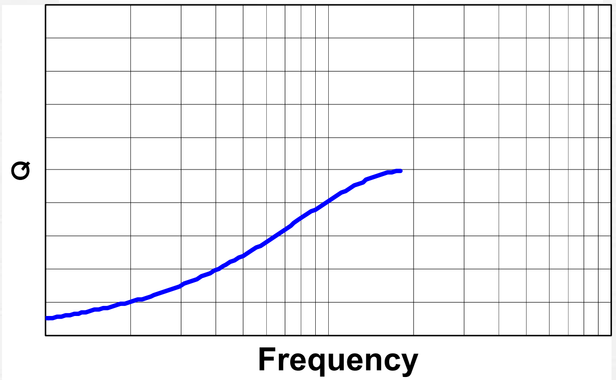


In case of resonance circuit with capacitors, generally inductor's Q factor characteristic has huge influence on the circuit.

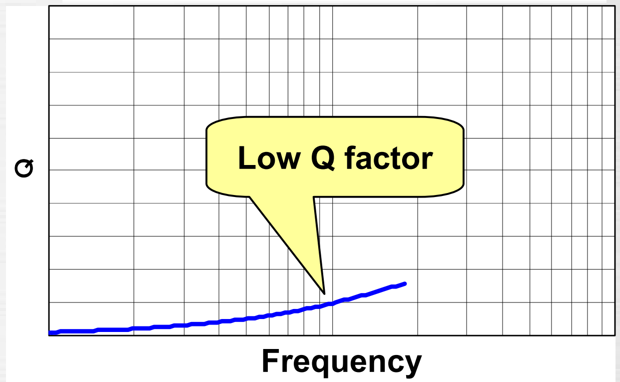
Example of matching circuit
Matching for amplifier and antenna



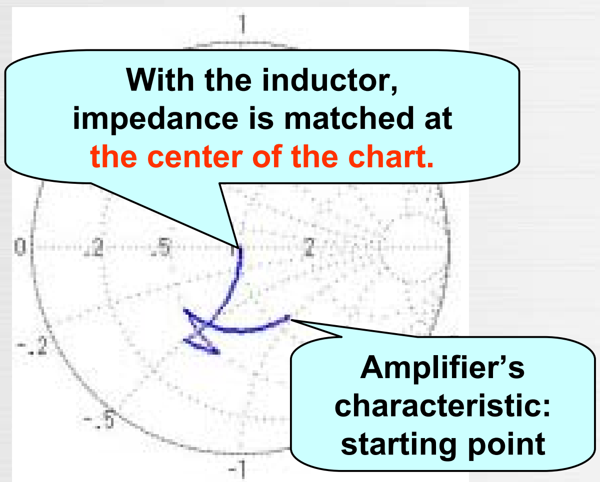
Inductor A: Q factor characteristic



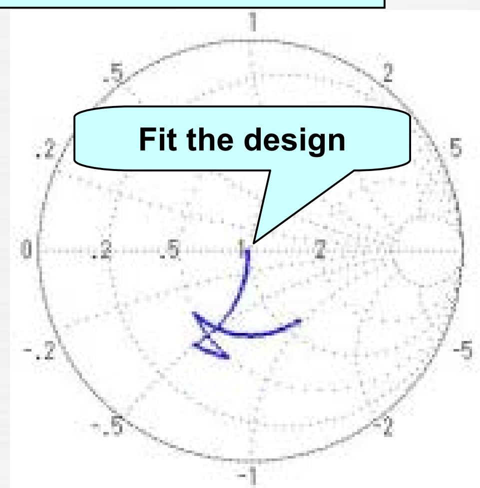
Inductor A: Q factor characteristic



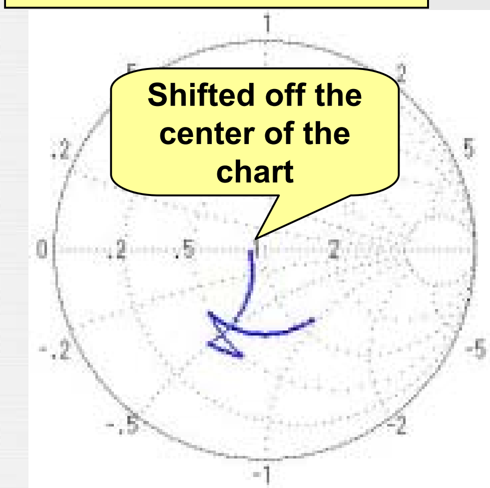
Example of matching design with pure inductor



Inductor A in use



Inductor B in use



In case of matching circuit, generally inductor’s Q factor characteristic has huge influence on the circuit.

Coffee Break "Q Factor of Inductor and Tan δ of Capacitor"

Q factor of inductor
inductor's loss elements

Impedance of pure inductor:
inductive reactance

Resistance elements
(summation of loss)

R XL

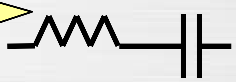
$$Q = \frac{|\text{Inductive reactance}|}{\text{Resistance elements}}$$

Q factor is an approximation value which expresses how close an inductor is to be a pure inductor.
The larger the Q factor an inductor has, the purer the inductor becomes on circuit.

Tan δ of capacitor
capacitor's loss elements

Impedance of pure capacitor:
Capacitance reactance

Resistance elements
(summation of loss)



R Xc

$$\text{Tan }\delta = \frac{\text{Resistance elements}}{|\text{Capacitance reactance}|}$$

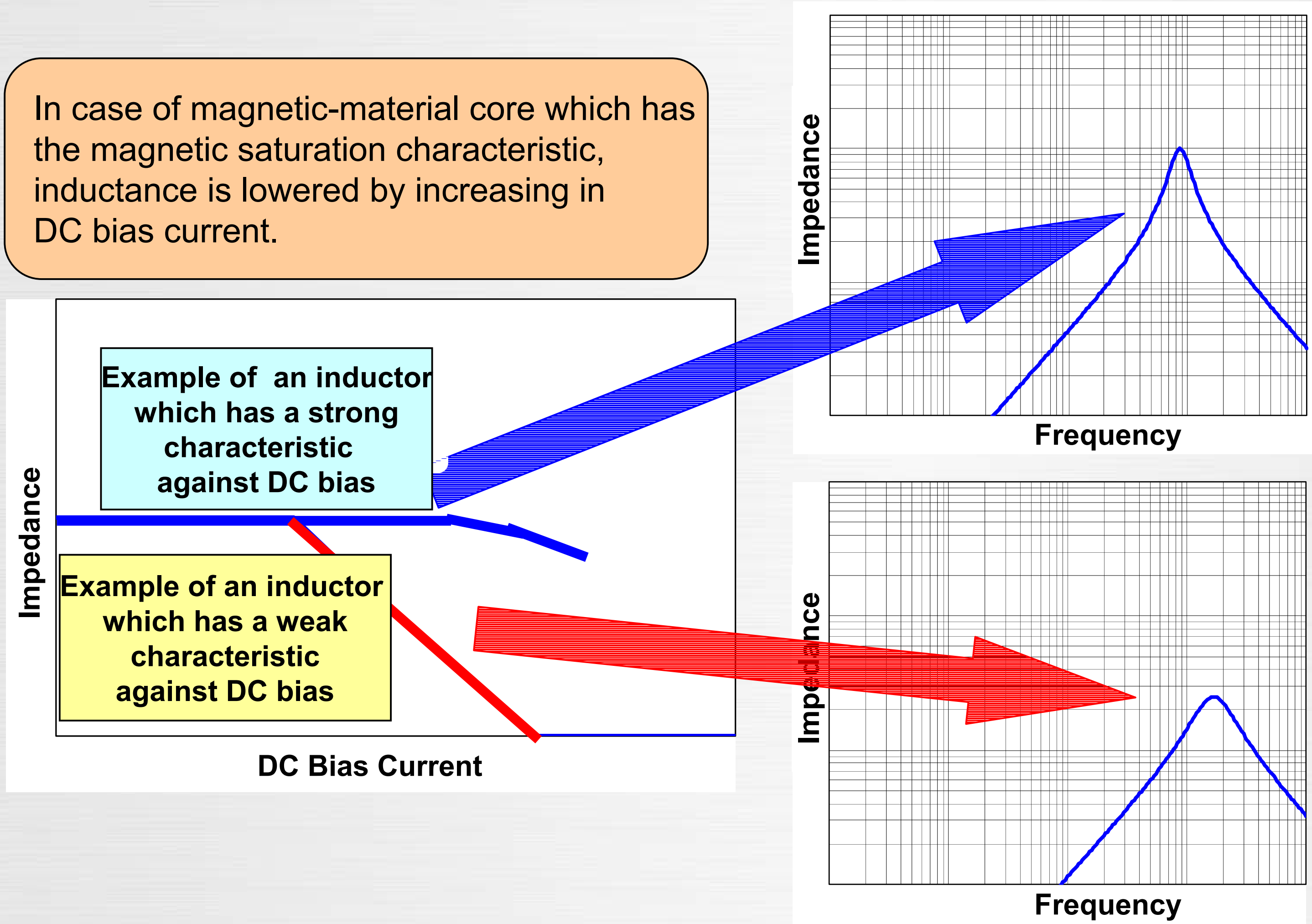
Tan δ is a value which explains how far a capacitor is from being a pure capacitor.
The smaller the tan δ a capacitor has, the purer the capacitor becomes on circuit.

Real Characteristics of Inductor “Example of DC Bias Characteristic”

Example of inductor’s
DC bias characteristic

Example of impedance characteristic

In case of magnetic-material core which has the magnetic saturation characteristic, inductance is lowered by increasing in DC bias current.



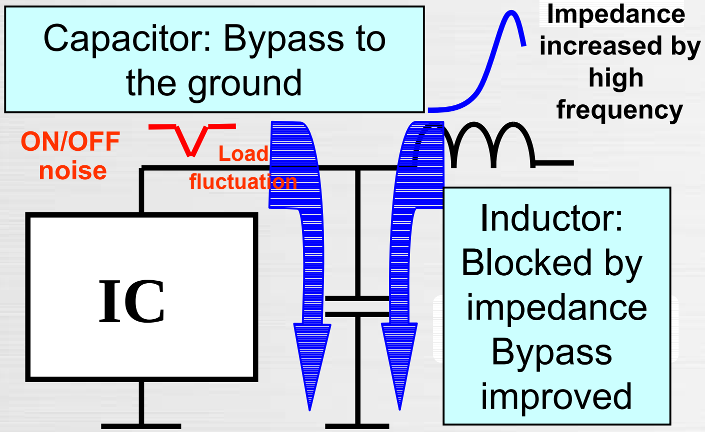
Impedance gets lowered as inductance is dropped by magnetic saturation.

An inductor which has a strong characteristic against DC bias can maintain high impedance level (vice versa).

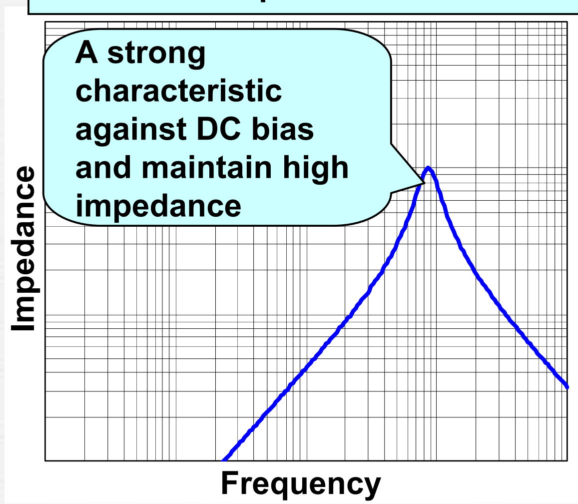
Generally, an inductor is selected based on a margin level for both required inductance and impedance under operational circumstances.

Example of the Influence on Inductor's DC Bias Characteristic in use of Power Supply Choke

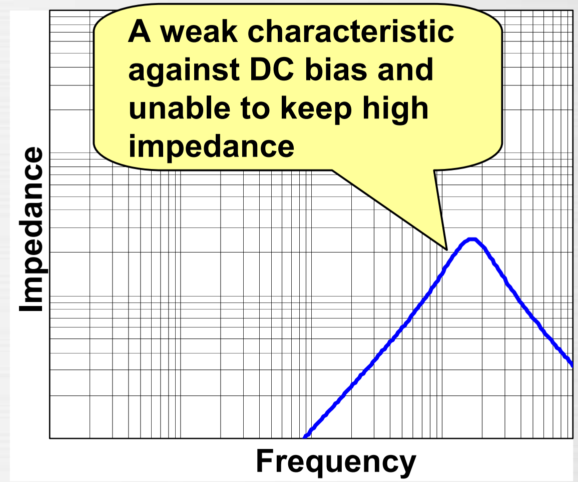
Example of power supply choke circuit

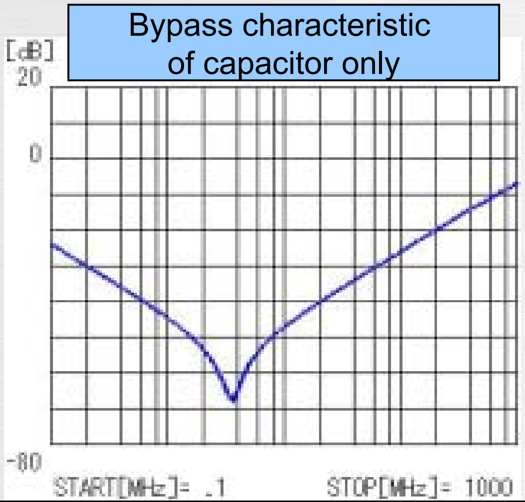


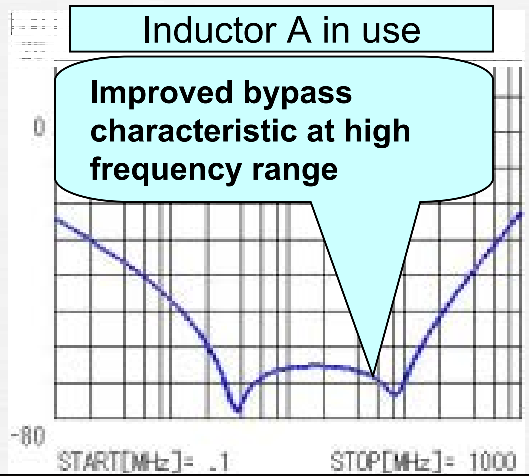
Inductor A: Impedance characteristic

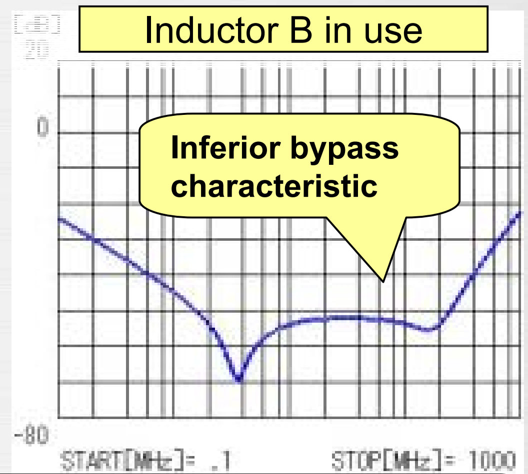


Inductor B: Impedance characteristic





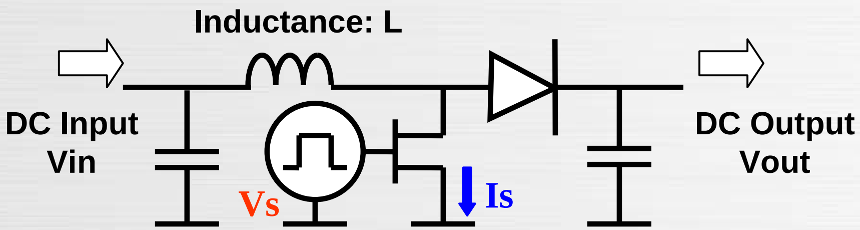




In case of power supply choke application, it should take full advantage of impedance characteristic in terms of designing of bypass circuit. Since impedance characteristic is degraded by DC bias, it should be paid attention to see if the required value left under operational circumstances comparing with self-resonance characteristic.

Example of the Influence on Inductor's DC Bias Characteristic of Power Supply Switching Circuit Application

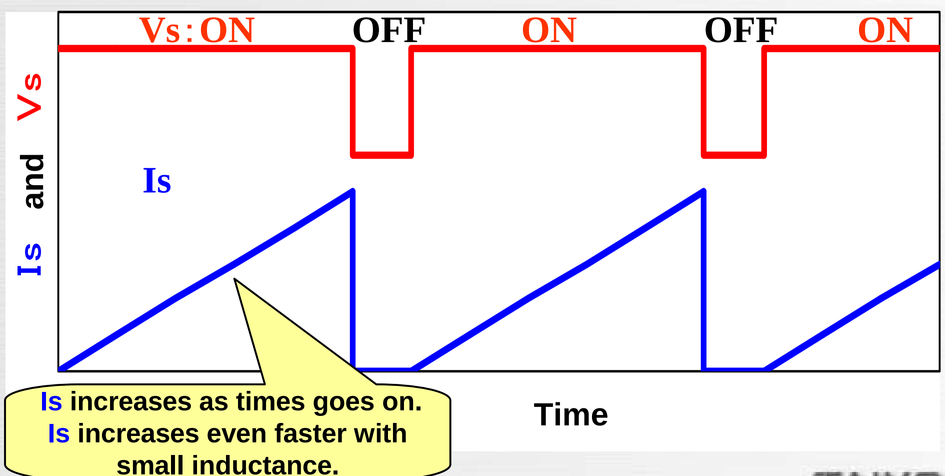
Example of step-up power supply circuit



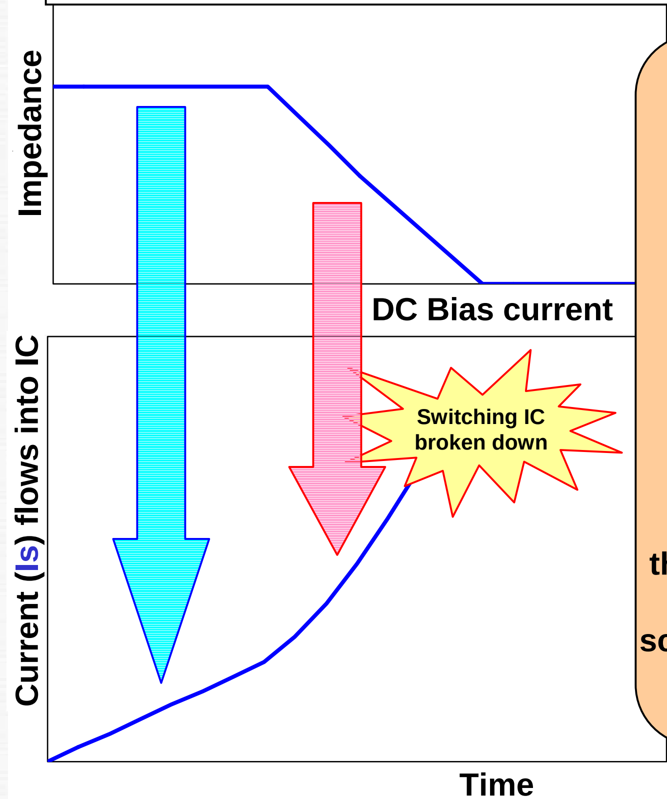
While Vs turned on, Is flows to IC and then voltage is raised by inductor. When Vs being off, it is added onto the input DC and then Output DC is up-converted.

When Vs is being on, Vin = L･dIs/dt, solving for this→
Is = Vin / L･t

Is gradually increases as Vs turned on,
it increases rapidly with small inductance .
It is important to know of the tolerance current when selecting an inductor for the power supply circuit.



General relationship between DC bias characteristic and Is



As DC bias current increases, the inductance starts decreasing.

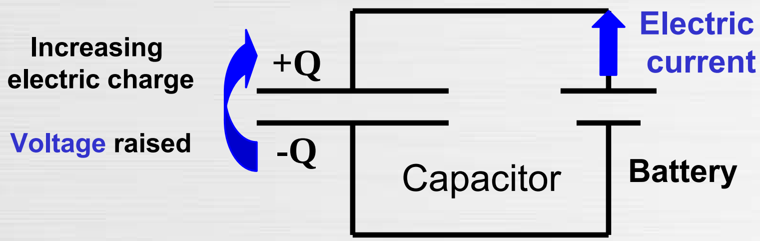
DC bias current passes at some point, inductance drops suddenly.

When DC bias current passes the tolerance current, (for the worst case scenario) the switching IC is broken down.

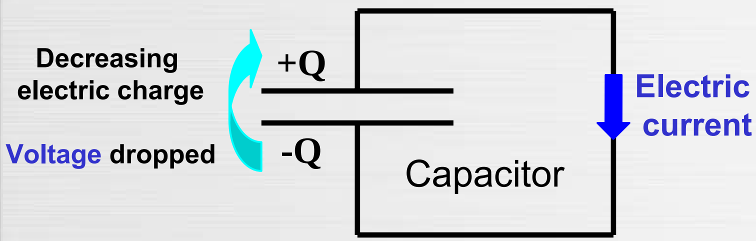
Switching interval is shortened by high frequency power supply IC, and therefore large inductance is no longer needed for IC.
Addition to this, flat DC bias characteristic isn't ideal for all kinds of circuit. It would be better to match a specific DC bias characteristic with IC and power supply demand.

Coffee Break "The Charging and Discharging Mechanisms of Capacitor"

Charging mechanism



Discharging mechanism



A time-varying electric charge induces electric current.

$$-I = dQ/dt$$

Capacitance is the constant of proportion derived from the relationship between the quantity of electric charge and voltage.

$$Q = C \cdot V$$

The relationship among voltage, electric current and capacitance

$$-V = 1/c \cdot \int i\,dt \text{ or } -I = C \cdot dV/dt$$

The equivalent relationship for inductor

$$-V = L \cdot di/dt$$

Apply voltage to a capacitor, electronic charge is built up in the inside of capacitor. On the other hand, when both sides of external electrodes are short-circuited, the capacitor discharges the built-up electronic charge.

The quantity of electronic charge is proportional to voltage. (In case with inductor, an electronic current creates magnetic flux. The quantity of magnetic flux is proportional to electronic current.)

Capacitor's capacitance is the constant of proportion between the quantity of electronic charge and voltage. (In case with inductor, inductance is the constant of proportion from magnetic flux and electronic current.

A time-varying electric charge or discharge induces electric current. In case with inductor, a time-varying magnetic flux induces electric voltage.

- Chapter 3 -

Electro-Magnetic Compatibility (EMC)

The Different Types of Noise

	Contents	Countermeasure components
Radiation noise	It leaks out as an electromagnetic wave. The sources are signal line and power line. There are restrictions in countries. (VCCI, FCC, CISPR, EN, etc.)	Mainly ML Ferrite Chip Beads BK series, Rectangular Ferrite Chip Beads (High Current) FB series M type. Resistors and capacitors may also be used.
Conduction noise (noise terminal voltage)	It runs through DC power line, i.e. switching noise, etc. The sources are DC-DC power supply converter, etc.	Mainly Surface Mount High Current Inductors NP series, Wound Chip Inductors LB series and such ferrite components and capacitors for DC-DC, etc.
Ripple voltage (current)	A fluctuation by voltage drop occurred when IC operates. It becomes a problem at power line with high power consumption for CPU, etc.	Mainly capacitors
Electrostatic	A discharge phenomenon, which is caused by friction charge. It causes element destruction and malfunctions.	Mainly Chip Varistors and Diodes. Capacitors and Beads may also be used.
Surge noise	Instantaneous high voltage and current. It is occurred by natural phenomenon (eg. thunderstorm), inserting and removing a cable, etc.	Spark Gaps and Varistors. Beads and Resistors for low voltage.

Standards of Radiation Electric Field

Global Standard: CISPR

- Japan: VCC class2 (Consumer Equipment)
- U.S.A.: FCC part15
- Europe: EN55022
- Other countries: Setting regulation based on CISPR

Regulation of the frequency band is between 30MHz to 1000MHz for VCCI.
Others are referred on the next page.

EMI Regulation Example for High Frequency Band (Tightening Regulation for GHz band noise)

1. CISPR 11 Group 2 Class B (1999 industry, chemistry, medical)

For equipment with embedded frequency of 400MHz and above

Regulated frequency: 1-2.4GHz band
Standard: 70dBuV/m and below (3m electric field intensity)

2. CISPR 22 CIS/G/210/CD (2001 IT equipment)

For equipment with embedded frequency of 200MHz and above

Regulated frequency: 1-2.7GHz band
Standard: Average of 50dBuV/m and below,
Max 70dBuV/m and below (3m electric field intensity)

3. FCC Part 15 (IT equipment)

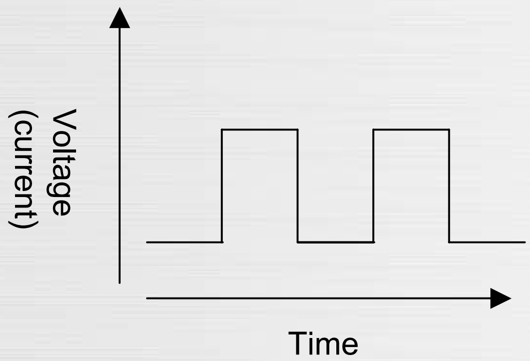
Measurement up to 2GHz is required for an operation between 108 to 500MHz band.

Measurement up to 5GHz is required for an operation between 500 to 1000MHz band.

Mechanism of Radiation Noise 1

Digital waveform

Measurement system: Oscilloscope



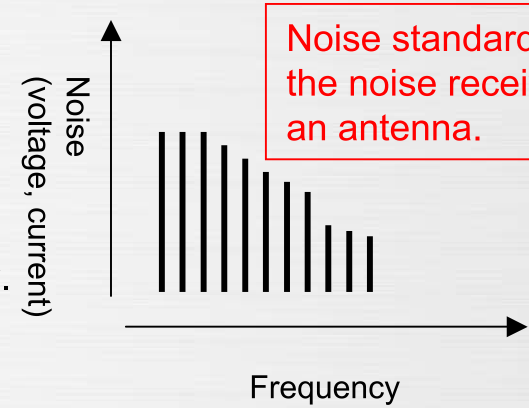
Fourier transform

Time axis is transformed to frequency.

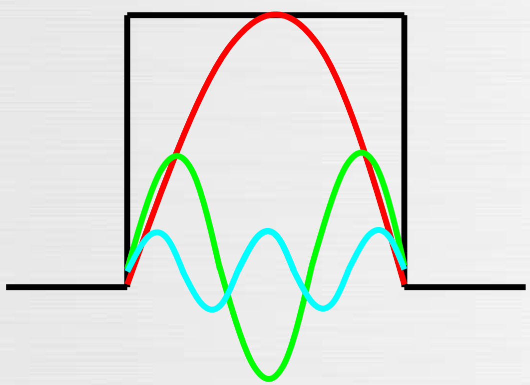
Spectrum

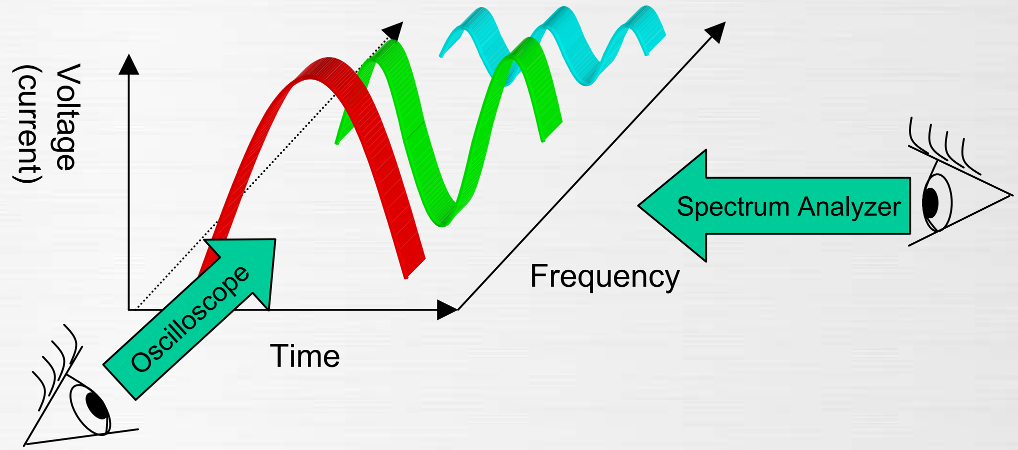
Measurement system: Spectrum Analyzer

Noise standard restricts the noise received with an antenna.

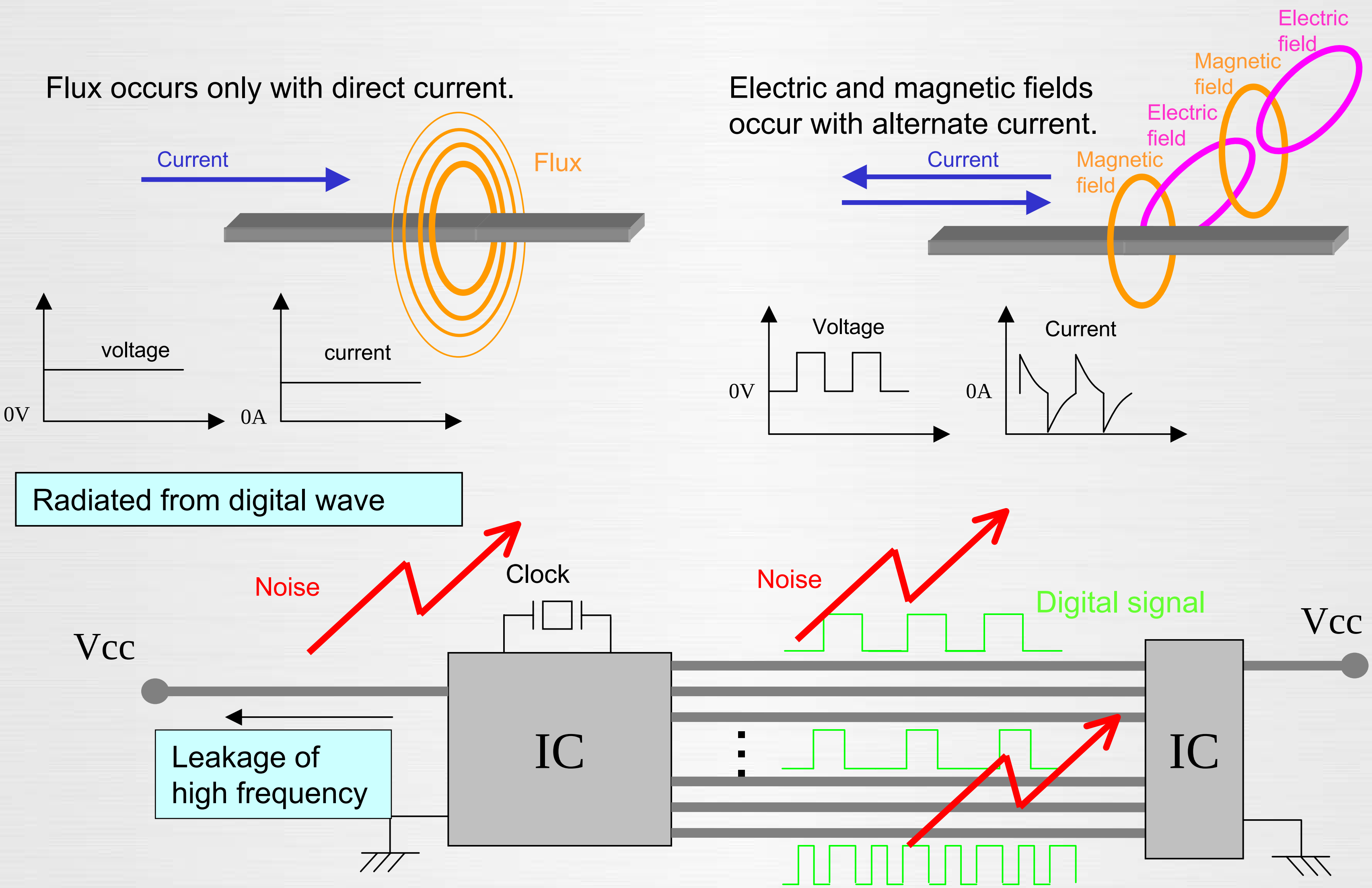


Digital wave is formed by various frequencies.

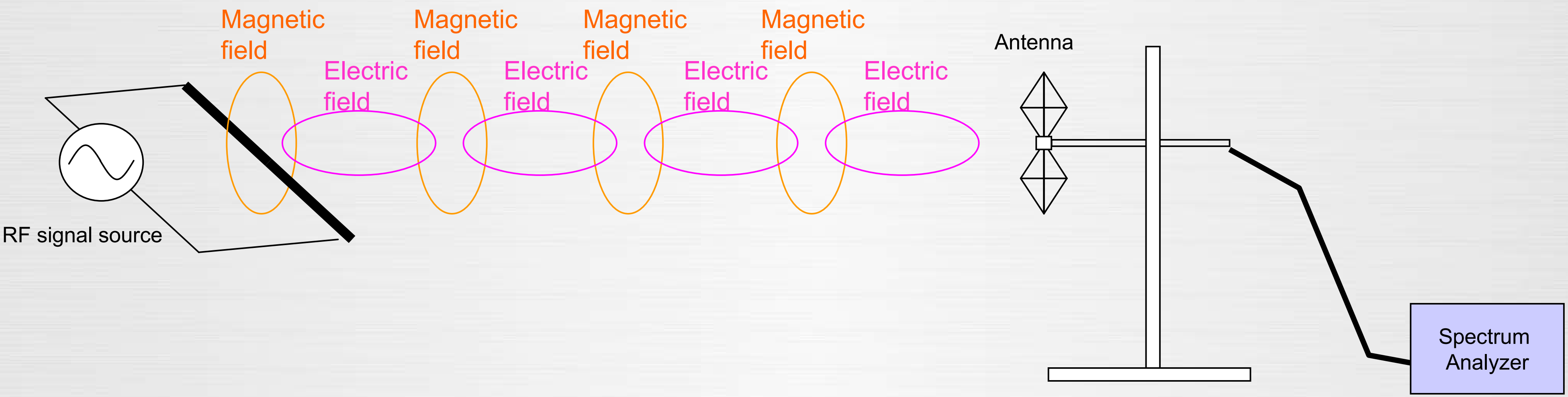




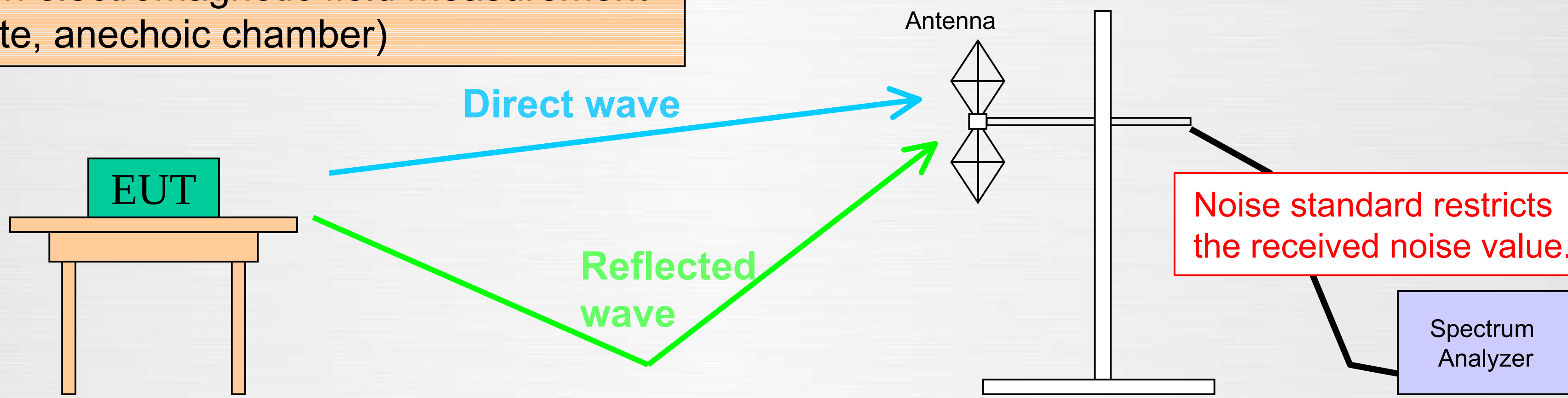
Mechanism of Radiation Noise 2



Mechanism of Radiation Noise 3

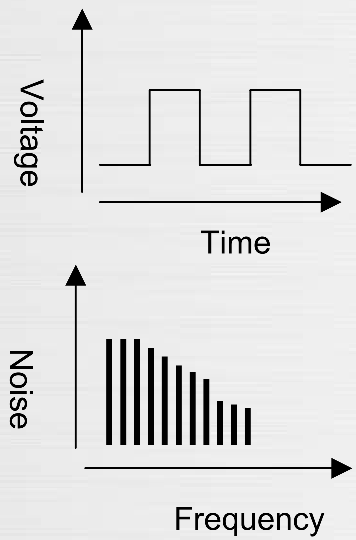


Radiation electromagnetic field measurement (open site, anechoic chamber)

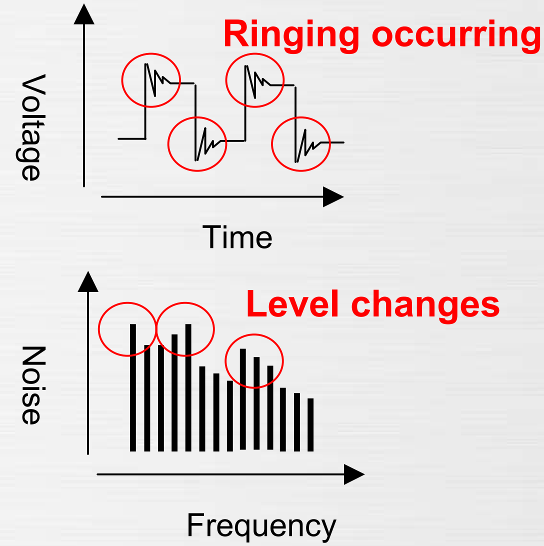


Noise standard restricts the received noise value.

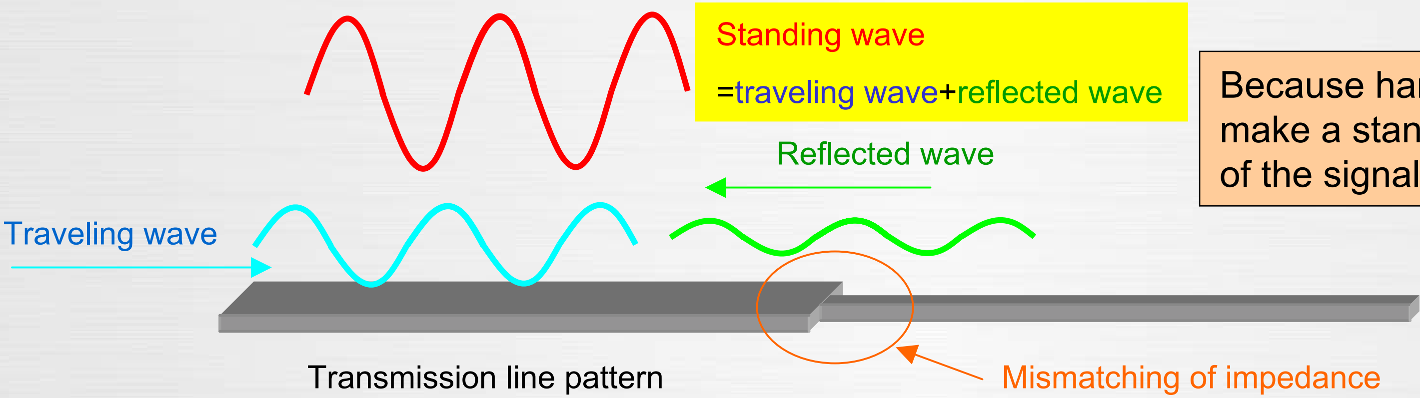
Mechanism of Radiation Noise 4



Spectrum changes with waveform distortion.



Cause: mismatching of transmission line



Because harmonics of a digital signal make a standing wave, the emission of the signal increases as noise.

Fin.

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