The Fundamental Technical Knowledge of Passive Components

— for Windows version —

TAIYO YUDEN CO., LTD.

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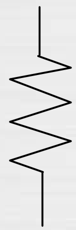
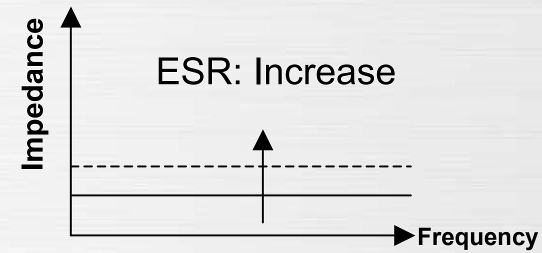
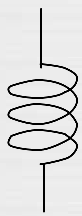
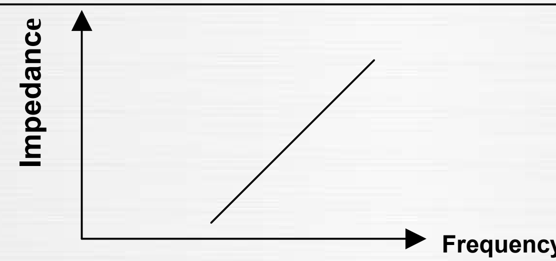
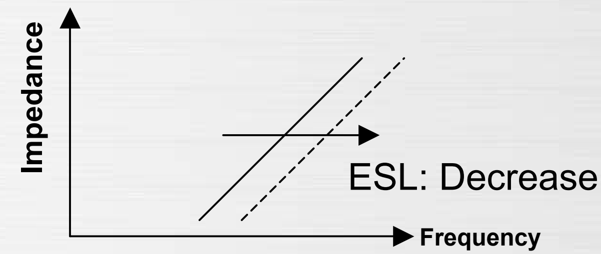
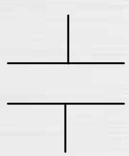
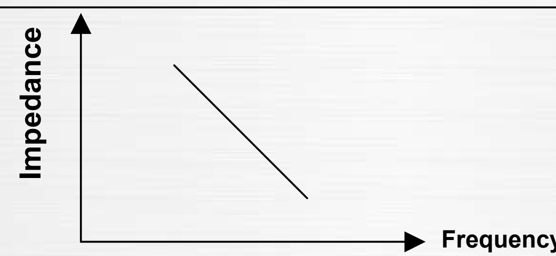
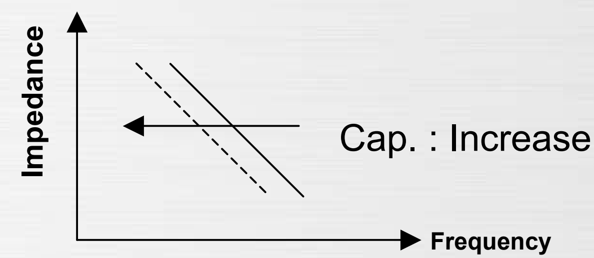
- Chapter 1-

Capacitor

Impedance Characteristics of Capacitor

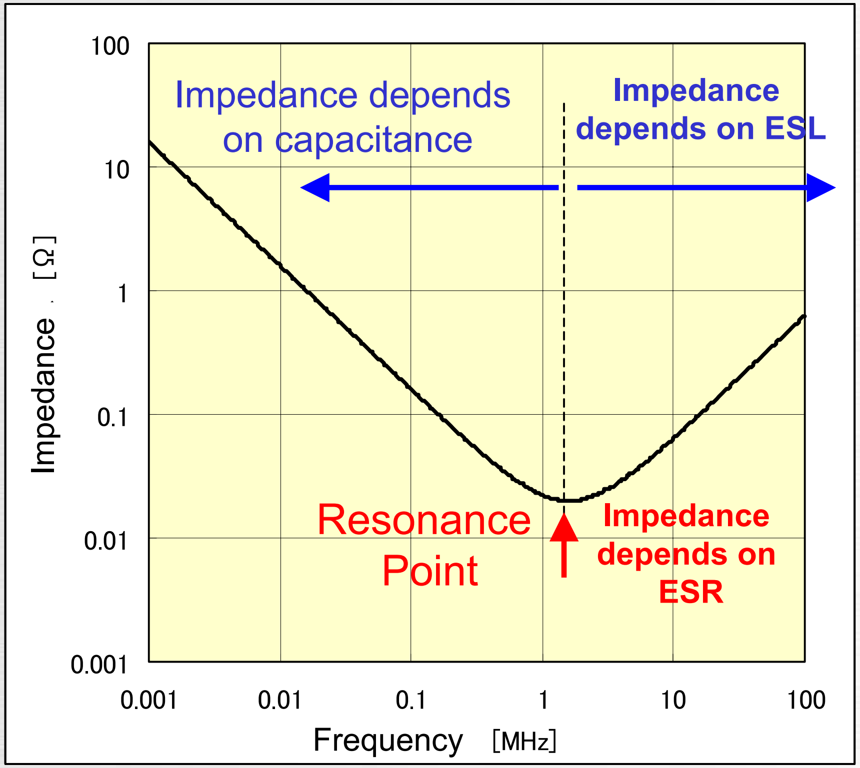
Impedance equivalent circuit with capacitor is the same as the RLC series model.

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?

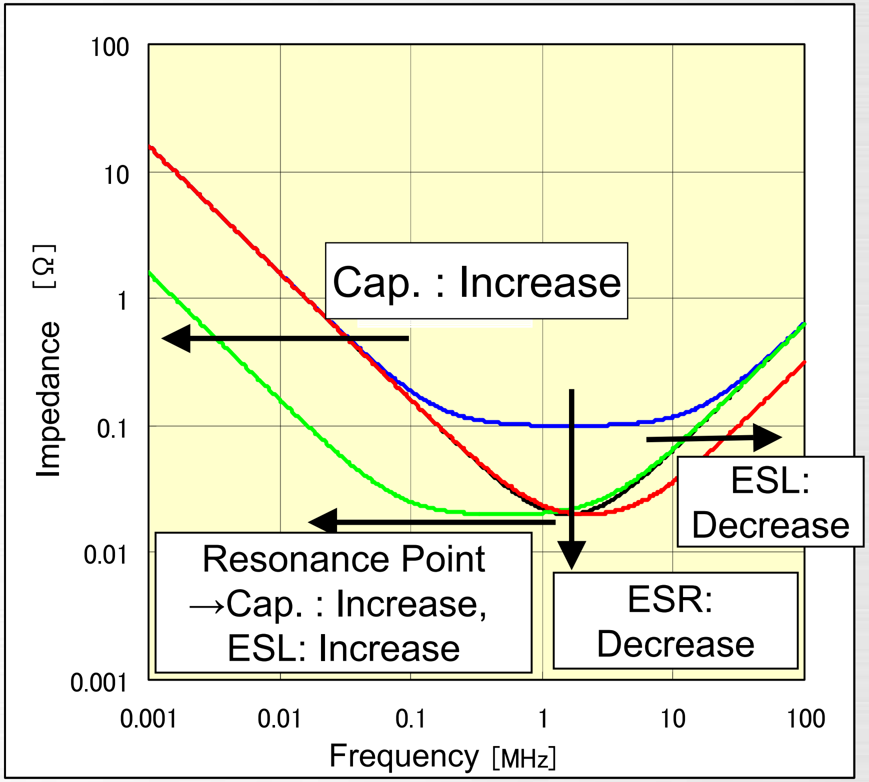
Impedance Characteristics of Capacitor

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

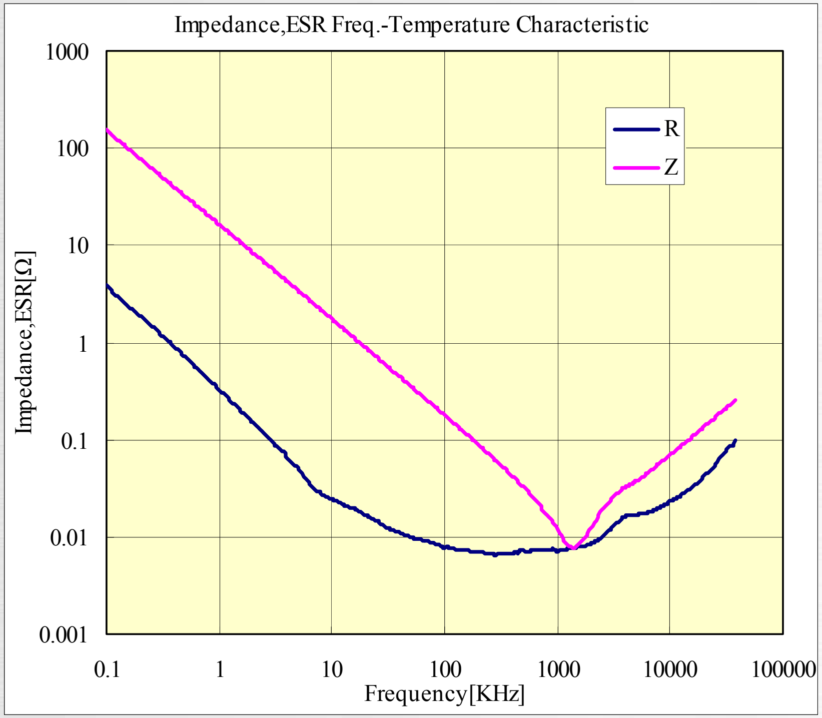
Impedance with different elements



Impedance characteristics vary depended on each element.

Impedance Characteristics of Capacitor

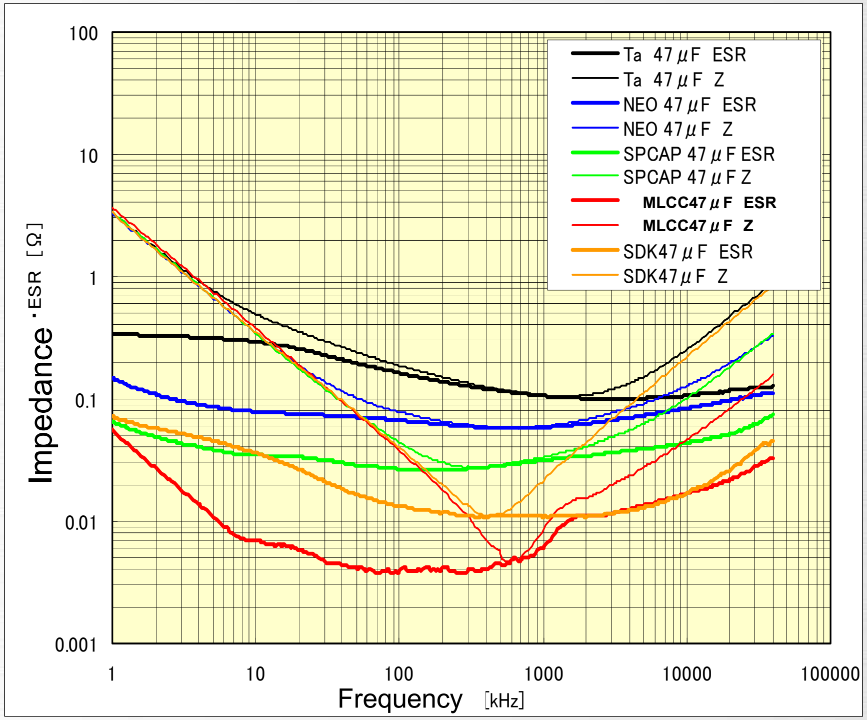
ESR varies depended on frequency



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.

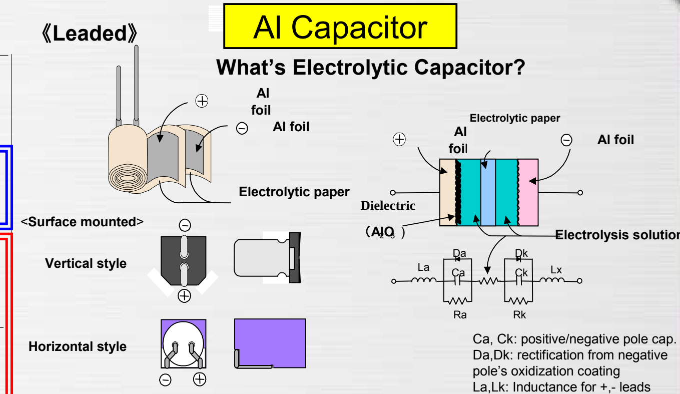
Reliabilities of Multi-Layered Ceramic Capacitor

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

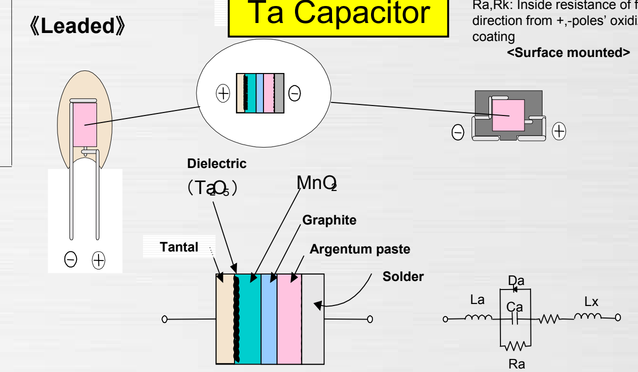
Al Capacitor

What's Electrolytic Capacitor?

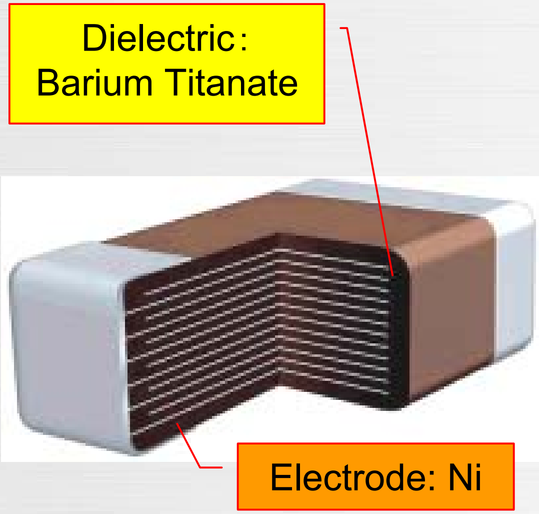


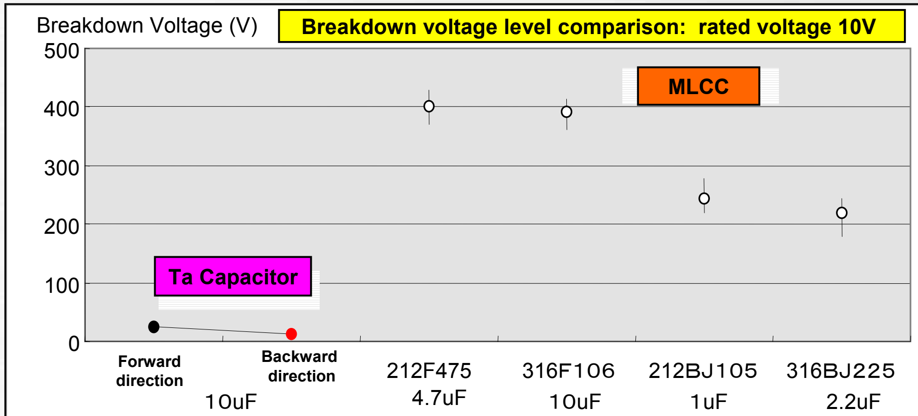
Ca, Ck: positive/negative pole cap.
Da,Dk: rectification from negative pole's oxidization coating
La,Lk: Inductance for +,- leads
R: resistance of electrolsis solution and paper
Ra,Rk: Inside resistance of forward direction from +,-poles' oxidization coating

Ta Capacitor



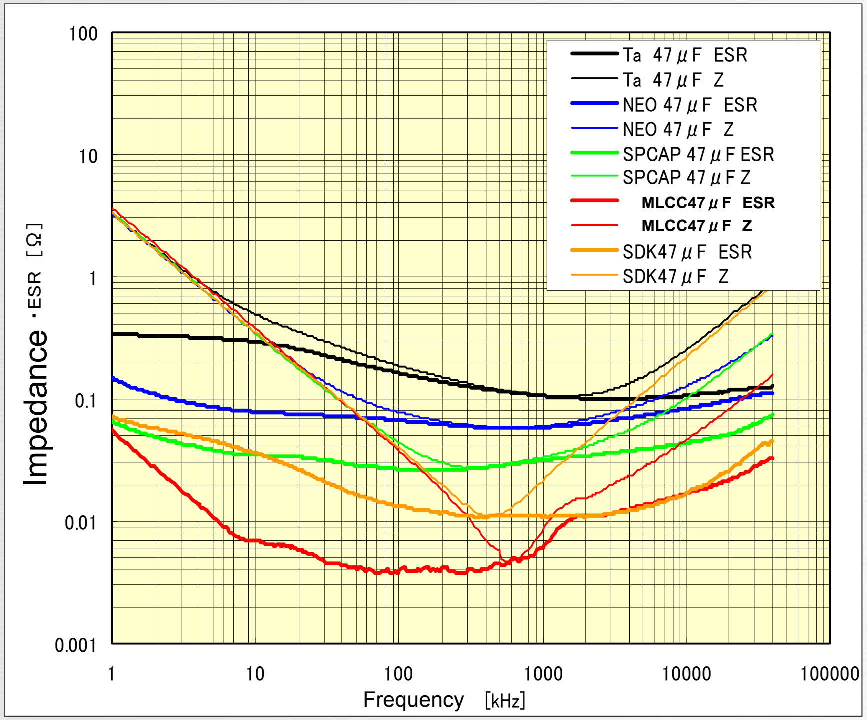
Ceramic Capacitor





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.

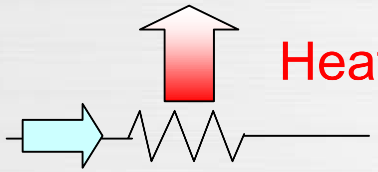
Al>Ta>Functional Ta>Functional Al>ML

MLCC has superior frequency characteristics.

The most competitive merit

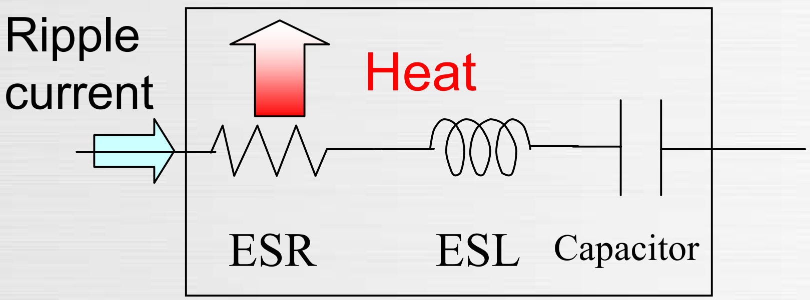
Characteristics Comparison for the Different Type of Capacitors

Ripple Current Characteristics



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

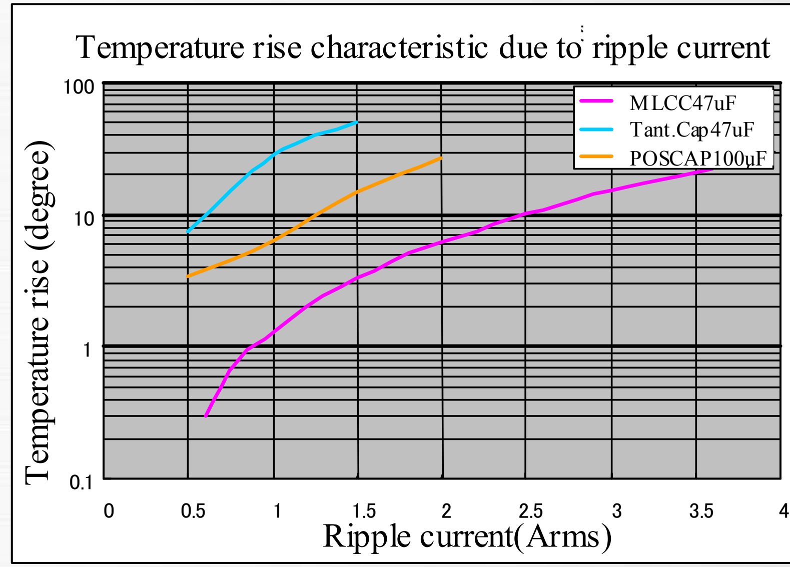
Capacitor



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.

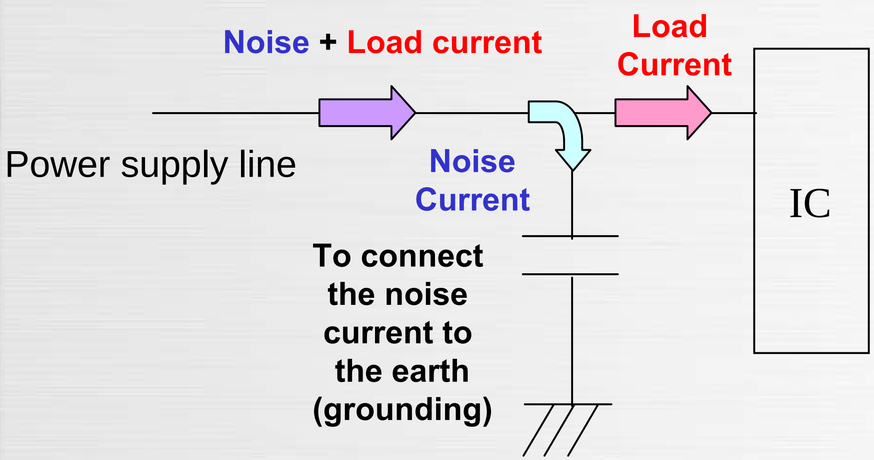
Operational recommendation of heat release value for MLCC is within 10℃.
There is no limitation of allowed ripple current for MLCC.

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.

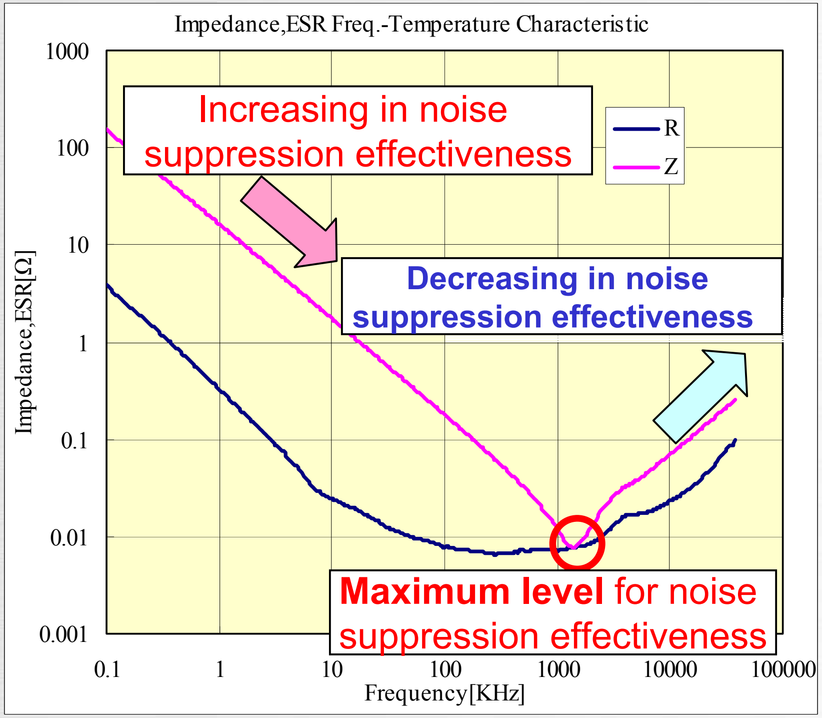
It efficiently grounds the noise current.

It effectively decreases the noise current.

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

The Functions of Bypass (decoupling) Capacitor

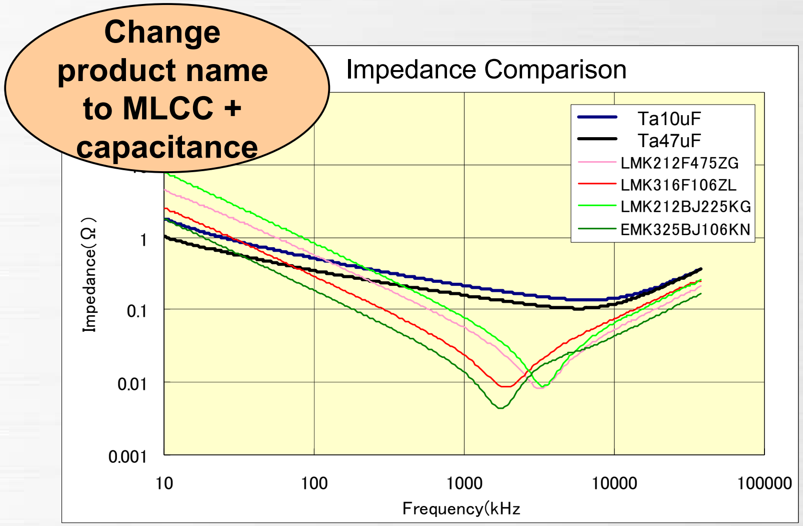
Selection Criteria for Capacitor



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.

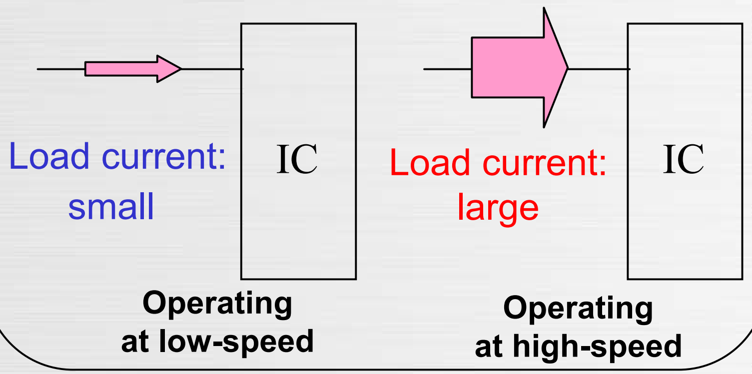
Effectiveness of reduction in high frequency noise for MLCC is more superior than that of Ta capacitor.

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

The Functions of Backup Capacitor

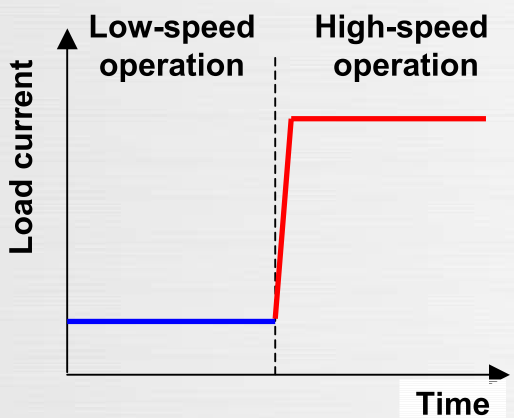
Load current to IC

Load current doesn't stay constant.



High-speed load change

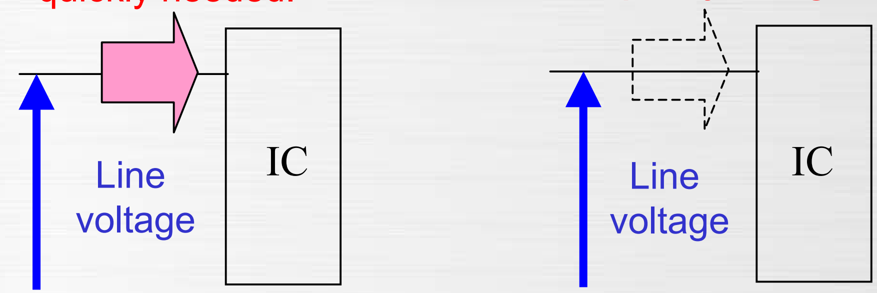
When IC's operational speed changes rapidly, large load current is quickly needed.



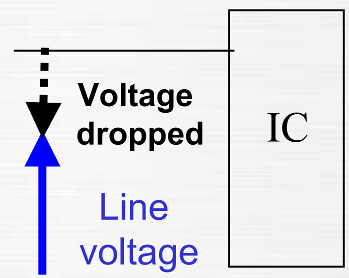
Power line for high-speed load changing

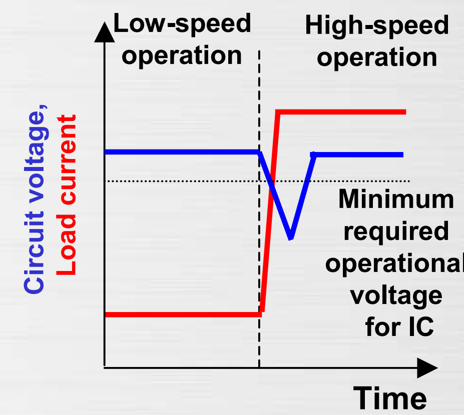
Large load current is quickly needed.

The current can't flow to IC quickly enough.



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



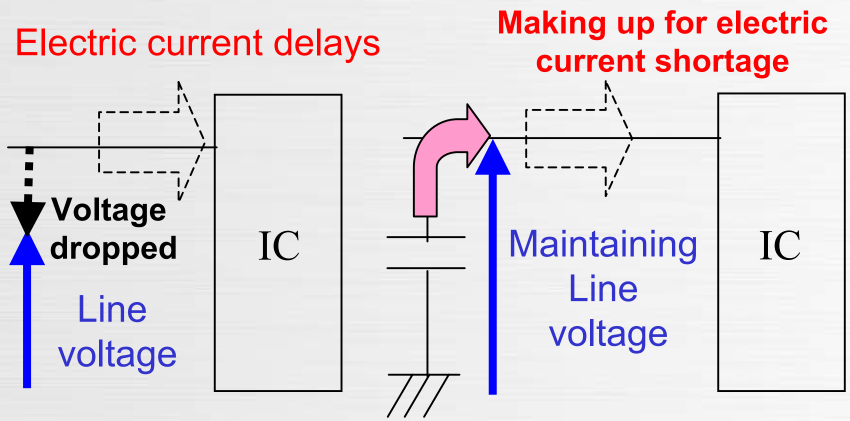


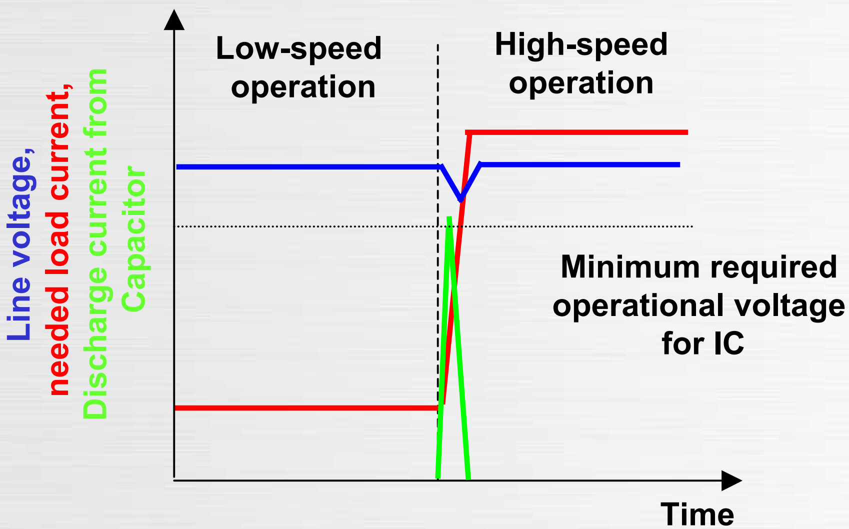
Line voltage decreases below the required operational voltage for IC.

The IC stops its operation.

The Functions of Backup Capacitor

The Role of Backup Capacitor

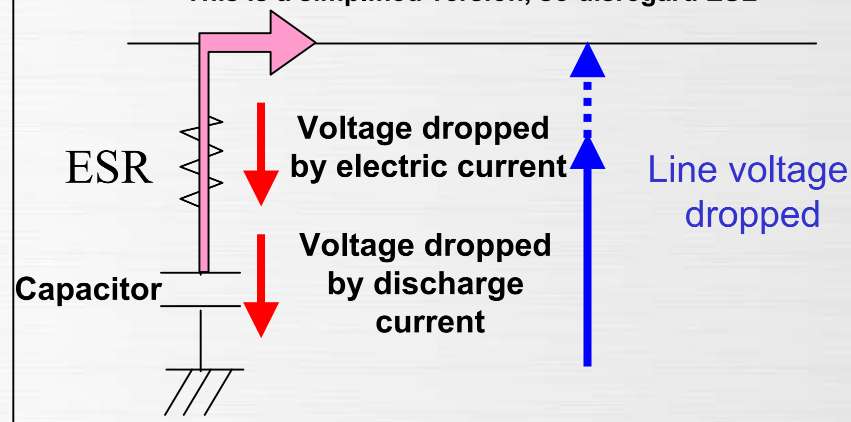




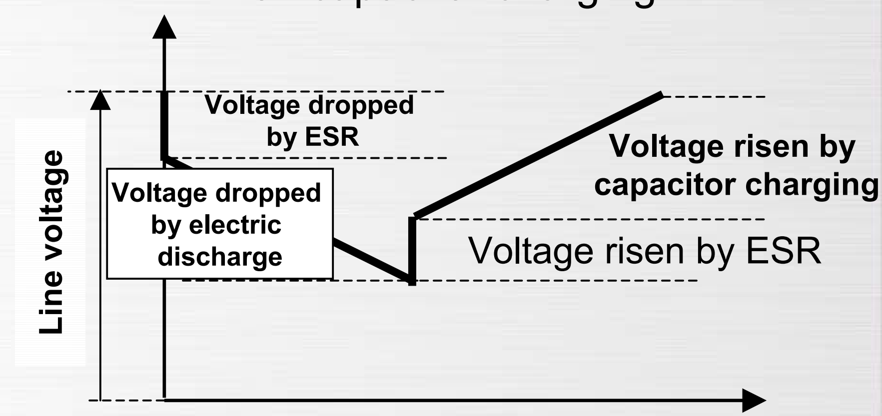
Keeping the minimum required operational voltage for IC → Maintaining stable operation

Capacitor's actual (considering equivalent circuit)

*This is a simplified version, so disregard ESL



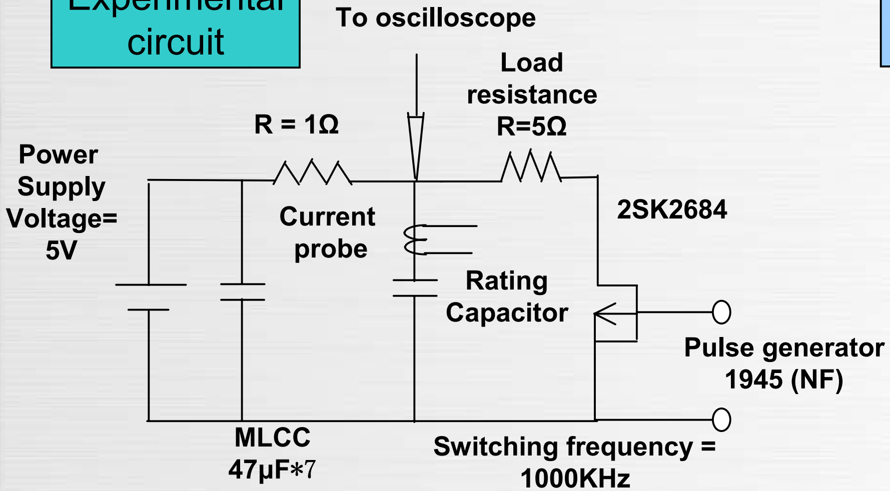
Voltage fluctuation occurs when capacitor charging



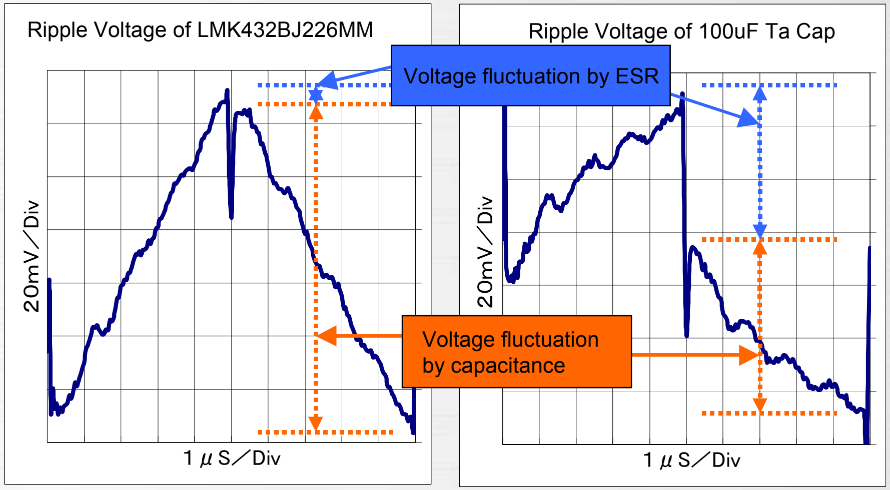
Capacitor and ESR decide the amount of voltage dropped

The Functions of Backup Capacitor

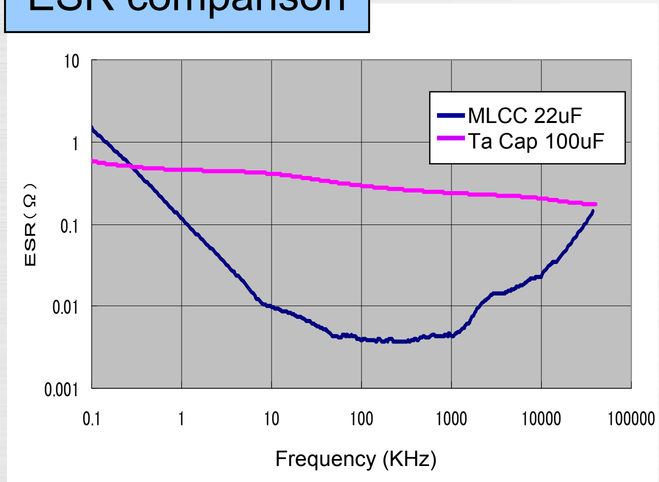
Experimental circuit



Experimental result for Capacitance and ESR



ESR comparison



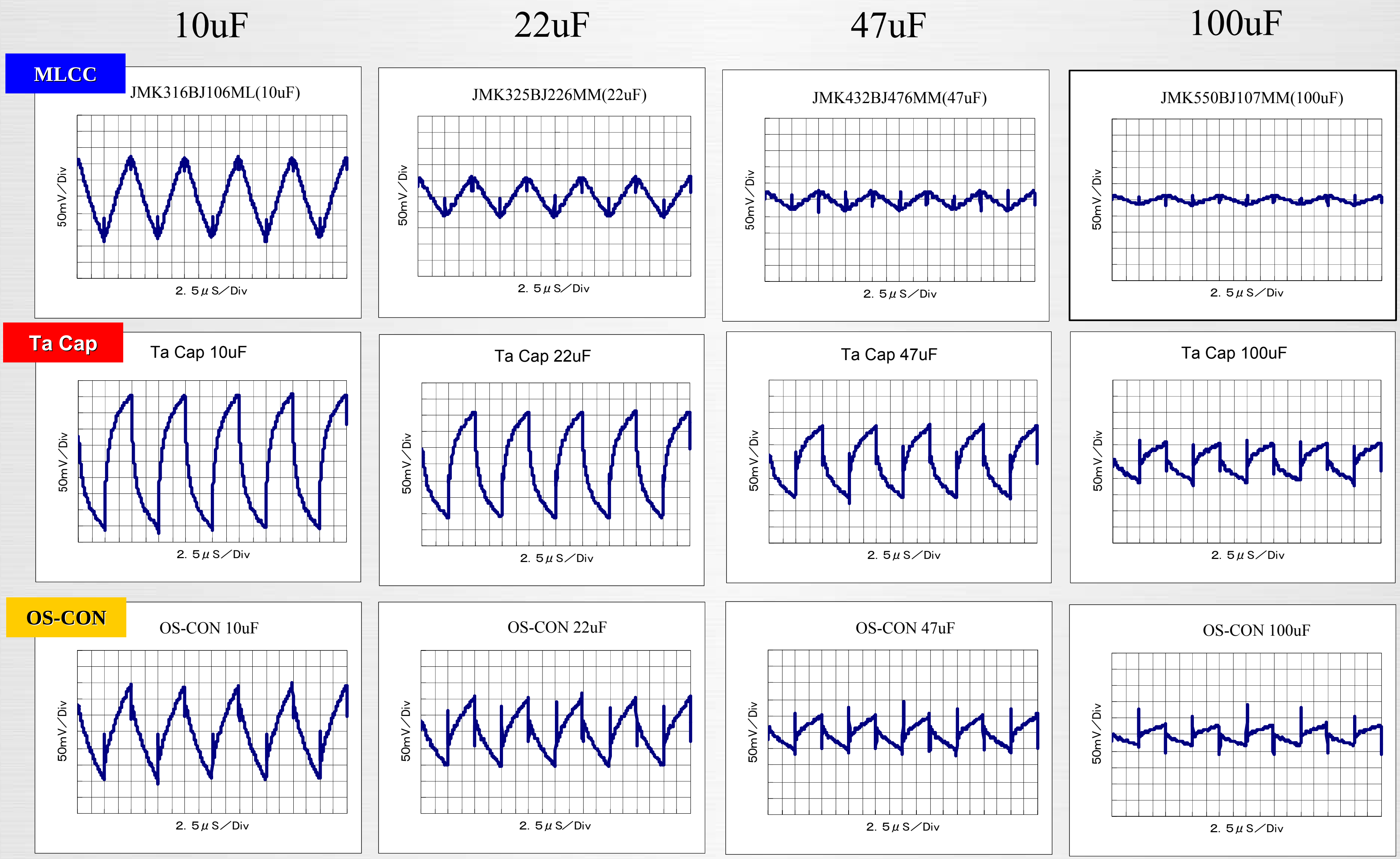
High Value
Low ESR
→ The fluctuation band of line becomes narrower.

Merits of MLCC

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

The effectiveness of MLCC's voltage fluctuation depressing effect is greater than that of Ta capacitor.

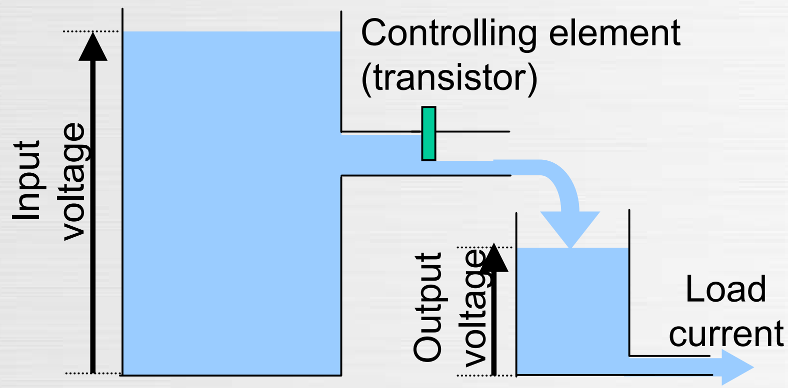
Application Examples for Backup Capacitor



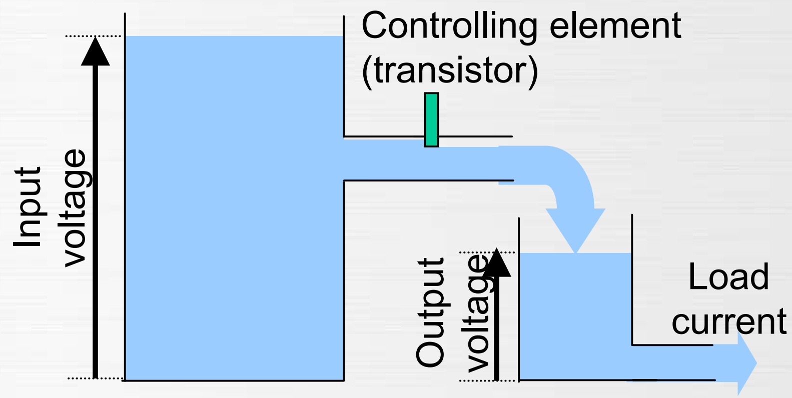
The Basic Knowledge of Power Supply Circuit

Series Regulator (3 Terminal Regulator)

Circuit operation (water gate model)



Load current fluctuation



Producing output voltage by lowering certain amount of input voltage

⇩

Step-down power supply

Controlling water gate to keep the water level constant

Controlling load current with transistor

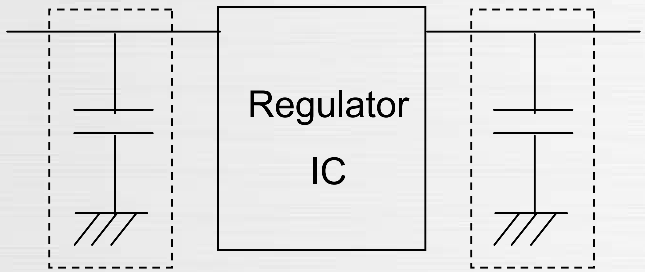
⇩

Output voltage stays constant.

Series Regulator (3 Terminal Regulator)

Circuit structure

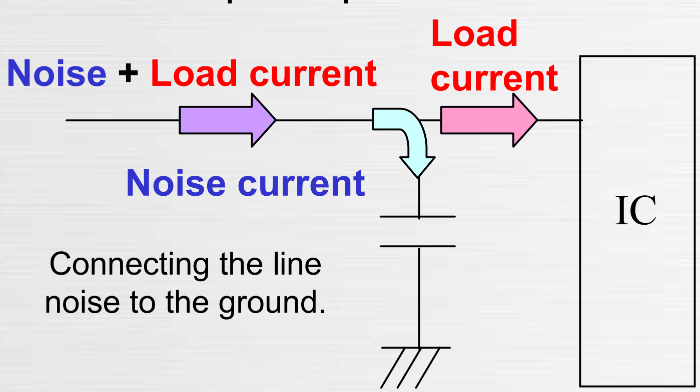
Input voltage > Output voltage



Input Capacitor Output Capacitor

Consisting of IC, input and output capacitors.

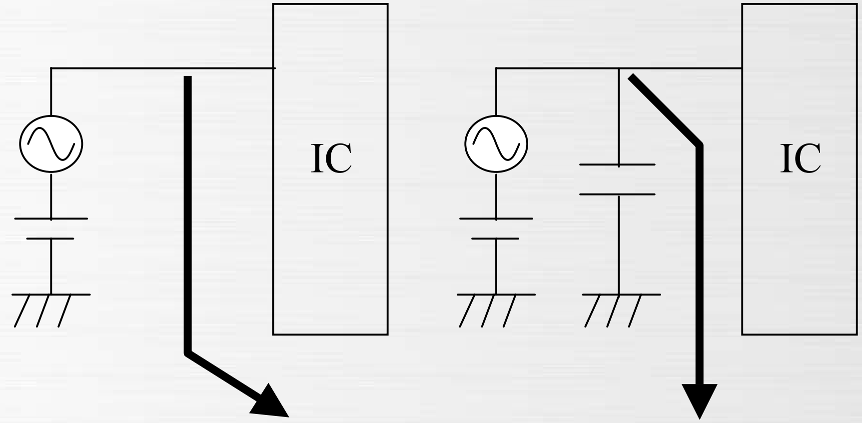
Function of input capacitor

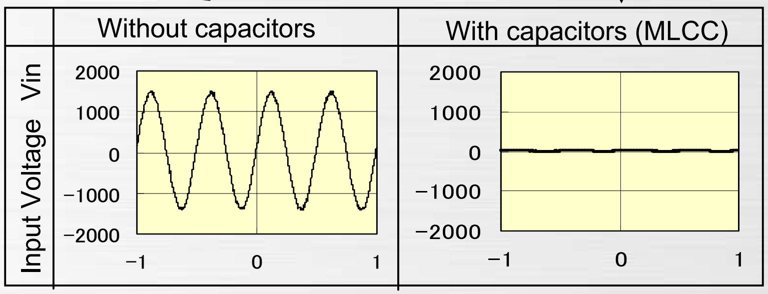


Same as the function of Bypass Capacitor

Effects of input capacitor

Add alternate current to input voltage purposely to measure input current amount with or without input capacitor





Vertical: mV Horizontal: u sec

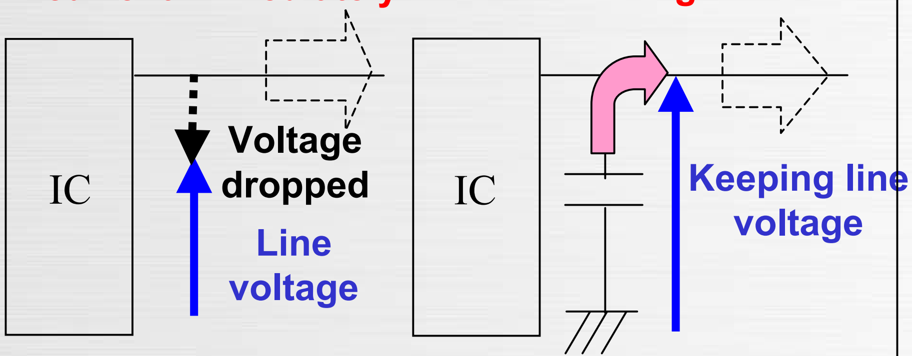
Input voltage is stabilized as input capacitor is connected.

Series Regulator (3 Terminal Regulator)

Function of output capacitor

Unable to supply current immediately

Cover the current shortage

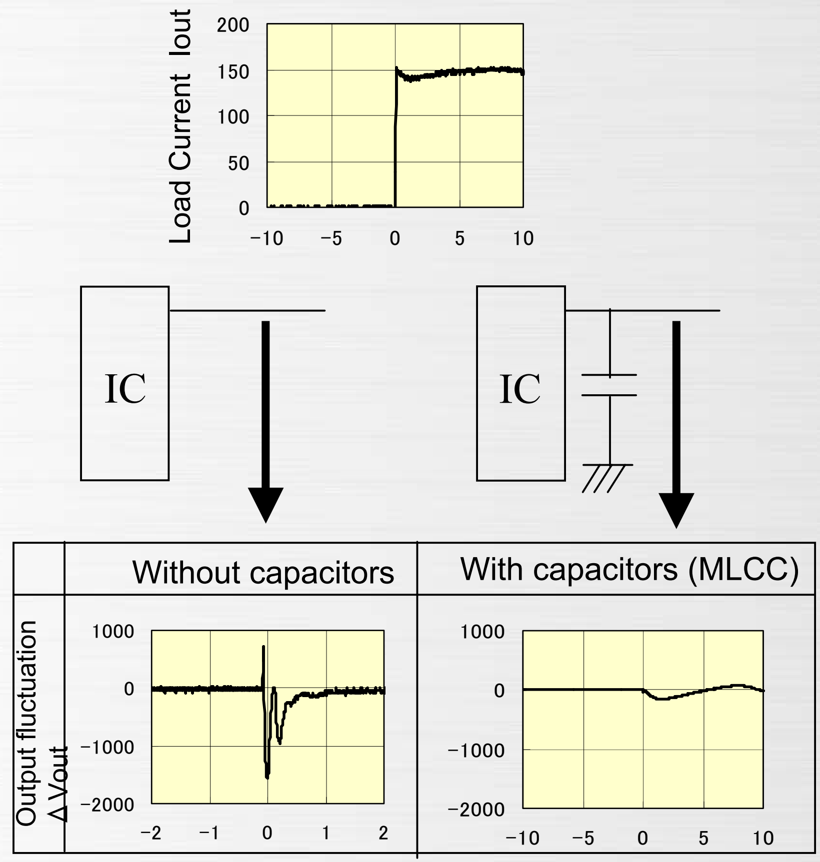


Supply current to control voltage fluctuation for rapid load change

Same as the function of Backup Capacitor

Effects of output capacitor

Measuring the voltage fluctuation when load change is occurred with/without output capacitor.

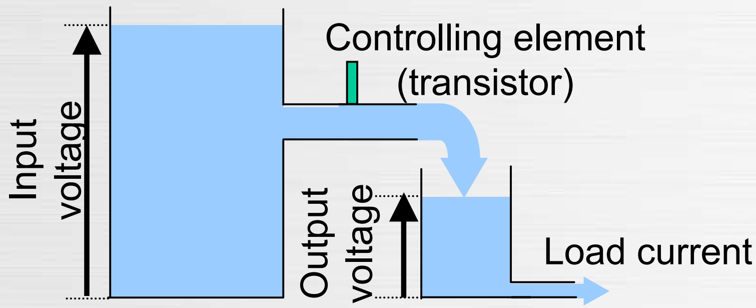


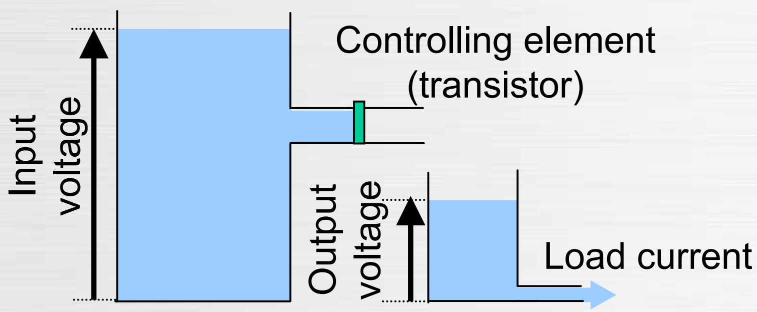
Output voltage is stabilized as output capacitor is connected.

Step-Down Converter

Circuit operation (water gate model)

Producing output voltage by lowering input voltage with transistor





Transistor for switching power supply has only ON or OFF signal.

⇩

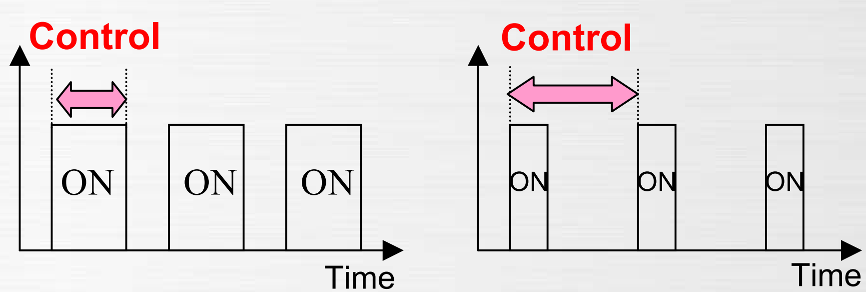
Switching operation

⇩

Controlling output voltage by switching

Turn-on cycle → Constant Time to be ON → Changes	⇨	PWM method
Turn-on cycle → Constant Time to be ON → Constant	⇨	PFM method

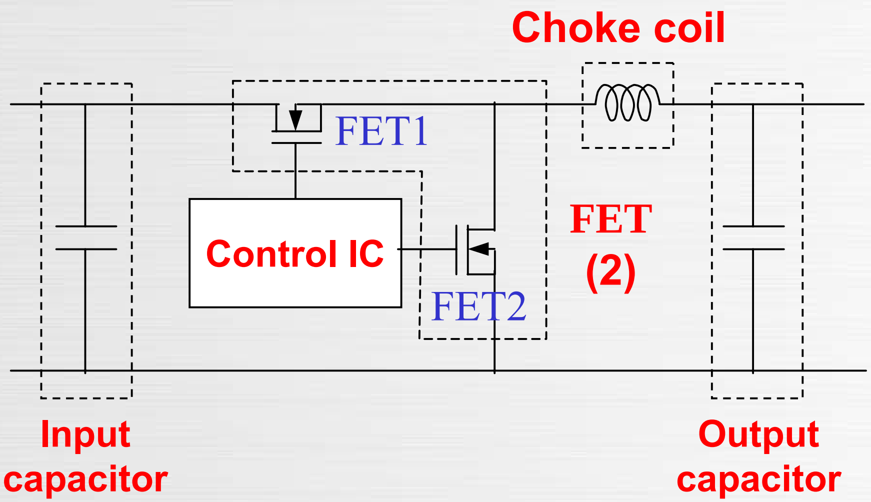
Turn-on cycle of the switch → Switching frequency



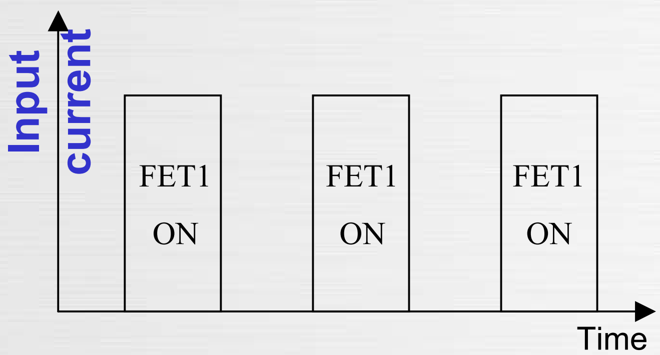
PWM PFM

Step-Down Converter

Circuit structure

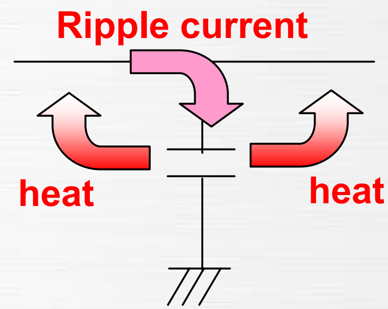


Input side current



Large amount of alternating current (ripple current) flows.

Operation of input capacitor



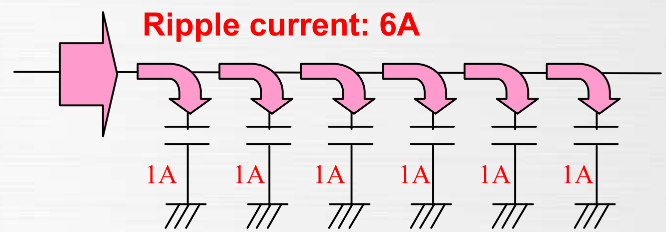
Ripple current flows into input capacitor.

Heat generated by ESR

Necessary characteristics of input capacitor

High tolerance for ripple current

Example: Permissible ripple current of a capacitor is 1A.

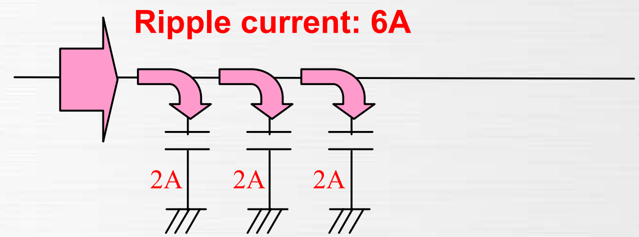


6

capacitors

Reduced

Example: Permissible ripple current of a capacitor is 2A.

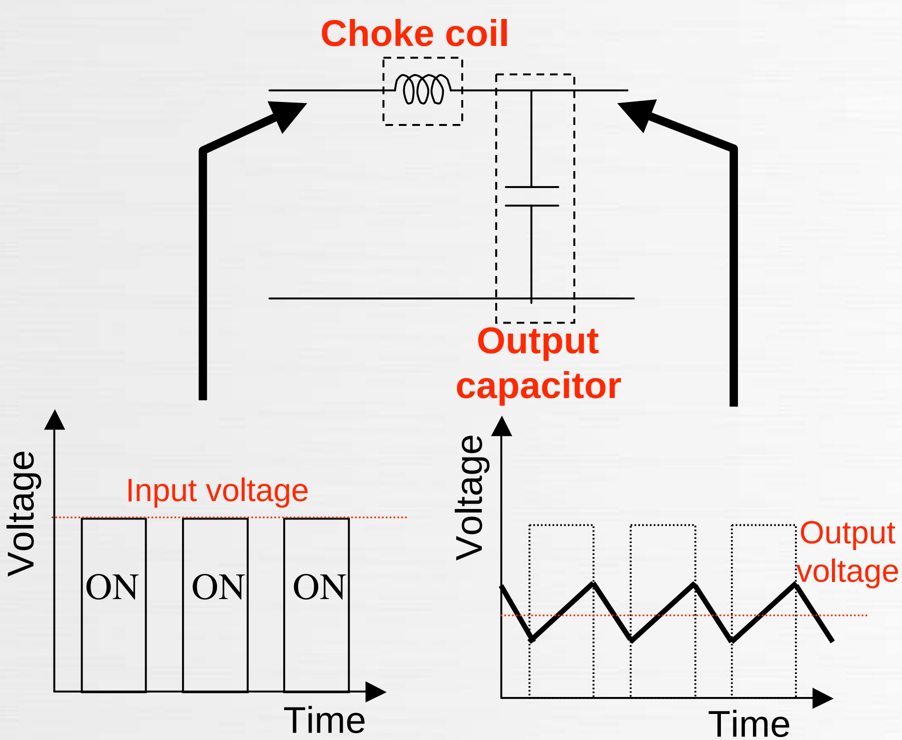


3

capacitors

Step-Down Converter

Output side operation



Input voltage is controlled by an on-off switching.

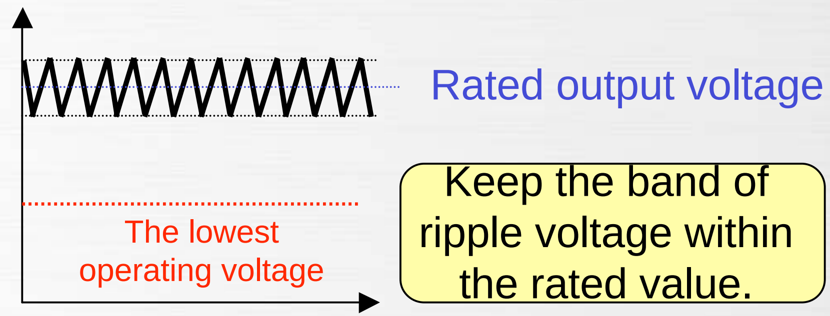
It is smoothed with a choke coil and an output capacitor.

Ripple voltage is included.

Points of output voltage to remember

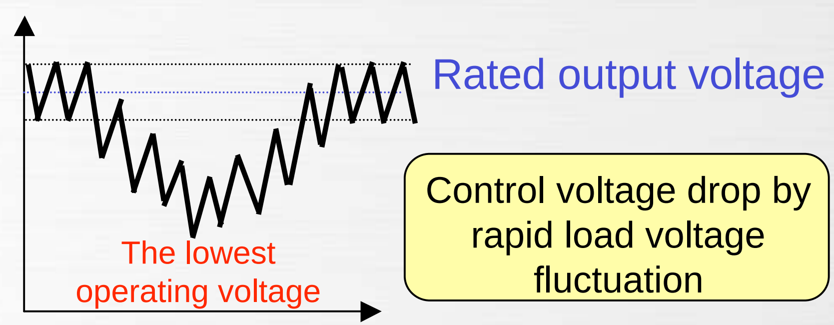
Keeping higher voltage than the lowest operating voltage of load IC.

Ripple voltage



Keep the band of ripple voltage within the rated value.

Rapid load voltage fluctuation



Control voltage drop by rapid load voltage fluctuation

Step-Down Converter

Factor for determining voltage drop by rapid load voltage fluctuation

Operation at rapid load change

↓

Same as Backup Capacitor

Necessary characteristics for capacitor when rapid load fluctuation occurred

High capacitance

→ Supply capacitor of high electronic charge

Low ESR

→ **Reducing voltage drop when supplying electronic charge**

High Value MLCC

↓

Suitable

Factor for determining ripple voltage

Repeating an on-off switching signal

↓

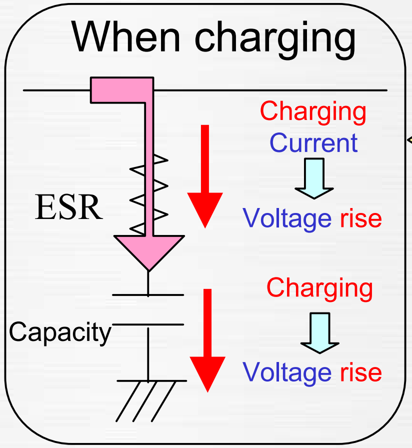
Charge and discharge are repeated with output capacitor.

↓

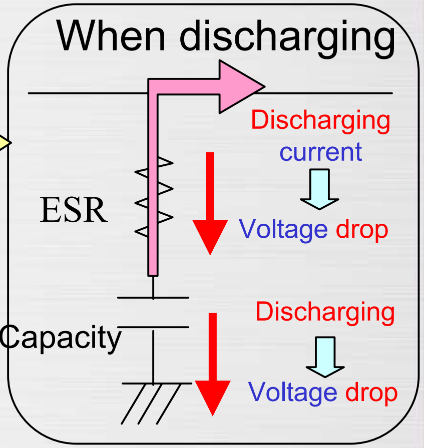
Voltage is fluctuated by current flowing in and out.

↓

Ripple voltage



Repeat

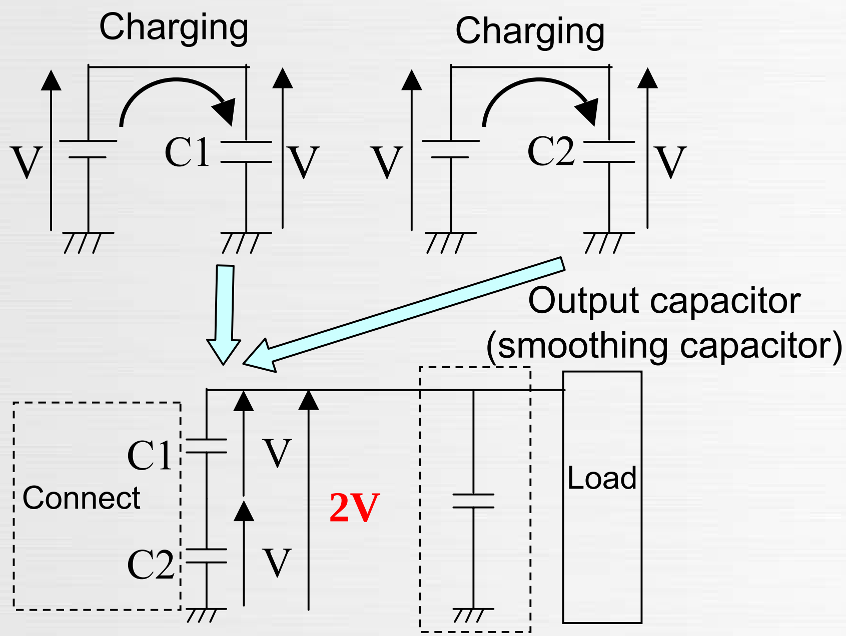


High capacitance and low ESR reduce ripple voltage.

Charge Pump (Boost)

Operation of charge pump (image)

Charging 2 capacitors separately



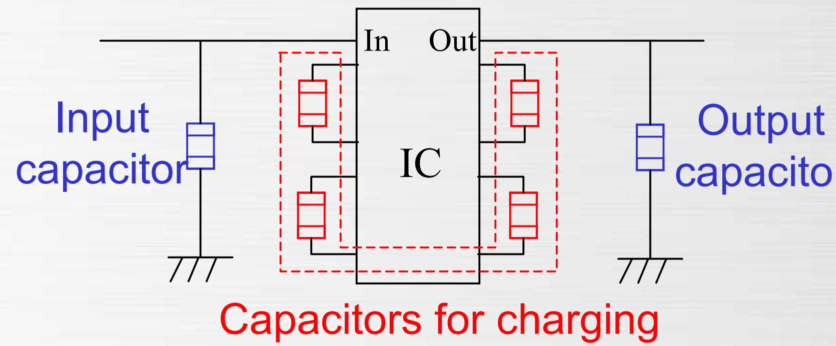
Connecting charged capacitors

Output double amount of voltage than input

Smoothing with output capacitor (Switching)

Output voltage is determined by the number of capacitors connected. (integral multiple)

Circuitry of charge pump (example: double boost)



Required characteristics of capacitor

Charging capacitor and output capacitor

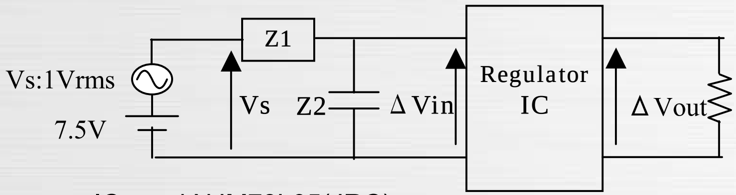
→ Lowering voltage fluctuation occurred by charging/discharging

Backup Capacitor
Same as step-down output capacitor

High capacitance and low ESR are required.

Summary Comparison of Various Input Capacitors

Measuring the noise absorption and the output voltage fluctuation by adding sine wave on input line



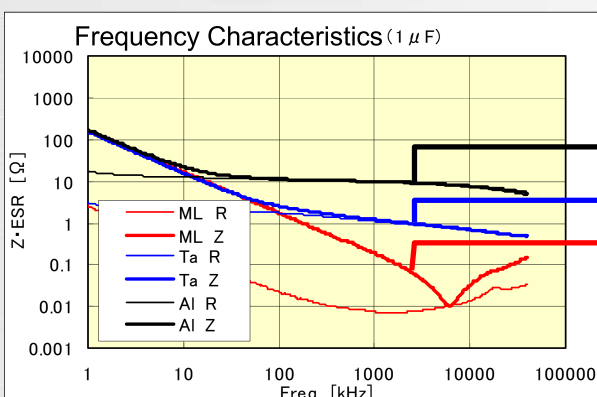
IC used:NJM78L05(JRC)
Capacitor used:LMK212BJ105KG, Ta1uF, Al1uF

$$\Delta\ Vin = \frac{Z2}{Z1+Z2}Vs$$ (Z1:Line impedance)

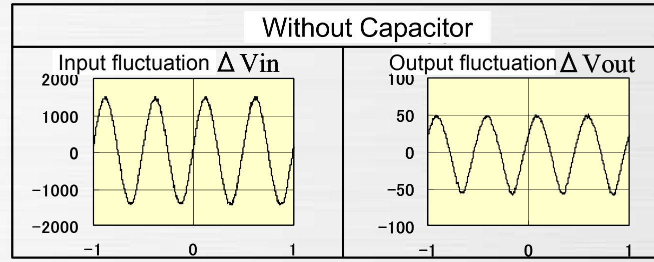
Capacitor (Z2) has low impedance.

→ Effect of noise suppression: large

Constant IC input voltage



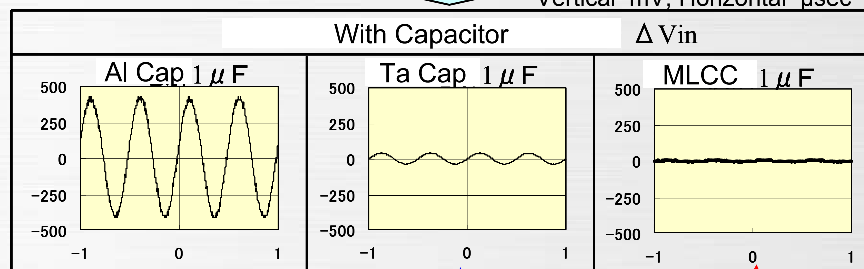
Vertical mV, Horizontal μsec



Input fluctuation of 1Vrms → Output fluctuation of 35Vrms

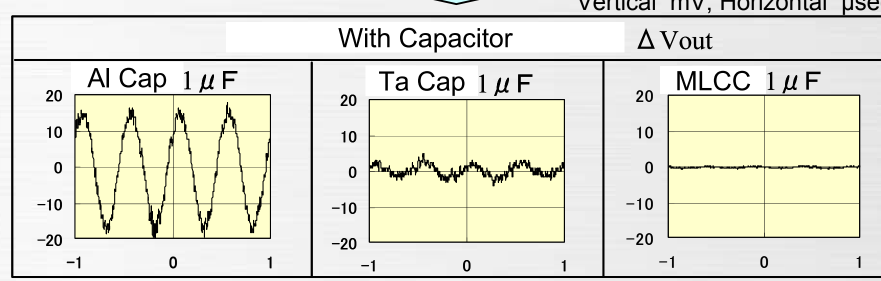
Input capacitor inserted

Vertical mV, Horizontal μsec



MLCC is excellent in noise suppression (low impedance).

Vertical mV, Horizontal μsec

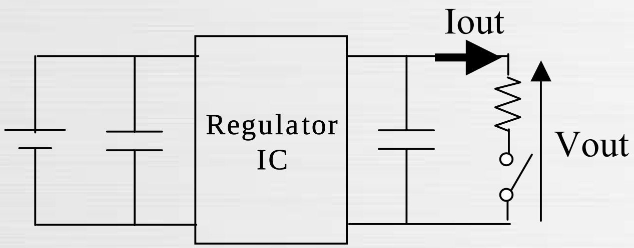


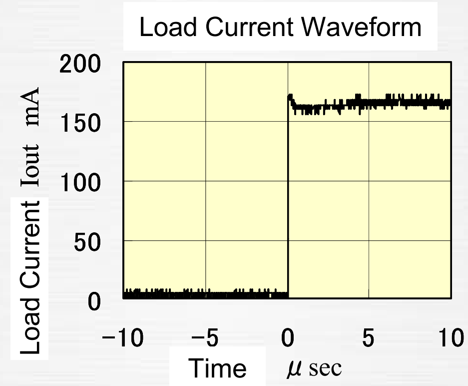
Output fluctuation becomes smaller as IC input voltage stays constant.

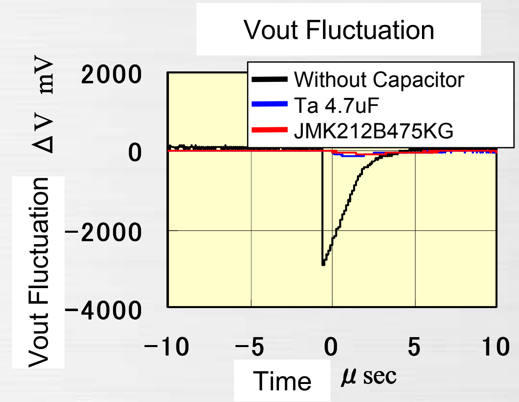
MLCC has lower impedance than that of Ta for a wide range of frequency.
MLCC is suitable for input capacitor.

Summary Operation Analysis of Output Capacitor

Observation of output voltage fluctuation

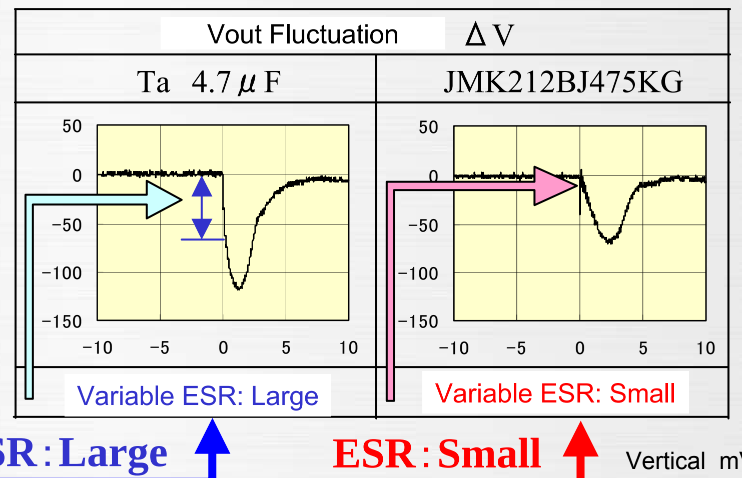




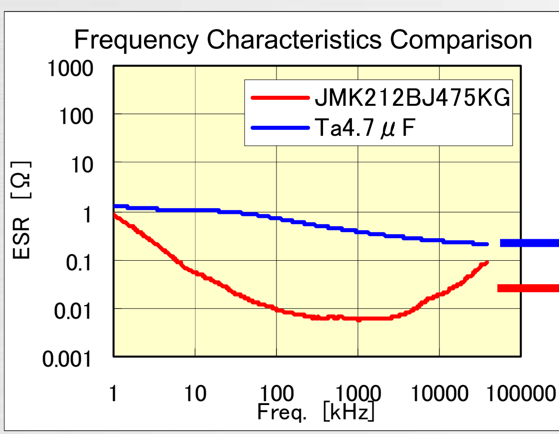


Waveform observation: Iout, Vout
(Observing by the type of output capacitors)

IC used: R1112N331B (Ricoh)
Input Cap: LMK212BJ225KG
Input V: 5V
Switching frequency: 100Hz
Load current: 150mA



Vertical mV, Horizontal μsec



Using output capacitor with low ESR reduces the output voltage drop when load fluctuation occurred.

MLCC with low ESR is well-suitable for output capacitor.

Development Method Direction for ML Lineups and Proposals

Market demand

Circuit segment

Digital circuit

Analog circuit

- Amplifier
- Arithmetic
- Oscillation
- Modem
- Digital
- Power supply

- Logic
- High frequency
- Power supply
- Audio
- Others

Capacitor application segment

Focusing on impedance and ESR characteristics

- Decoupling
- Backup
- Smoothing

- High pressure
- Filter
- Coupling
- Time constant, Resonance

Focusing on the stability of real capacitance, temperature and bias

Required performance

It is for circuit noise suppression and often used in digital circuits.
Low Impedance, Low ESR
MLCC with Y5V characteristic and 0.1-10uF is best suited

It may also be used for a circuit with large load change (CPU), stability of power line and protection of IC.
Low ESR, Low ESL, Low Impedance
MLCC with characteristics of Y5V,X5R,X7R and 0.1-10uF is best suited.

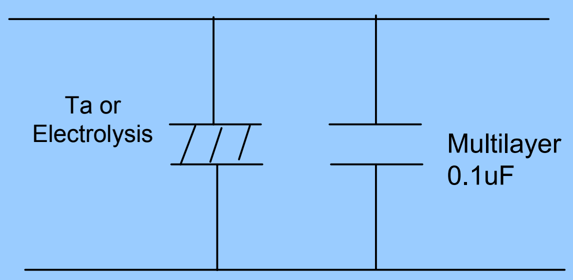
It is for in/output of power supply circuit and more used as the miniaturization of equipment.
Real capacitance, Low ESR, Low ESL, Low Impedance
Rated Voltage and Reliability
MLCC with characteristics of X5R, X7R and 1- tens of uF is best suited.

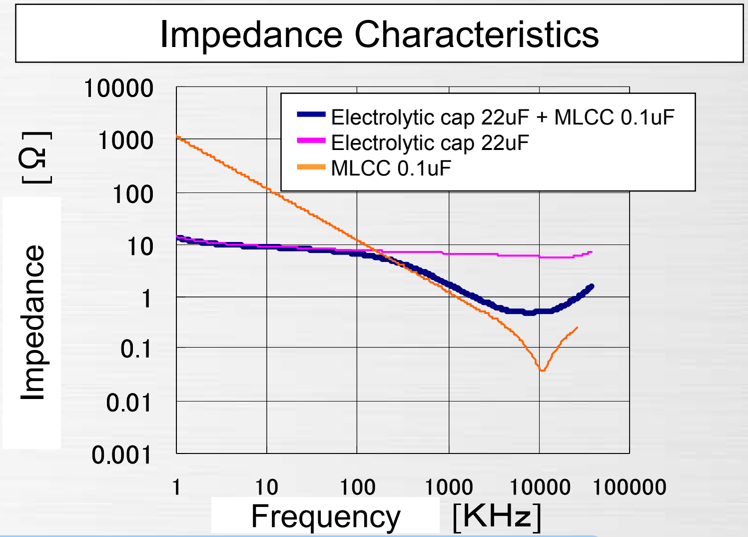
It is for amplifier, arithmetic, modem and filter circuits.
Stability of capacitance temperature and bias is important.
Temperature compensating dielectric type MLCC is best suited.
(CFCAP, TC type multilayer)

Proposal for Bypass Capacitor

Replacement proposal for high capacitance Ta or Al electrolysis with ML 0.1uF

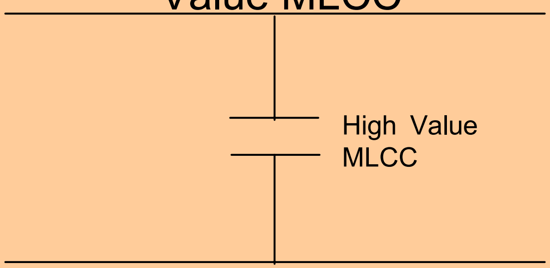
Common Case Example

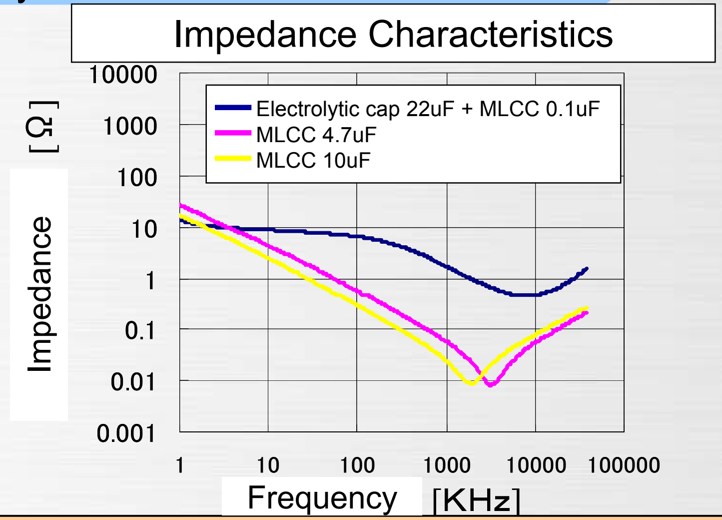




Impedance for high frequency decreases.
→ High frequency characteristic is advanced.

Replaced only by a single High Value MLCC

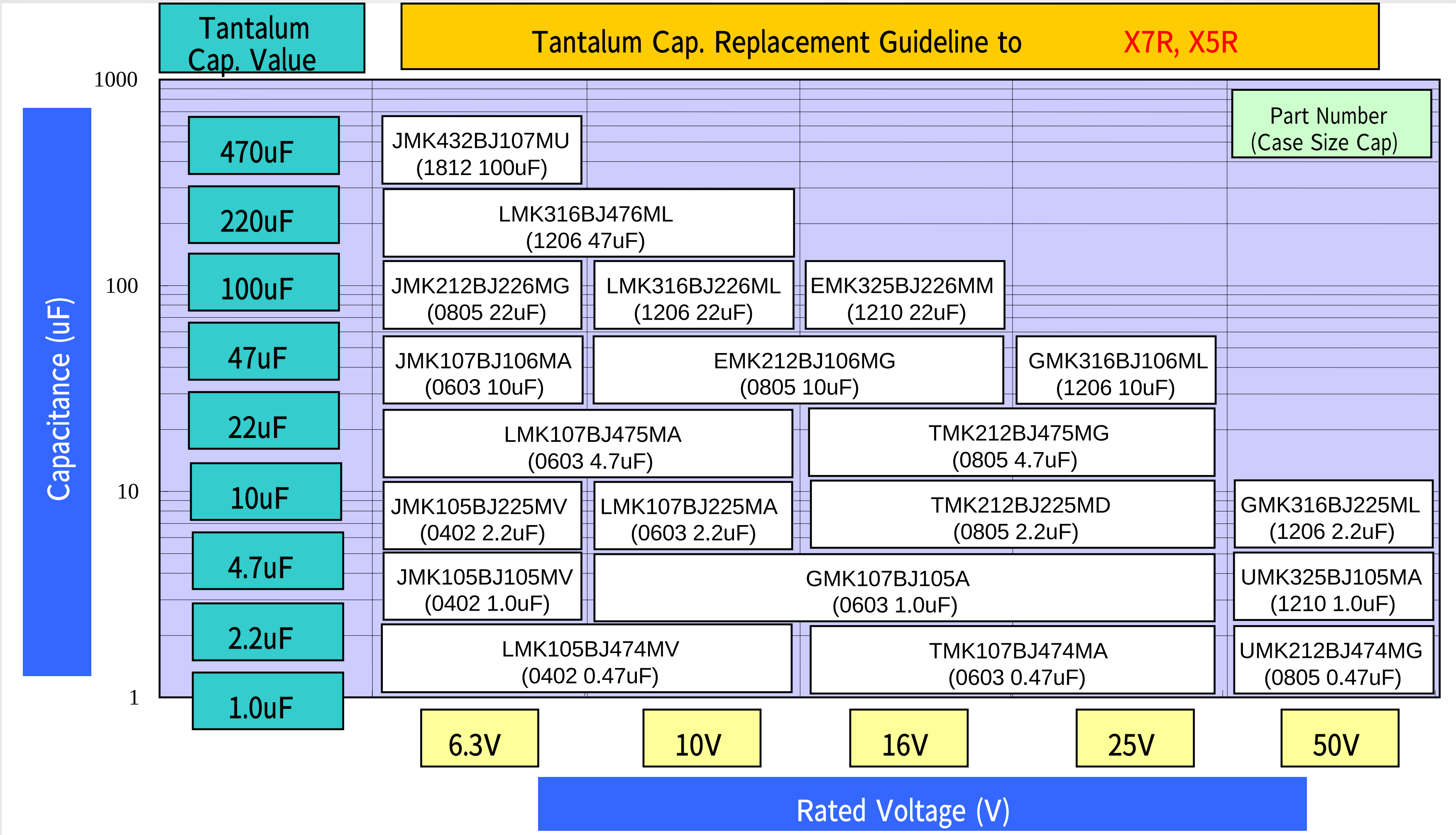




Replaced only by a single MLCC

Wider low impedance range compared with parallel use.

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

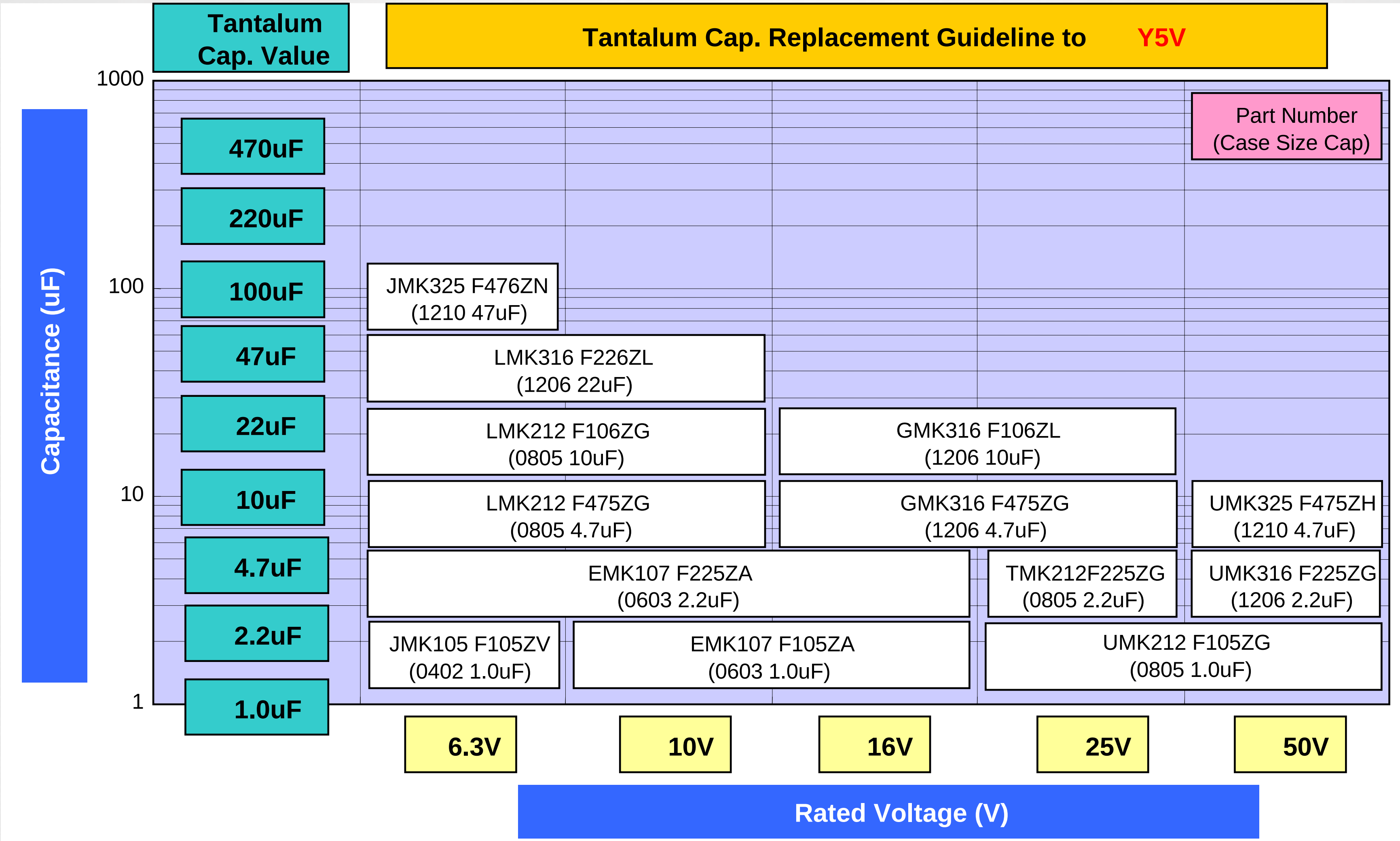


Note: Suggested capacitance value of MLCC may be changed depending on the frequency level of noise.

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.

Ta cap & Al cap replacement guideline to MLCC Y5V

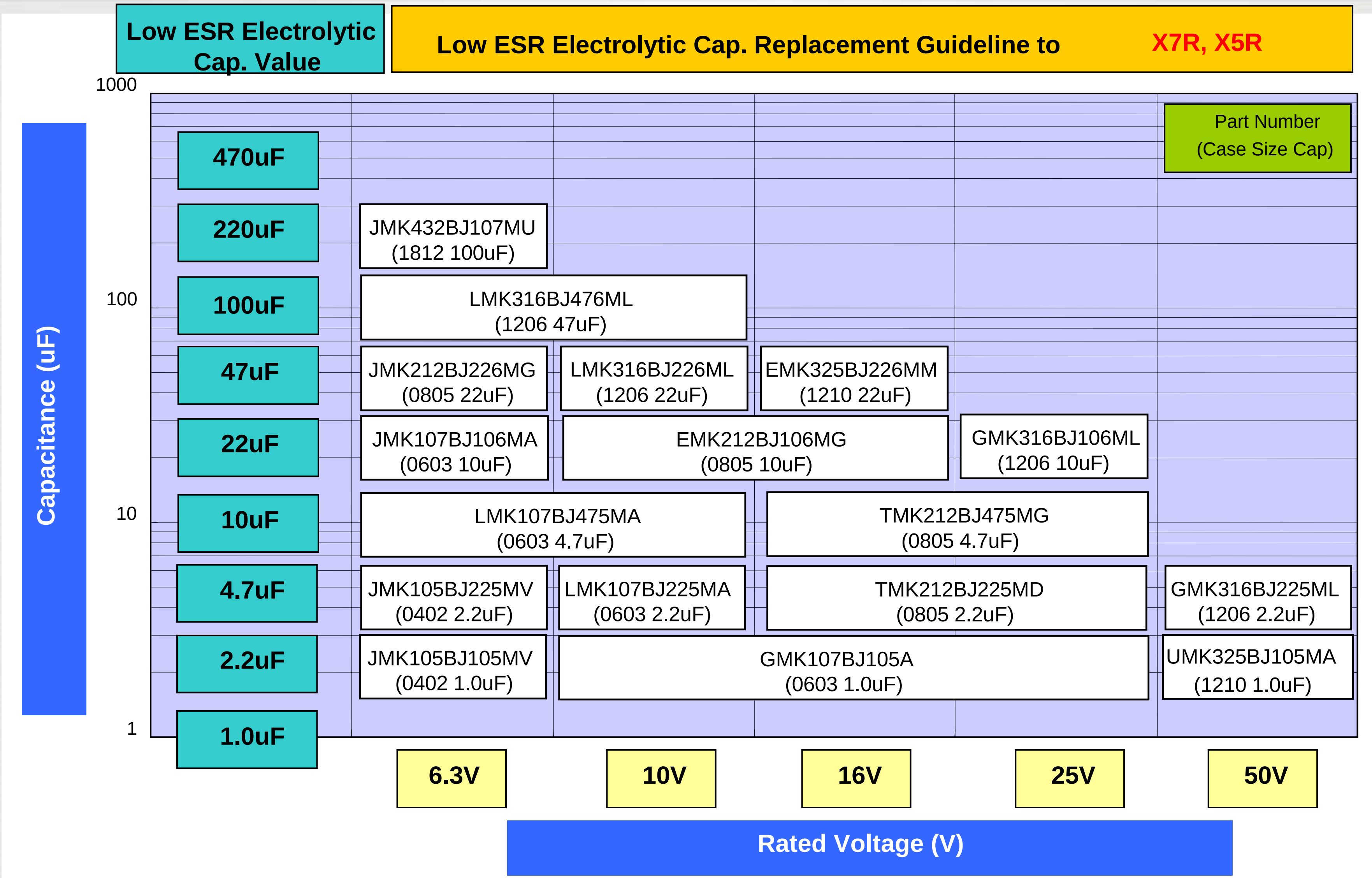


Note: Suggested capacitance value of MLCC may be changed depending on the frequency level of noise.

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

MLCC requires as much as 1/5 to 1/20 of Al capacitors capacitance to replace.

Low ESR Electrolytic 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.

TAIYO YUDEN

- Chapter 2-

Inductor

Impedance of Inductor and Capacitor "Inductive Reactance & Capacitive Reactance"

Ohm's law: (Alternate voltage) = (Impedance) × (Alternate current)

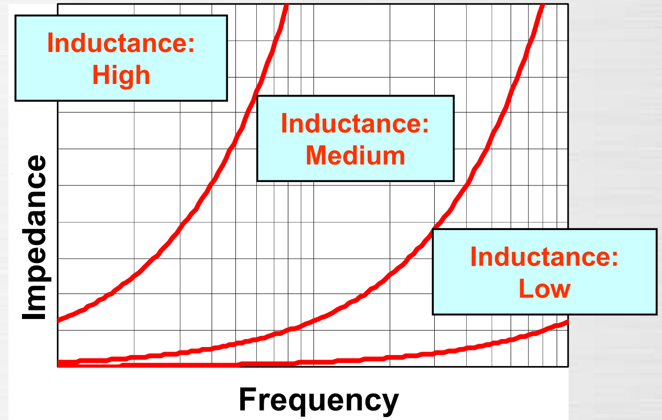
Impedance of pure inductor: inductive reactance: it increases as frequency increases.

Inductance: L

According to the Ohm's law, the impedance of pure inductor is proportional to frequency and inductance.

Frequency : f
Voltage magnitude : VO
V=V0・exp(jωt)

$V = L \cdot di/dt$
Solving for V: $V0 = j2\pi f \cdot L$
Impedance is equal to: $Z = XL = 2\pi f \cdot L$



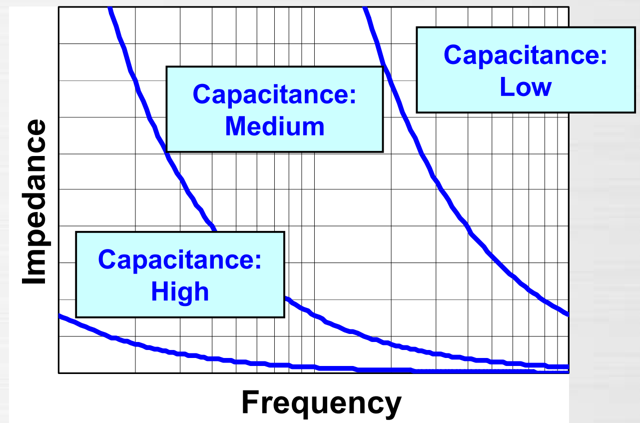
Impedance of pure capacitor: capacitive reactance: it decreases as frequency decreases.

Frequency : f
Voltage magnitude : VO
V=V0・exp(jωt)

Capacitance :C

According to the Ohm's law, the impedance of pure capacitor is inversely proportional to frequency and capacitance.

$V = 1/C \cdot \int i\,dt$
Solving for V: $V0 = 1/(j2\pi f \cdot C)$
Impedance is equal to: $Z = Xc = 1/(2\pi f \cdot C)$

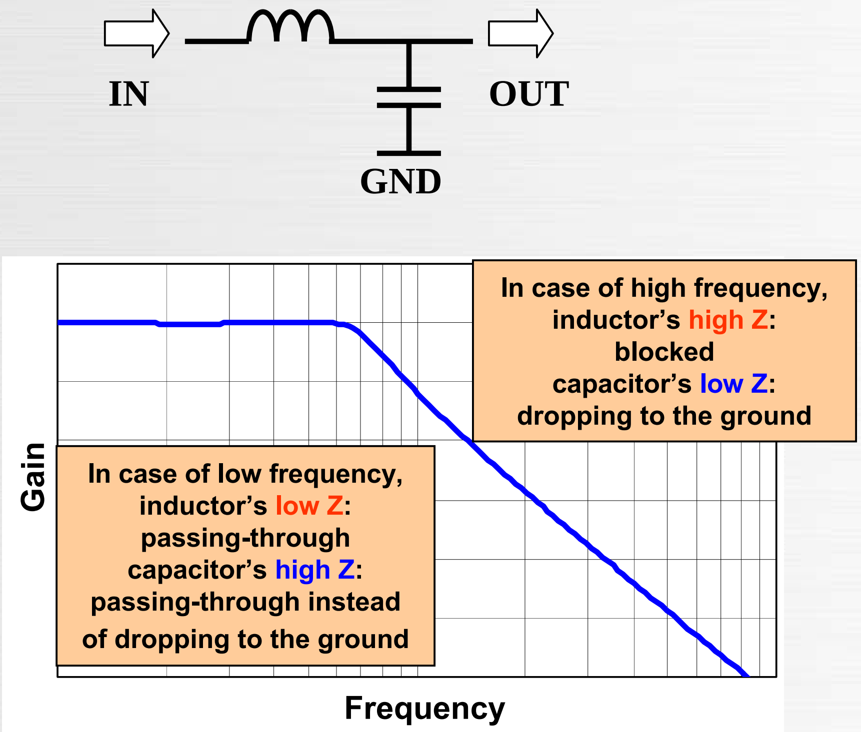


Usage of Inductor and Capacitor: “Low-pass Filter and High-pass Filter”

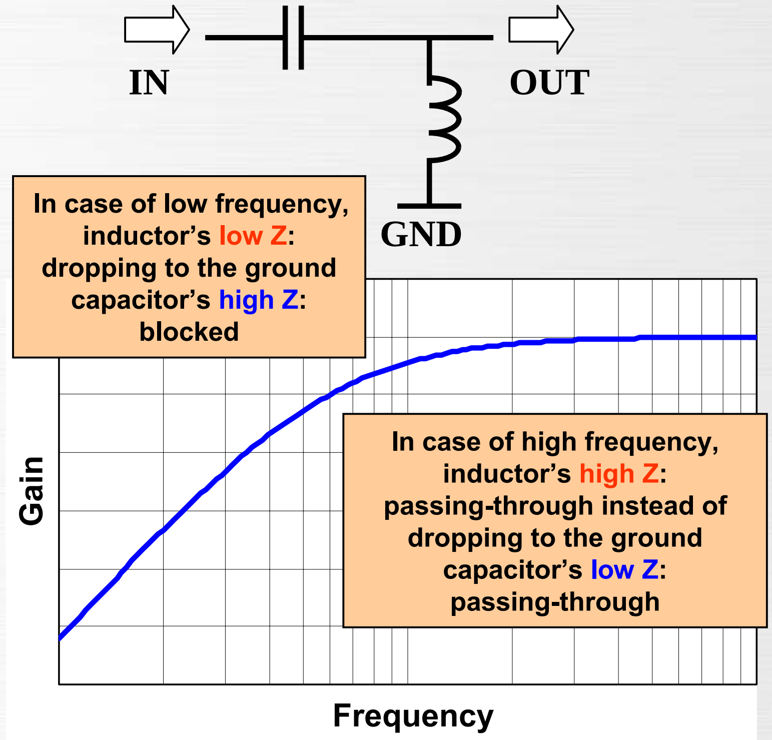
Impedance of inductor: It increases as frequency increases.

Impedance of capacitor: It decreases as frequency increases.

Typical characteristic of low-pass filter



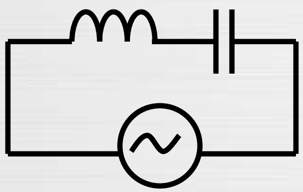
Typical characteristic of high-pass filter



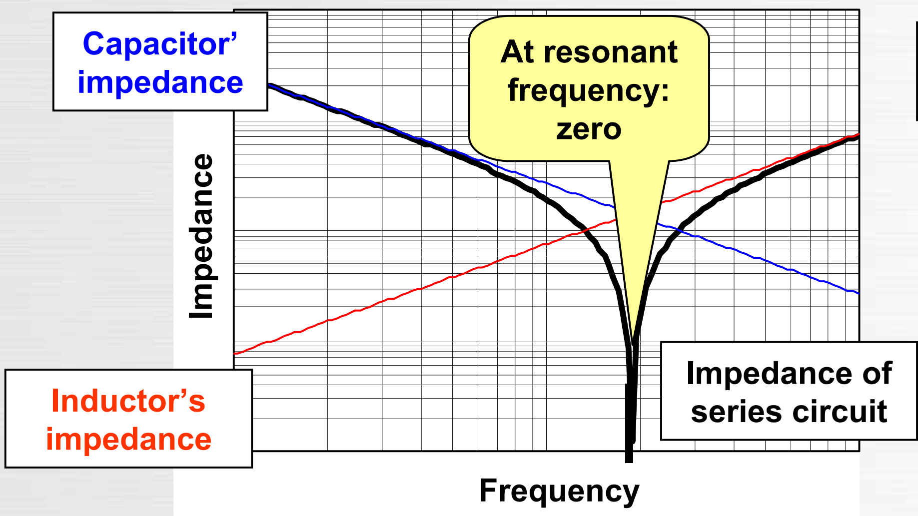
Series Circuit･Series Resonance and Parallel Circuit･Parallel Resonance of Inductor and Capacitor

Impedance of inductor: It increases as frequency increases.
Impedance of capacitor: It decreases as frequency increases.

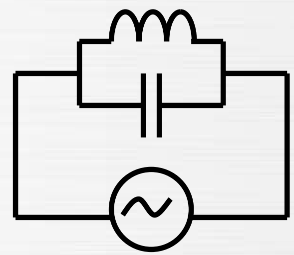
Series circuit of pure
inductor and capacitor:
Series resonance



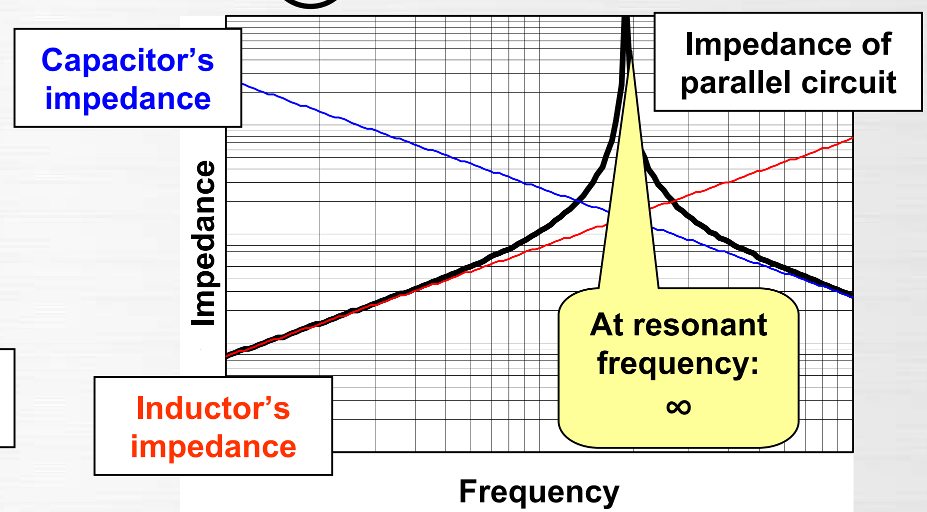
Series circuit:
Basically addition



Parallel circuit of pure
Inductor and capacitor:
Parallel resonance



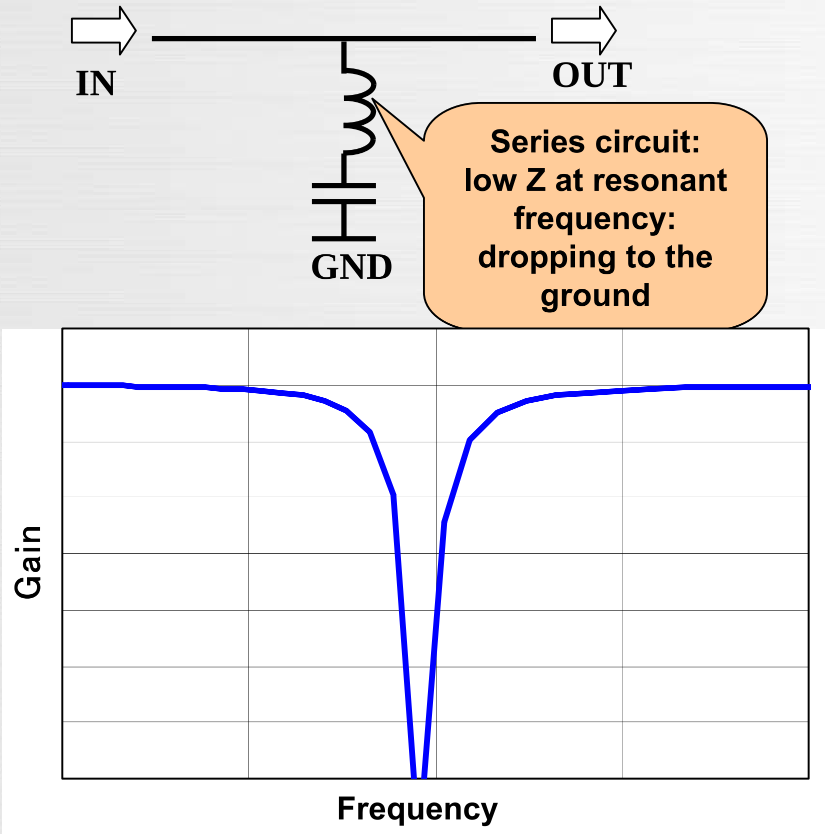
Parallel circuit:
Basically an electric current flows in lower impedance.

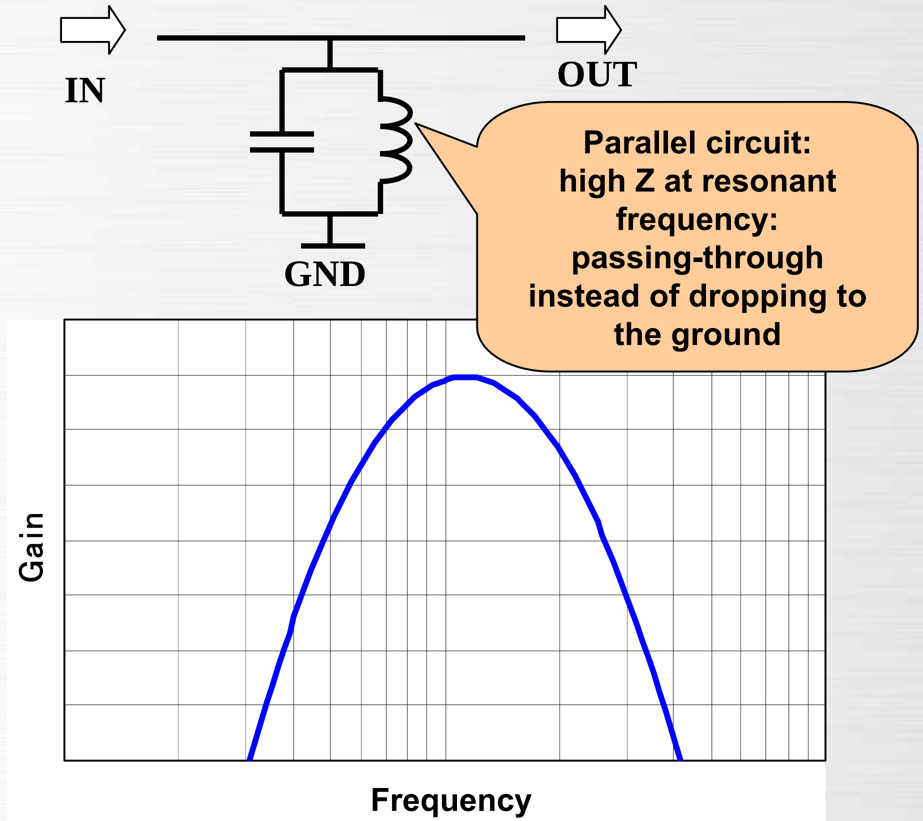


Application of Inductor and Capacitor "Band-pass Filter and Trap Filter"

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

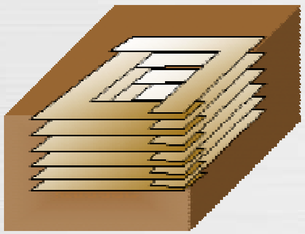
Typical characteristic of trap filter	Typical characteristic of band-pass filter

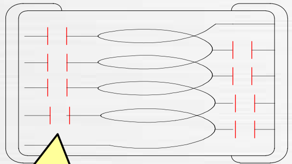




Real Characteristics of Inductor "Self-Resonance Point Characteristic"

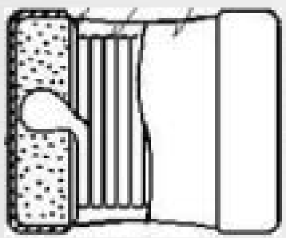
Multilayer inductor

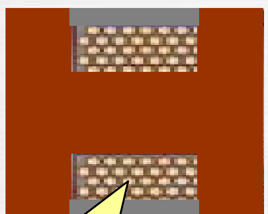




Ex) Stray capacitance existed between internal and external electrode

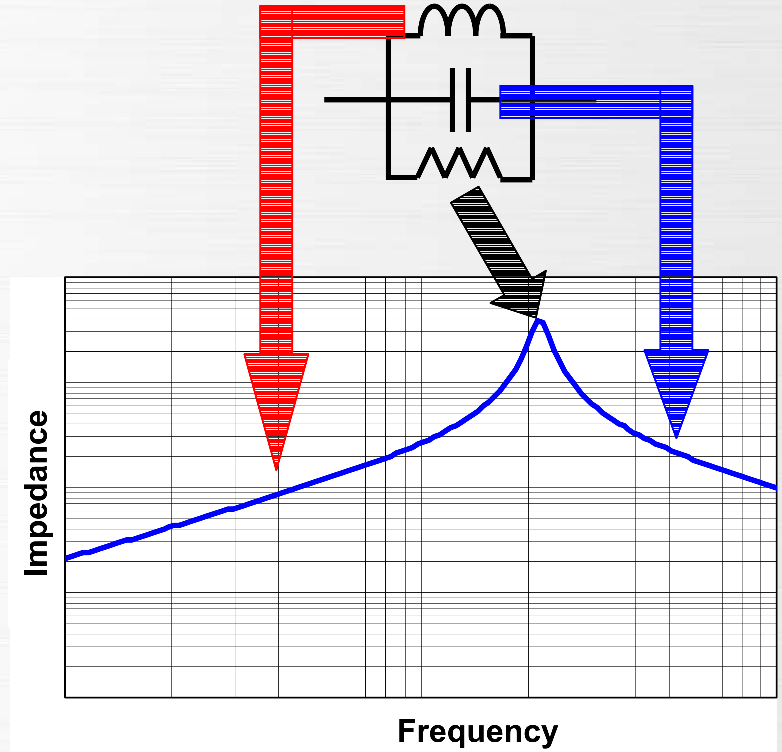
Wound chip inductor





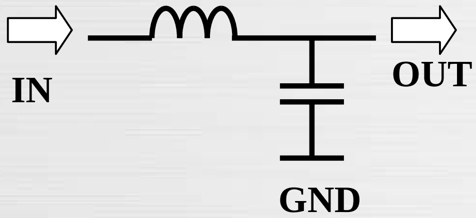
Ex) Stray capacitance existed between winding wires

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

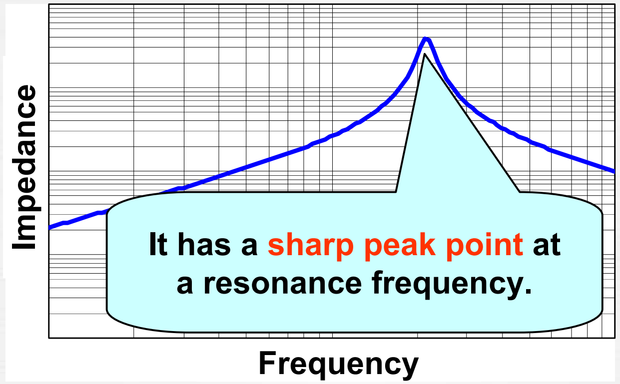


Inductor for the low frequency side,
capacitor for the high frequency side and
at resonance point, impedance is limited.

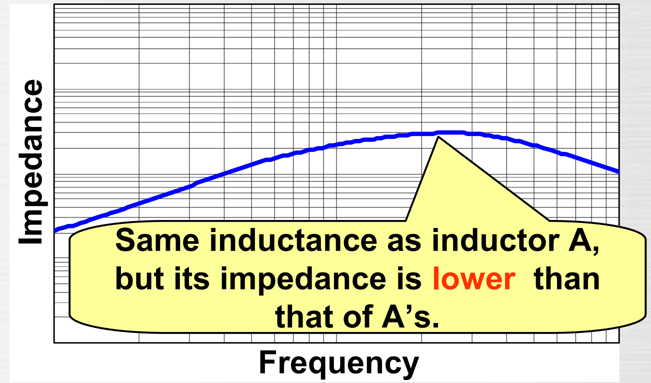
Example of Low-pass filter



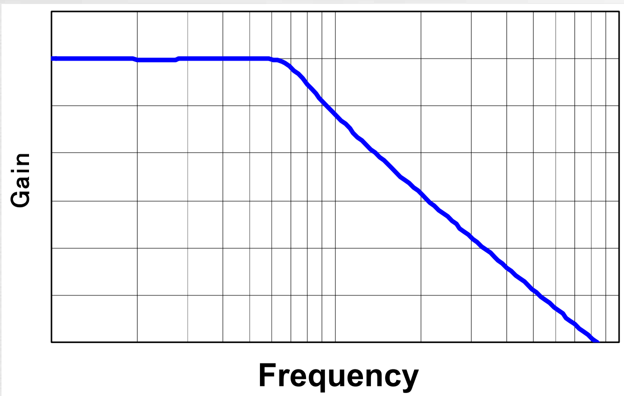
Inductor A: impedance characteristic



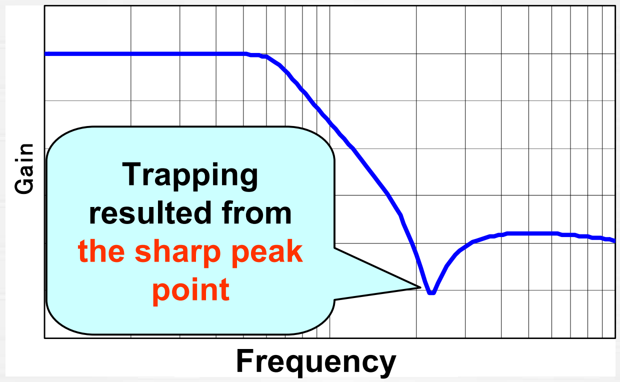
Inductor B: impedance characteristic



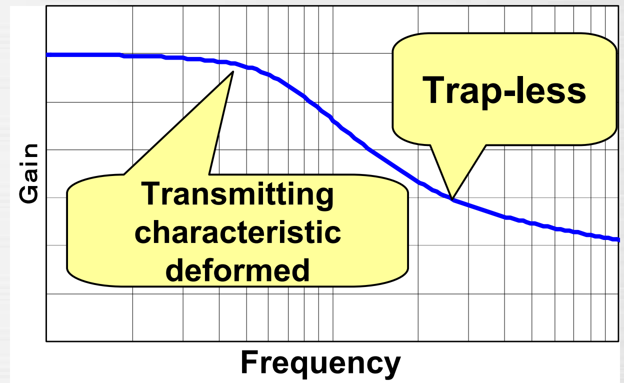
Filter characteristic of pure inductor



Inductor A in use



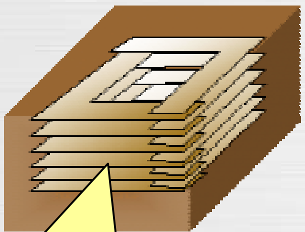
Inductor B in use



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.

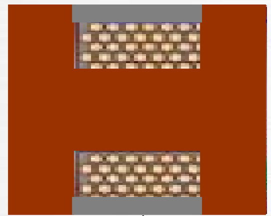
Real Characteristics of Inductor "Lost Elements and Q Characteristic"

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)

R XL

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

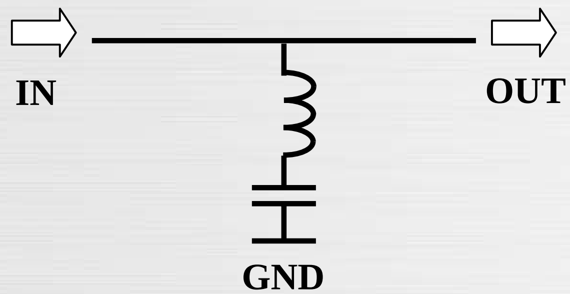
<u>Core materials:</u>
Hysterisis loss, Eddy current loss, dielectric material loss and more …
<u>Internal electrode:</u>
DCR, resistance loss in high frequency zone originated from skin effect and more…
Pure inductor has no loss at all.

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.

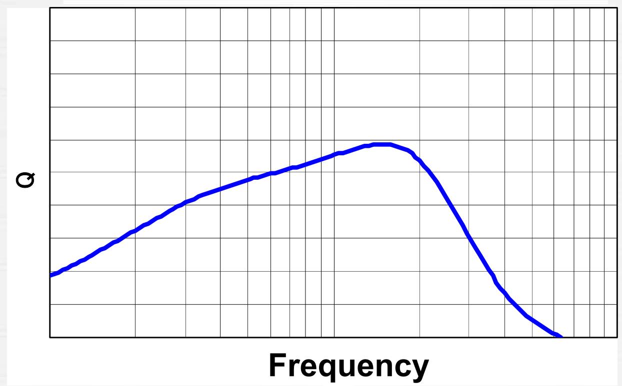
Q Factor and Filter Characteristics of Inductor "Example of How the Difference in Q Factor Influences Trap-Filter Characteristic"

Example of trap filter

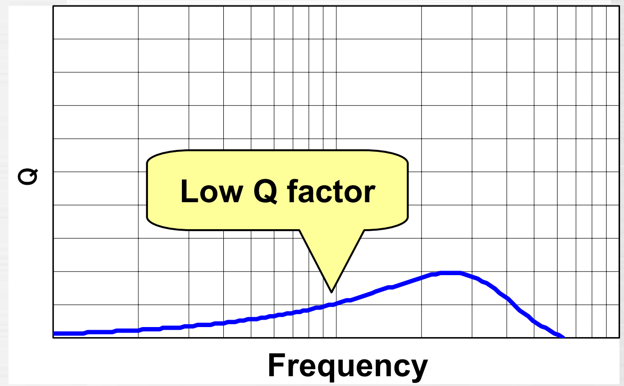
Series resonance of inductor and capacitor



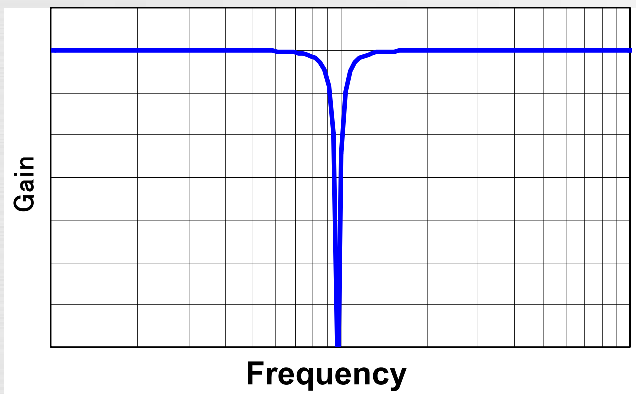
Inductor A: Q factor characteristic



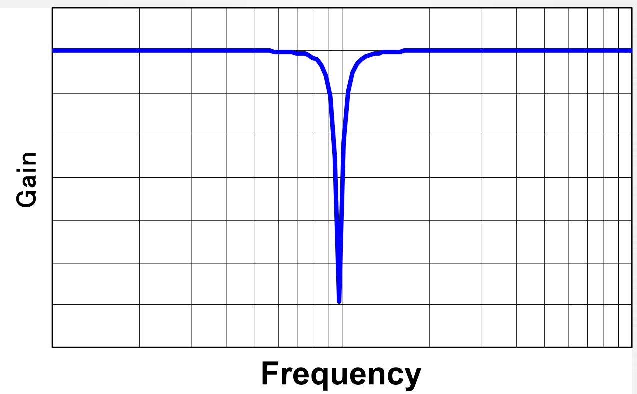
Inductor B: Q factor characteristic



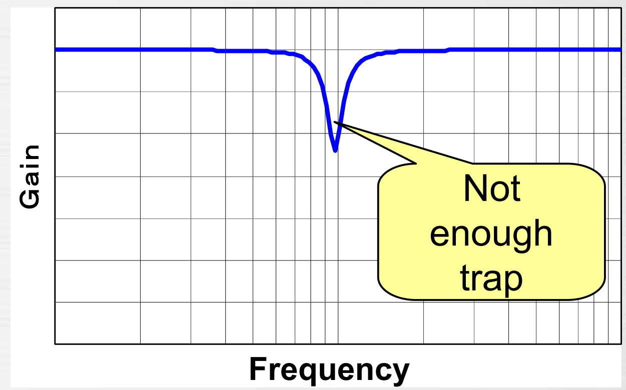
Filter characteristic example of pure inductor



Inductor A in use



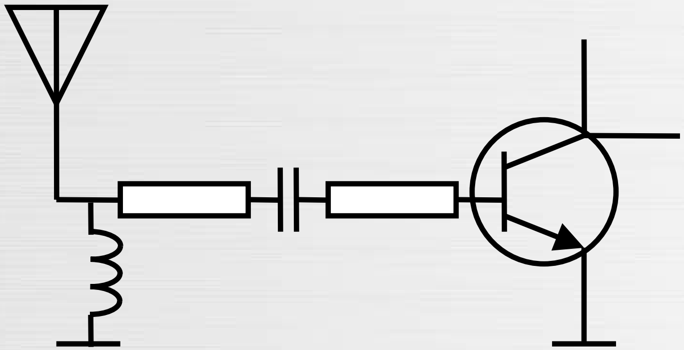
Inductor B in use



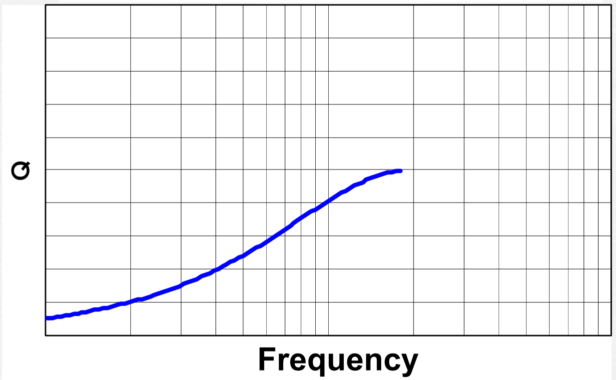
In case of resonance circuit with capacitors, generally inductor's Q factor characteristic has huge influence on the circuit.

Q-Value and Matching Characteristics “Example of How the Difference in Q-value Influences Matching Characteristic”

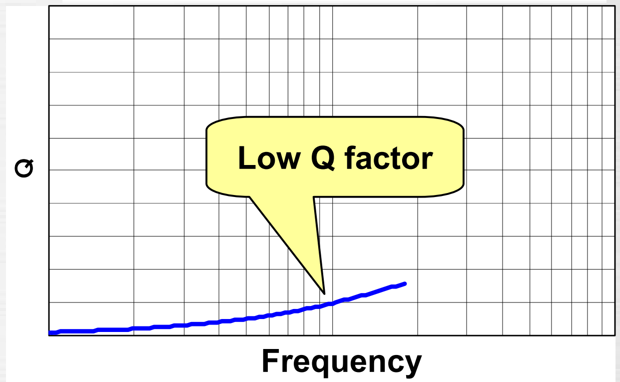
Example of matching circuit
Matching for amplifier and antenna



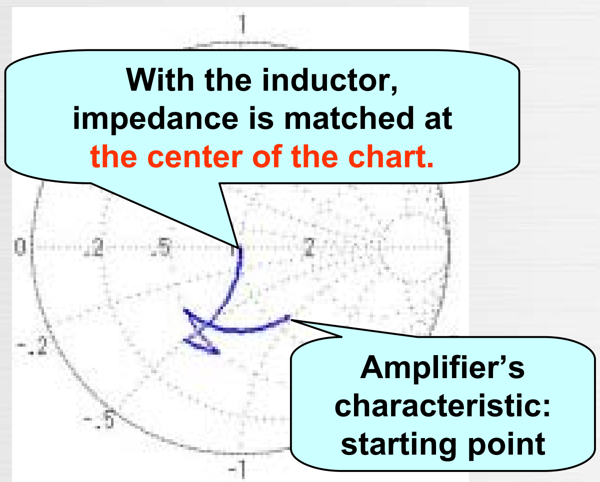
Inductor A: Q factor characteristic



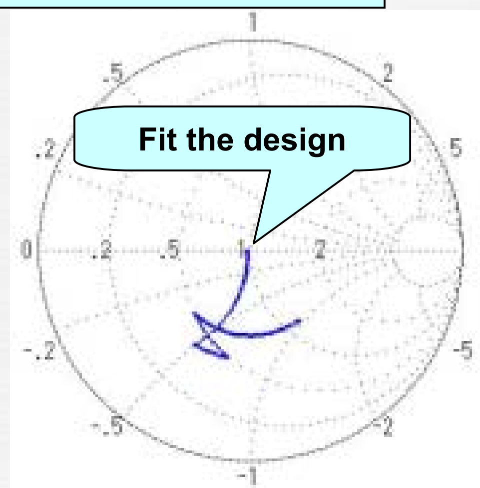
Inductor A: Q factor characteristic



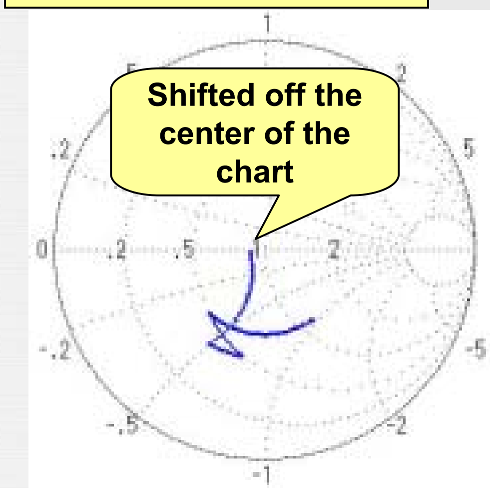
Example of matching design with pure inductor



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)

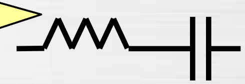
$$Q = \frac{|\text{Inductive reactance}|}{\text{Resistance elements}}$$

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)



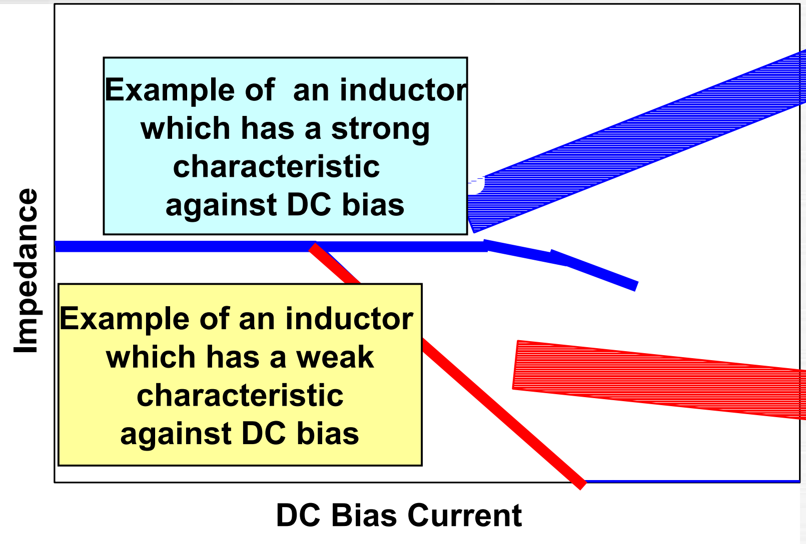
$$\tan\delta = \frac{\text{Resistance elements}}{|\text{Capacitance reactance}|}$$

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.

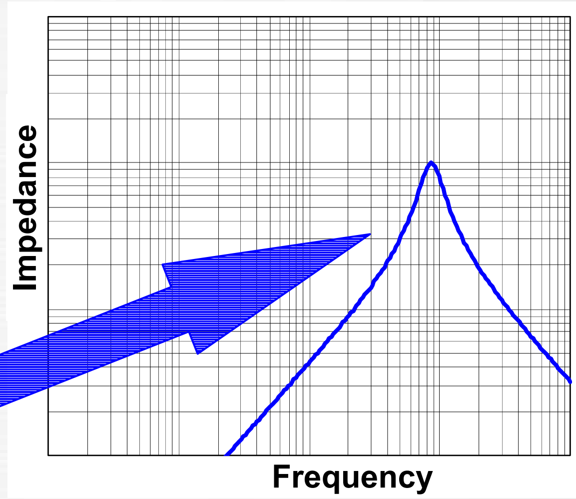
Real Characteristics of Inductor "Example of DC Bias Characteristic"

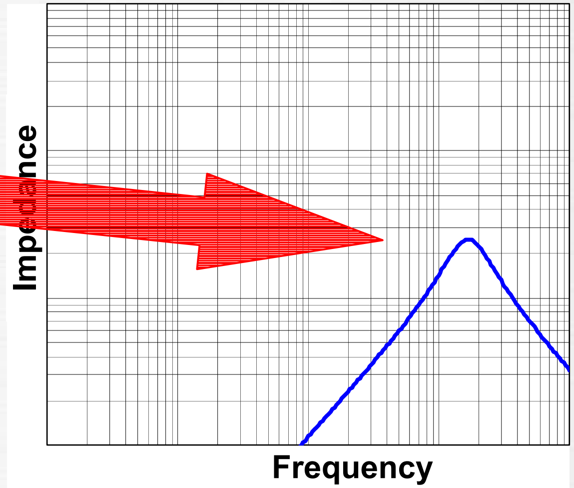
Example of inductor's DC bias characteristic

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



Example of impedance characteristic



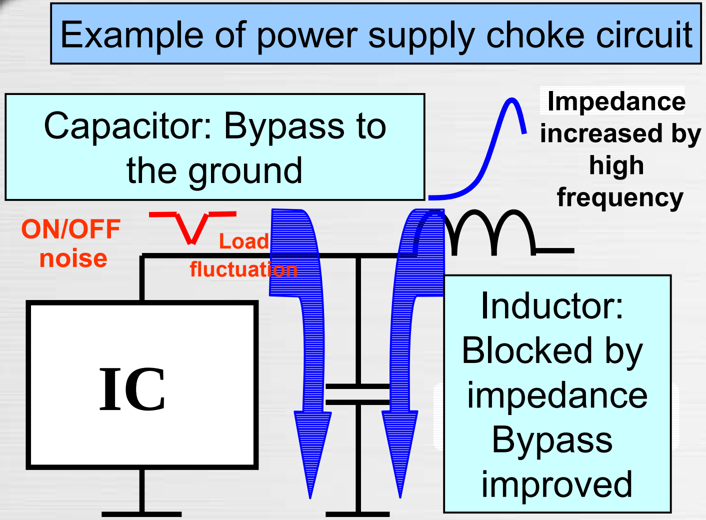


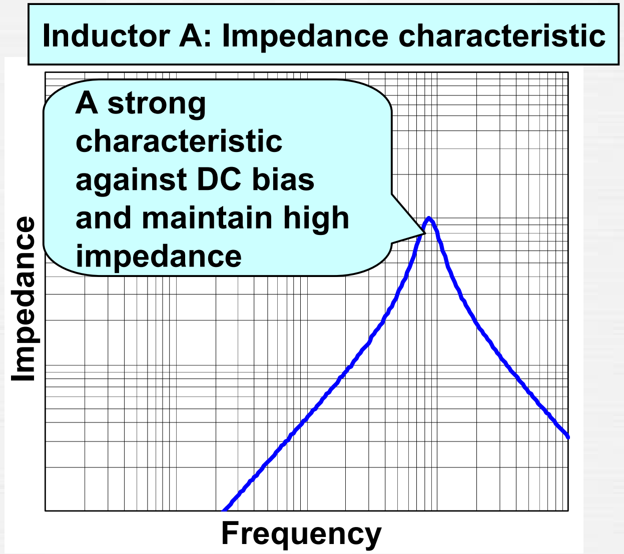
Impedance gets lowered as inductance is dropped by magnetic saturation.

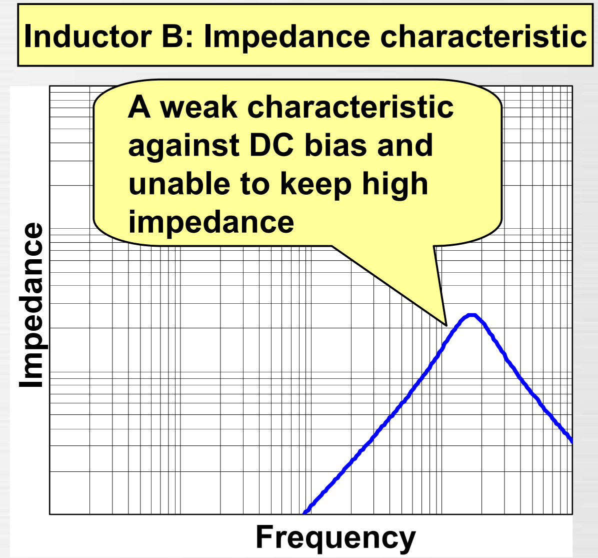
An inductor which has a strong characteristic against DC bias can maintain high impedance level (vice versa).

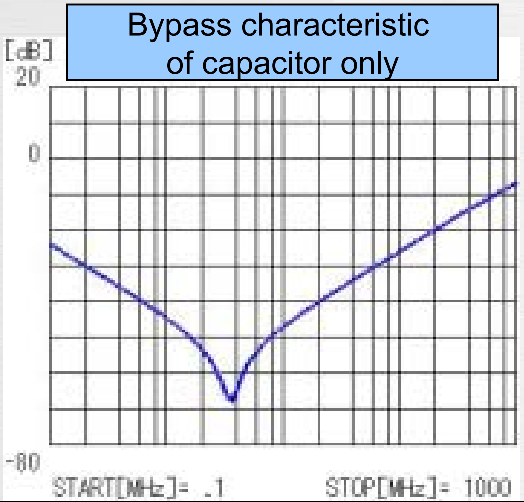
Generally, an inductor is selected based on a margin level for both required inductance and impedance under operational circumstances.

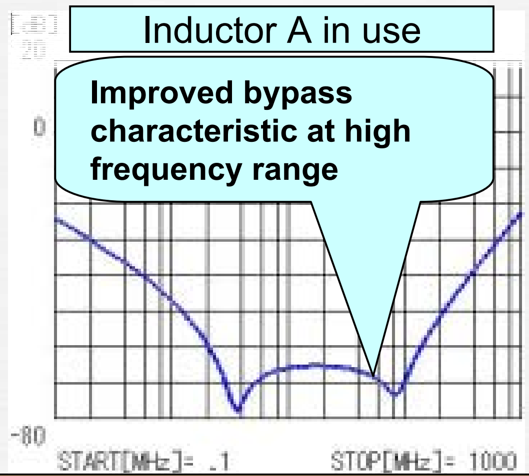
Example of the Influence on Inductor's DC Bias Characteristic in use of Power Supply Choke

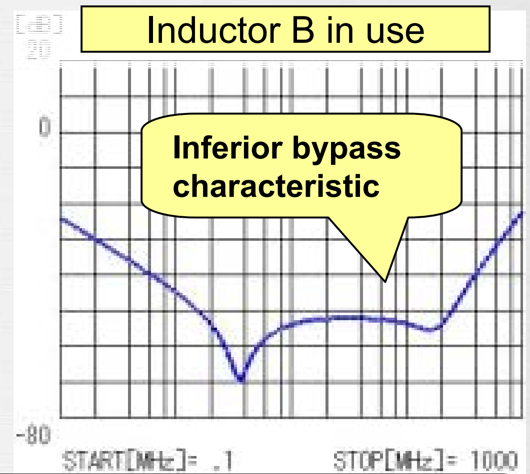








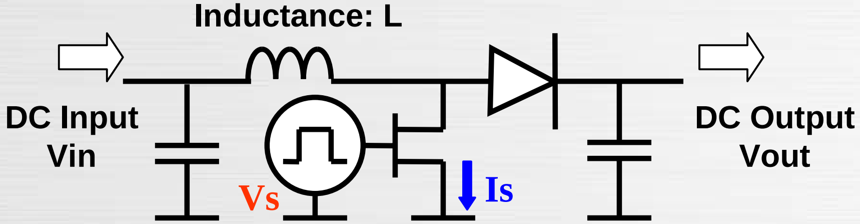




In case of power supply choke application, it should take full advantage of impedance characteristic in terms of designing of bypass circuit. Since impedance characteristic is degraded by DC bias, it should be paid attention to see if the required value left under operational circumstances comparing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

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

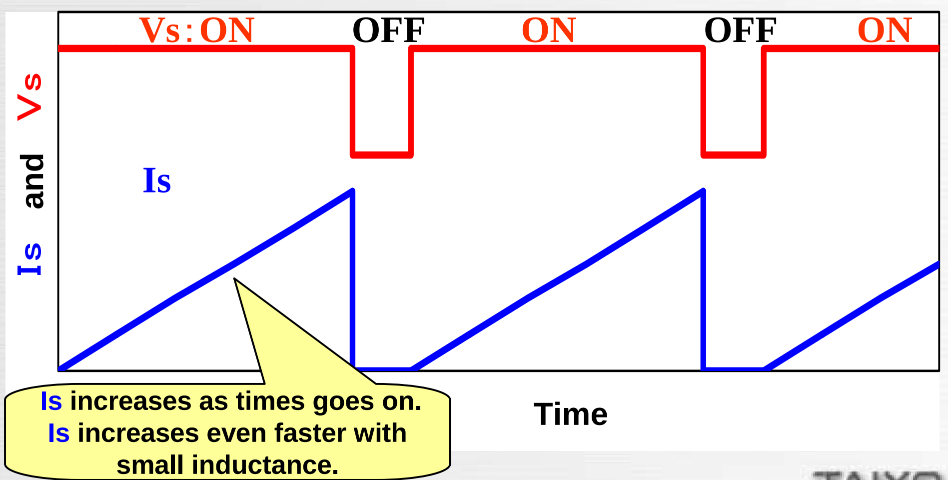
Example of step-up power supply circuit



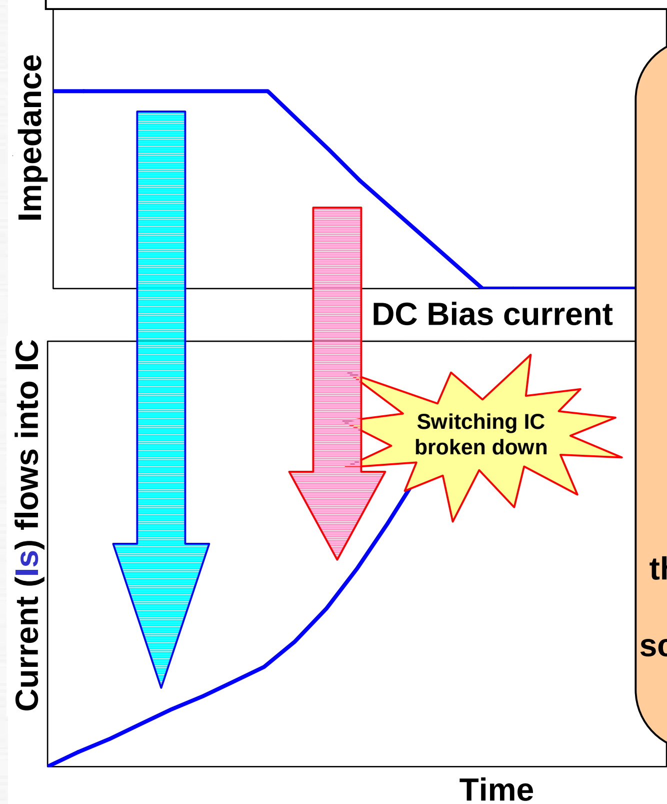
While Vs turned on, Is flows to IC and then voltage is raised by inductor. When Vs being off, it is added onto the input DC and then Output DC is up-converted.

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.

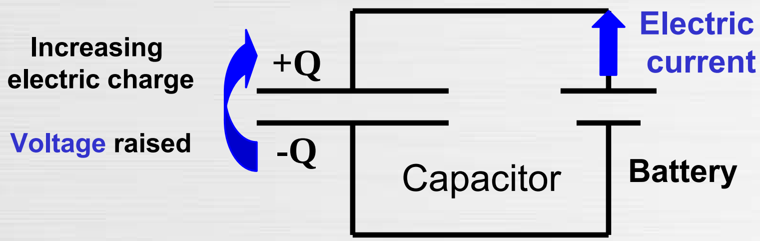
DC bias current passes at some point, inductance drops suddenly.

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

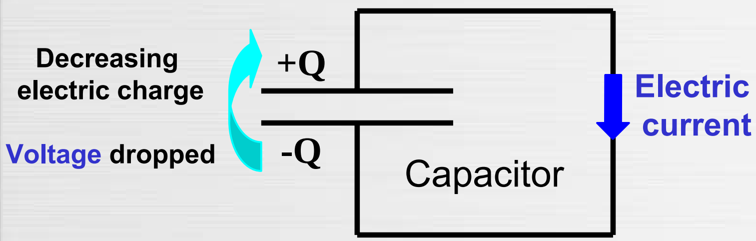
Switching interval is shortened by high frequency power supply IC, and therefore large inductance is no longer needed for IC.
Addition to this, flat DC bias characteristic isn't ideal for all kinds of circuit. It would be better to match a specific DC bias characteristic with IC and power supply demand.

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.

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)

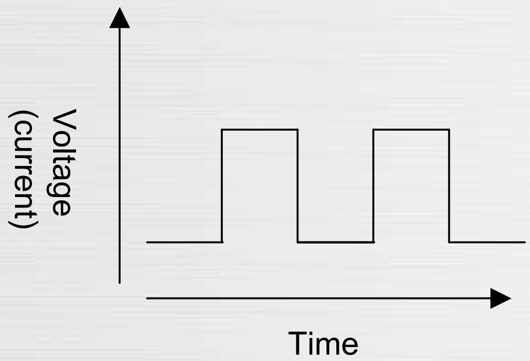
Measurement up to 2GHz is required for an operation between 108 to 500MHz band.

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

Mechanism of Radiation Noise 1

Digital waveform

Measurement system: Oscilloscope



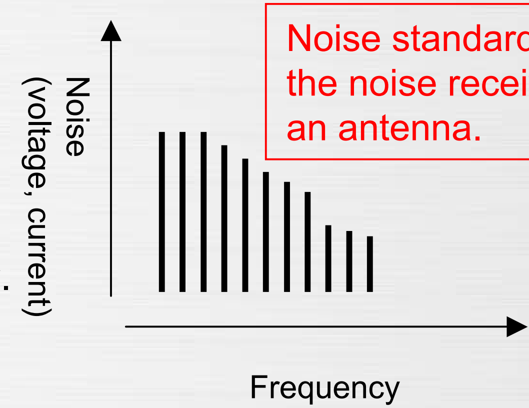
Fourier transform

Time axis is transformed to frequency.

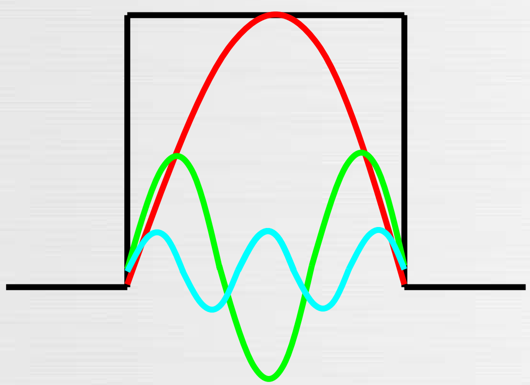
Spectrum

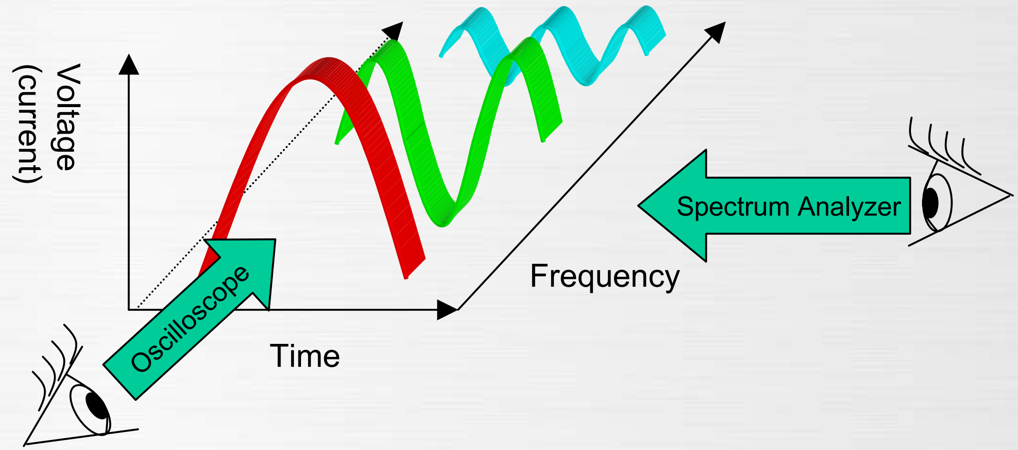
Measurement system: Spectrum Analyzer

Noise standard restricts the noise received with an antenna.



Digital wave is formed by various frequencies.

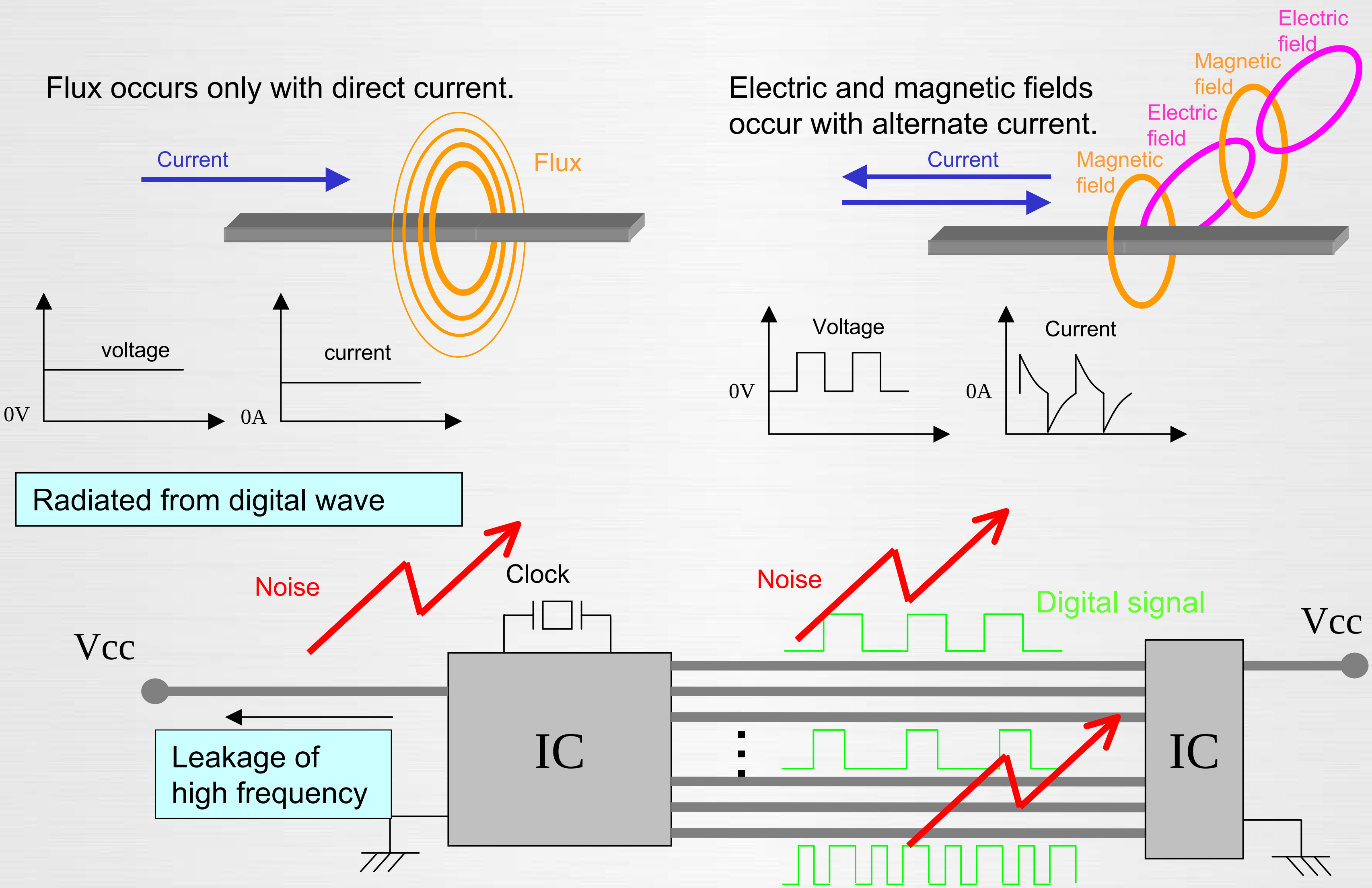




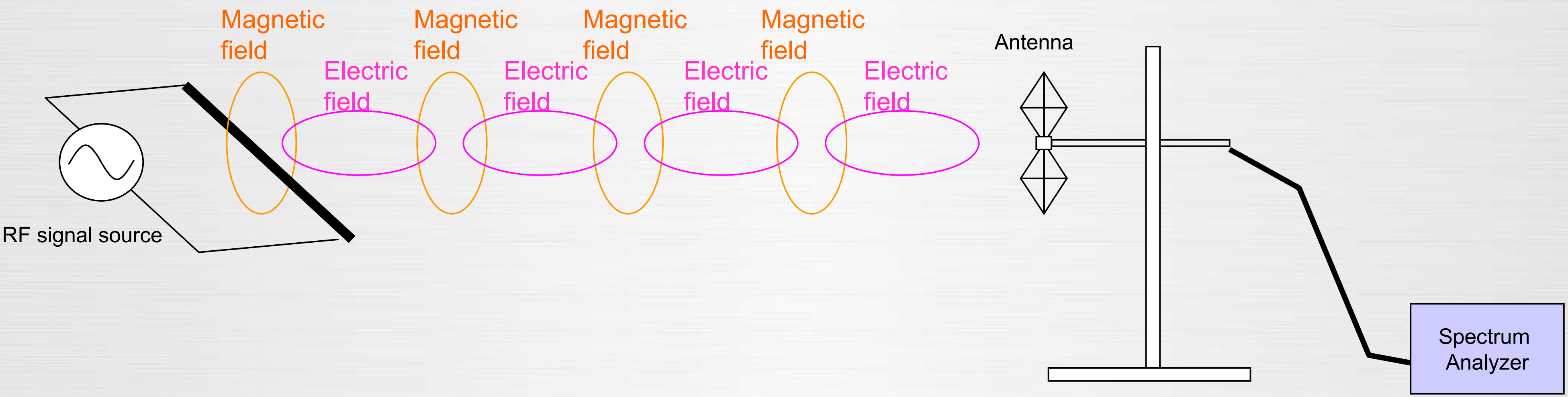
Mechanism of Radiation Noise 2

Flux occurs only with direct current.

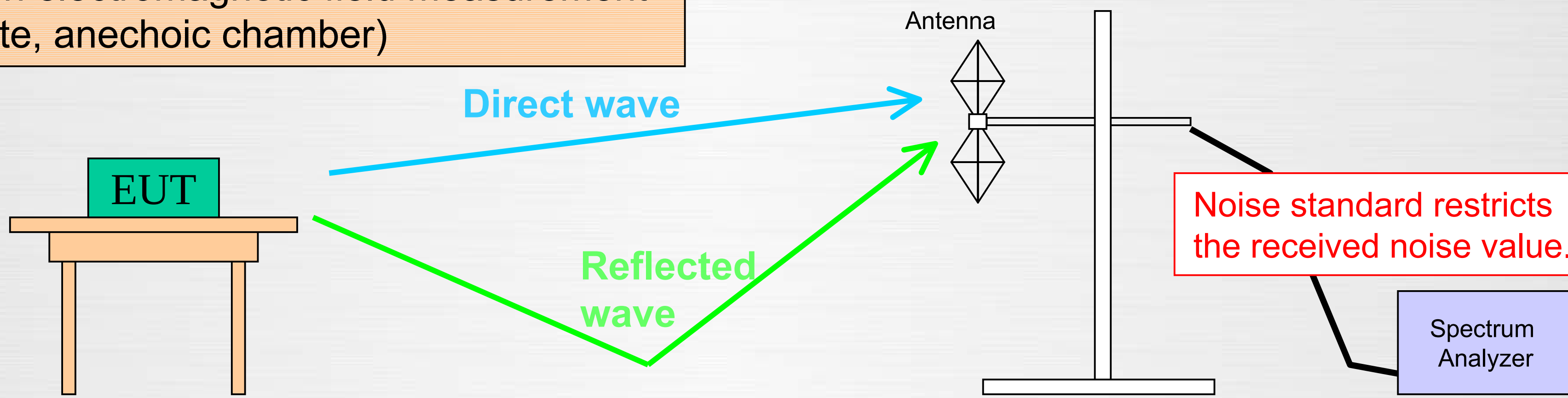
Electric and magnetic fields occur with alternate current.



Mechanism of Radiation Noise 3

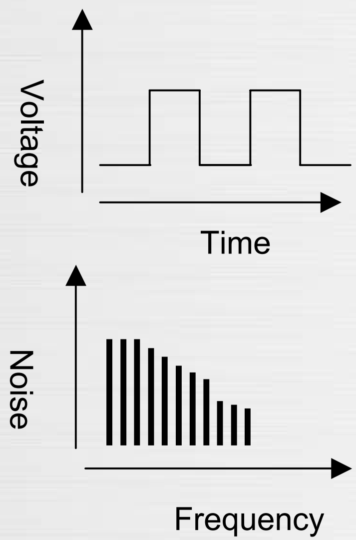


Radiation electromagnetic field measurement (open site, anechoic chamber)

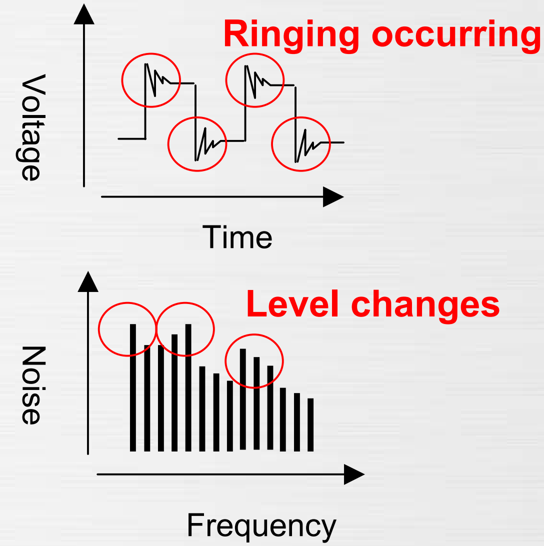


Noise standard restricts the received noise value.

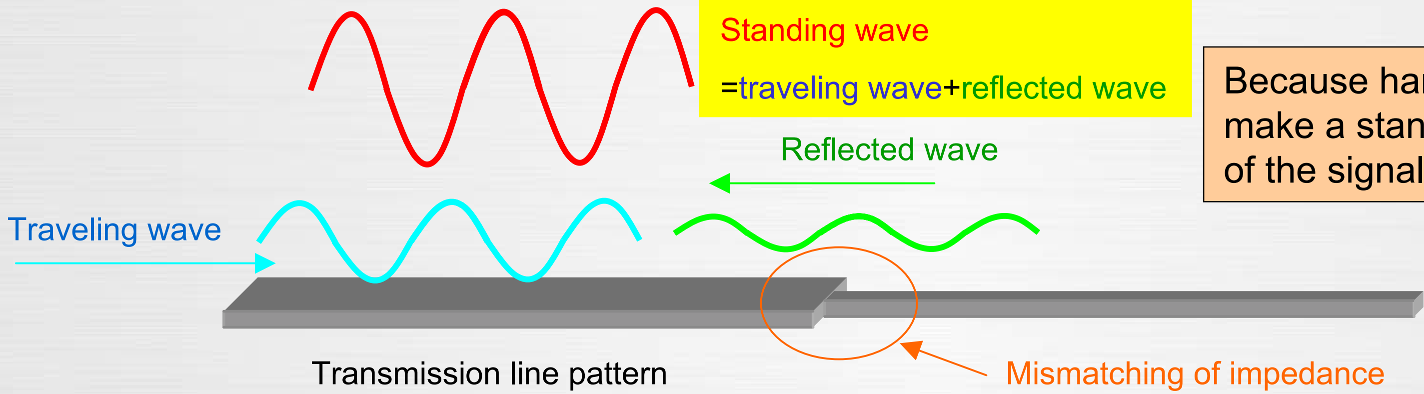
Mechanism of Radiation Noise 4



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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