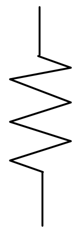
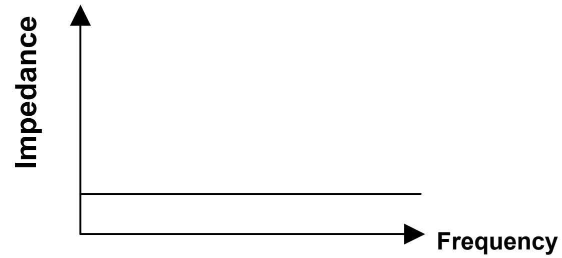
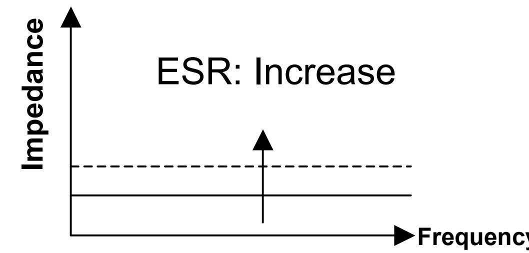
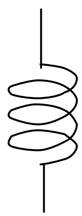
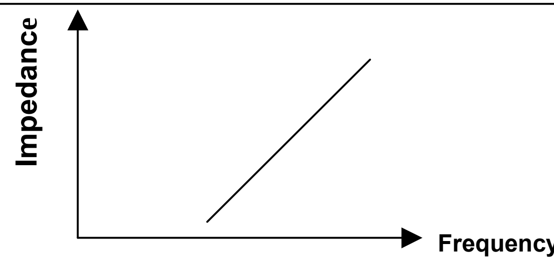
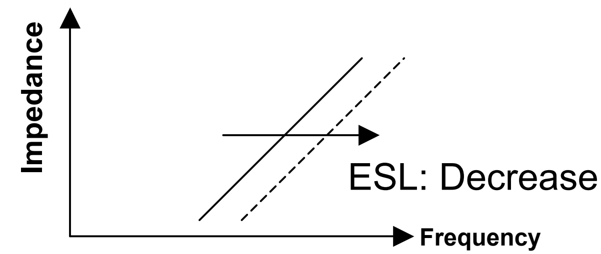
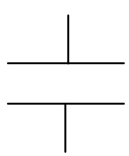
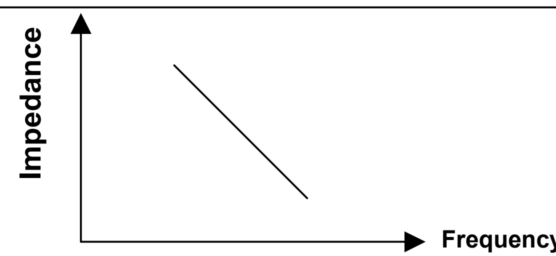
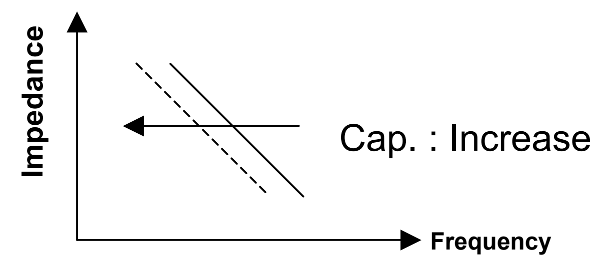
- Chapter 1-

Capacitor

Impedance Characteristics of Capacitor

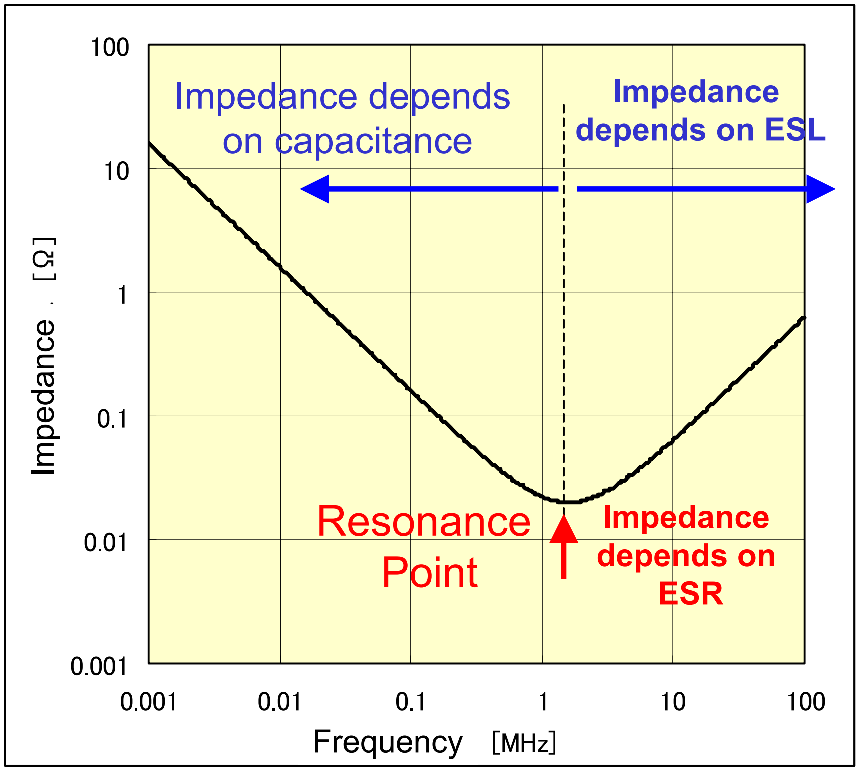
Impedance equivalent circuit with capacitor is the same as the RLC series model.

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?

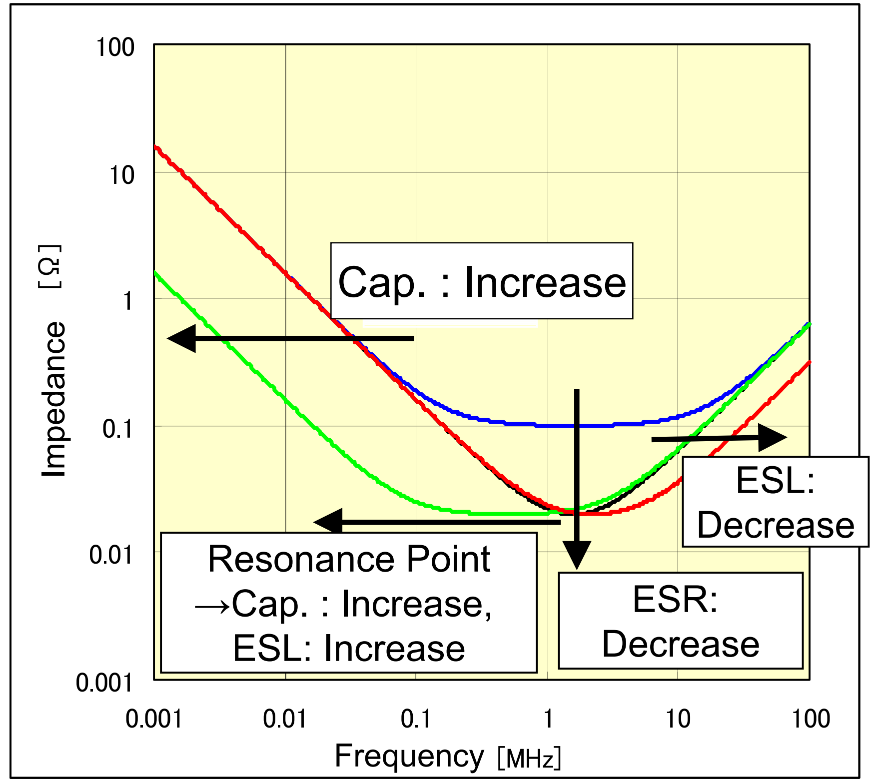
Impedance Characteristics of Capacitor

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

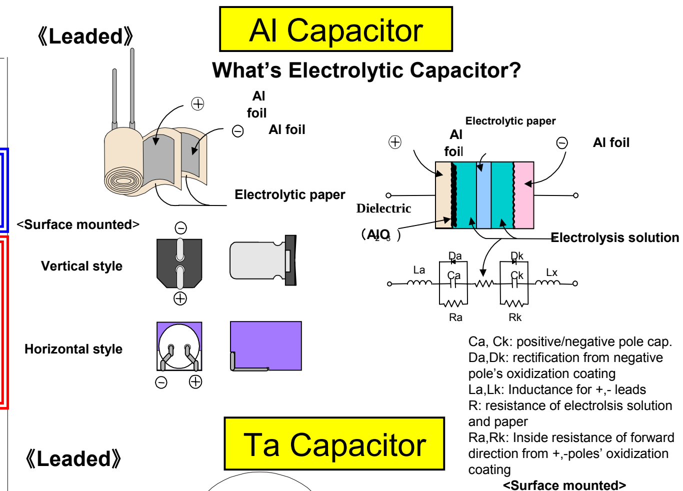


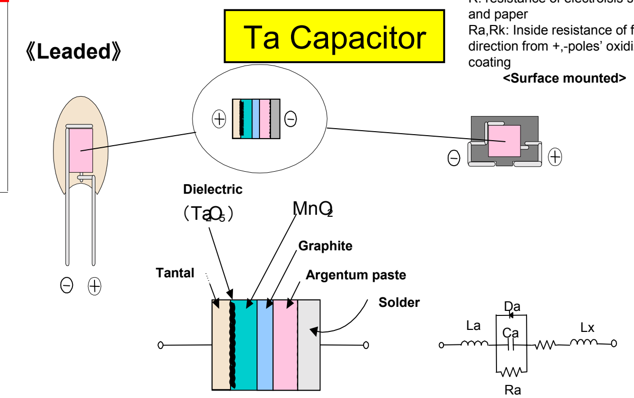
Impedance characteristics vary depended on each element.

Reliabilities of Multi-Layered Ceramic Capacitor

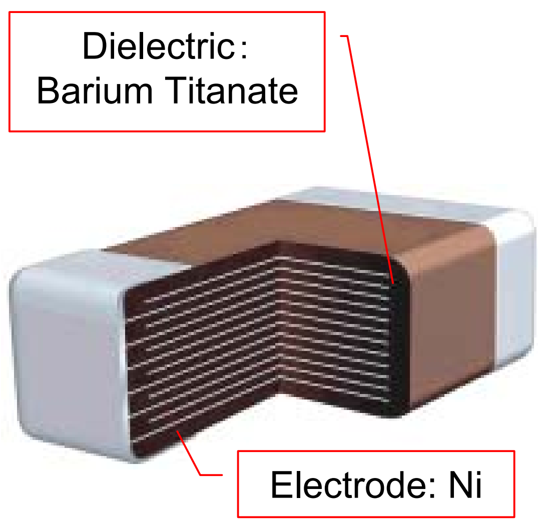
1. Operational condition comparison chart for Circuit

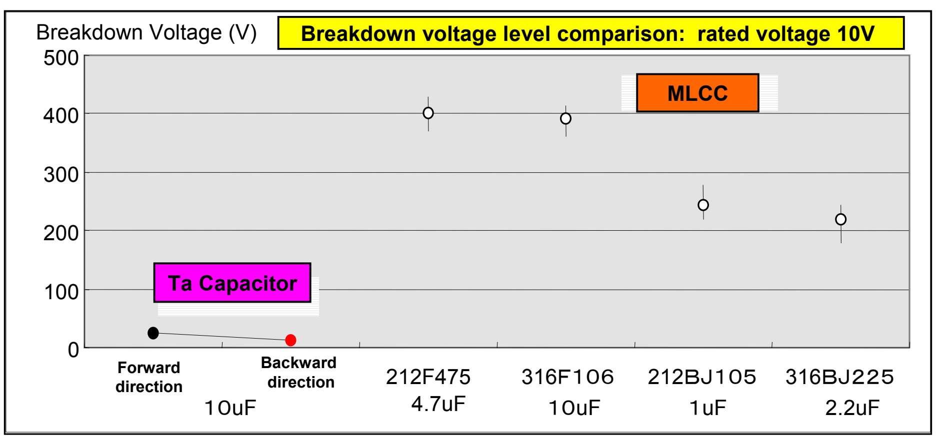
	Polarity	De-rating	Ripple CU. Limitation	Heat Resistance	Solvent Resistance	Loading Test
MLCC	No	◎	◎	◎	◎	◎
Ta Cap.	Yes	×	△	×	△	×
Al Cap.	Yes	×	×	△	×	△
Application Problems	*Layout *Polarity exam When mounting *Reverse voltage Consideration	*Operational limitation for rated voltage (70～50%level)	*Have 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





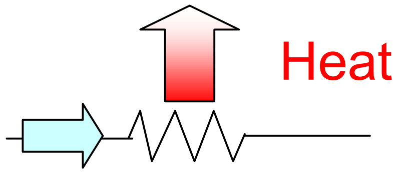
Ceramic Capacitor





Characteristics Comparison for the Different Type of Capacitors

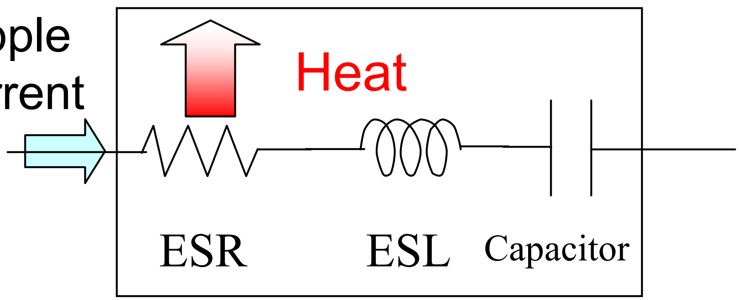
Ripple Current Characteristics



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

Capacitor

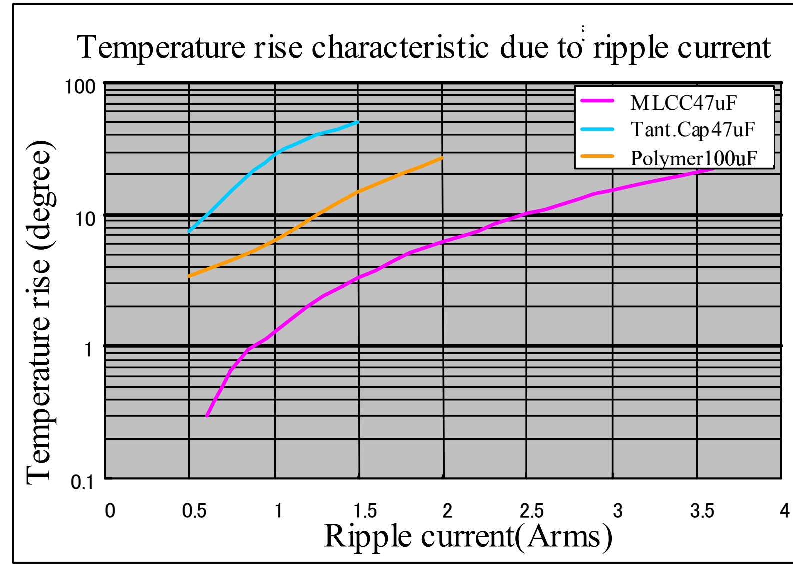
Ripple current



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.

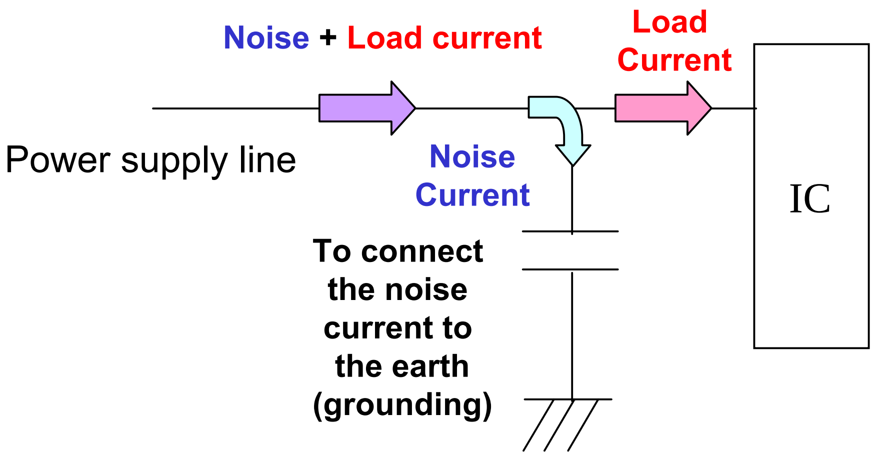
Operational recommendation of heat release value for MLCC is within 10℃.
There is no limitation of allowed ripple current for MLCC.

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



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.

The principle of operation for Bypass Capacitor

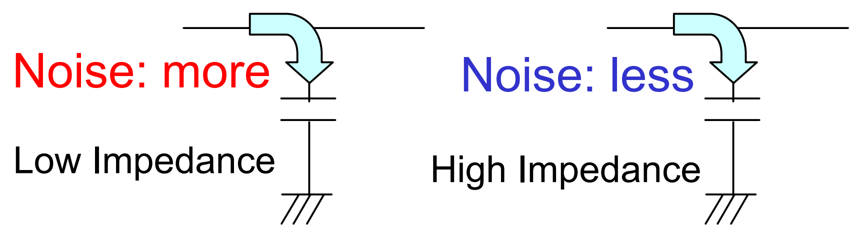
DC does not go through the capacitor
(Impedance:∞)

DC is supplied directly to IC

AC (noise) does go through the capacitor

AC (noise) is grounded

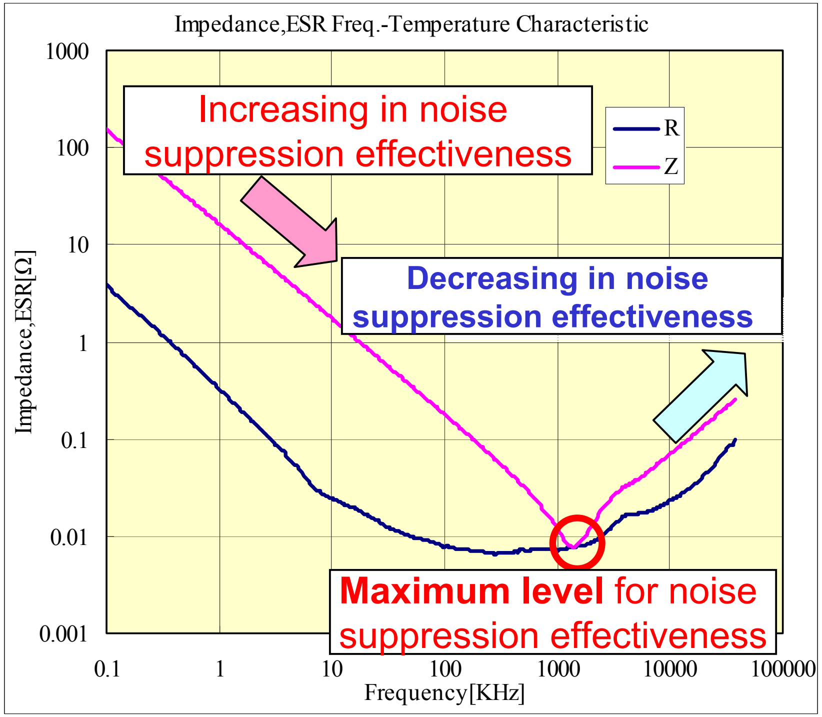
Noise Suppression → Stabilize IC operation



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

The Functions of Bypass (decoupling) Capacitor

Selection Criteria for Capacitor



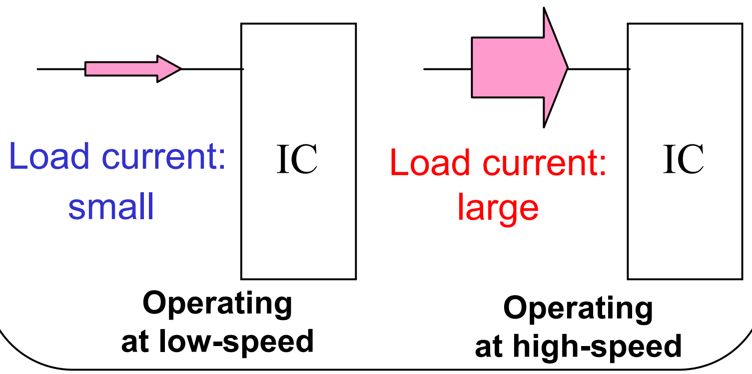
Several kinds of Noise Frequencies

Select a Capacitor based on noise frequency needs to be eliminated

The Functions of Backup Capacitor

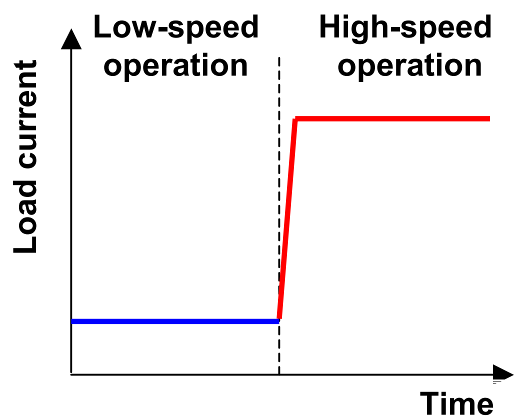
Load current to IC

Load current doesn’t stay constant.



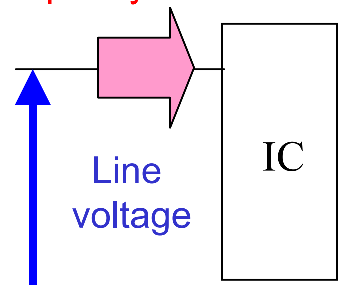
High-speed load change

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

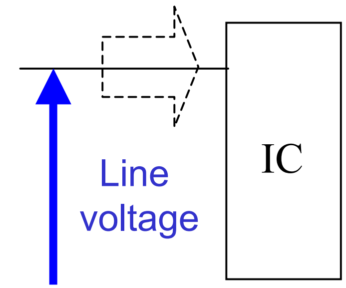


Power line for high-speed load changing

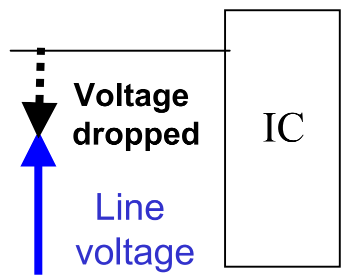
Large load current is quickly needed.

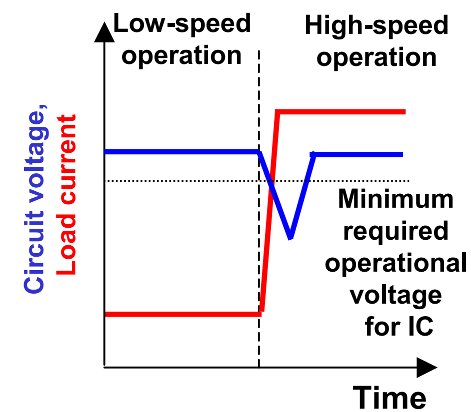


The current can’t flow to IC quickly enough.



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



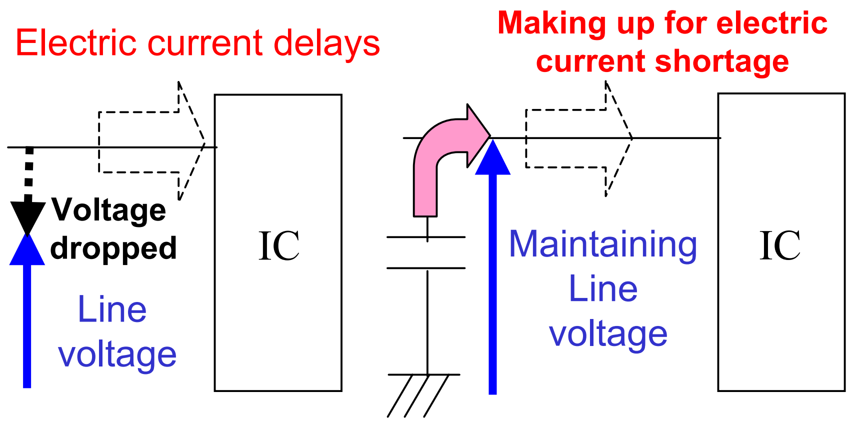


Line voltage decreases below the required operational voltage for IC.

The IC stops its operation.

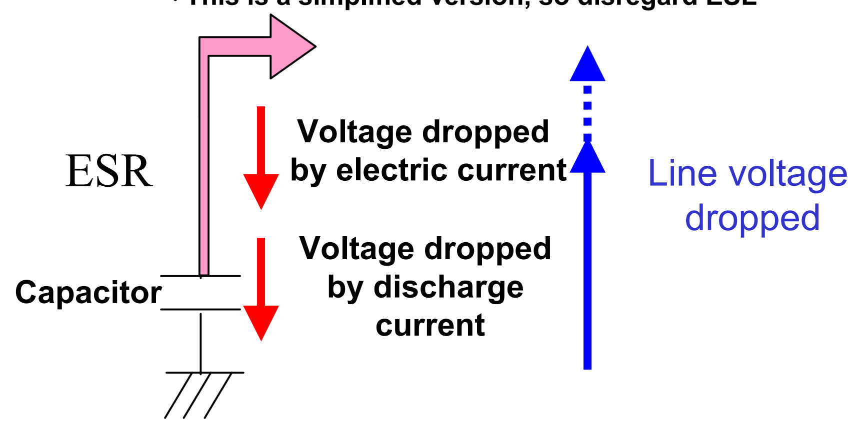
The Functions of Backup Capacitor

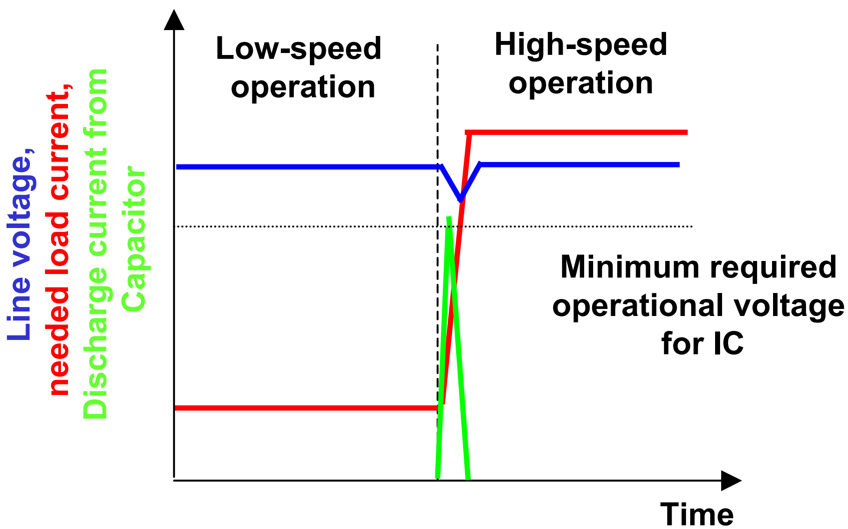
The Role of Backup Capacitor



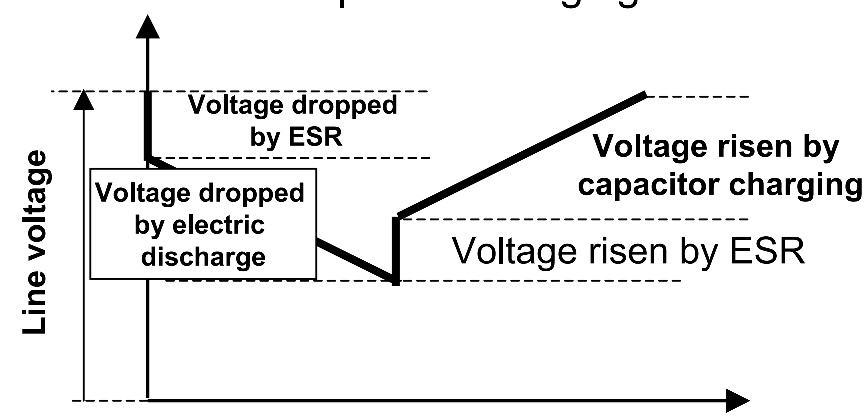
Capacitor's actual
(considering equivalent circuit)

*This is a simplified version, so disregard ESL





Voltage fluctuation occurs
when capacitor charging

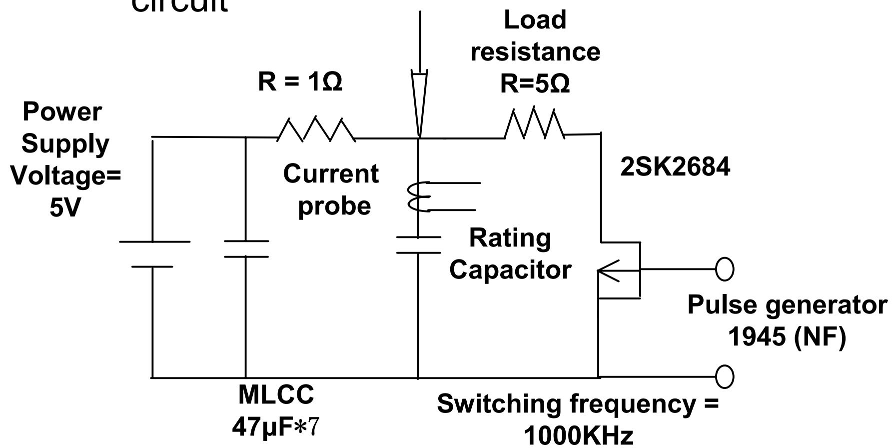


Keeping the minimum required operational voltage for IC ⇒ Maintaining stable operation

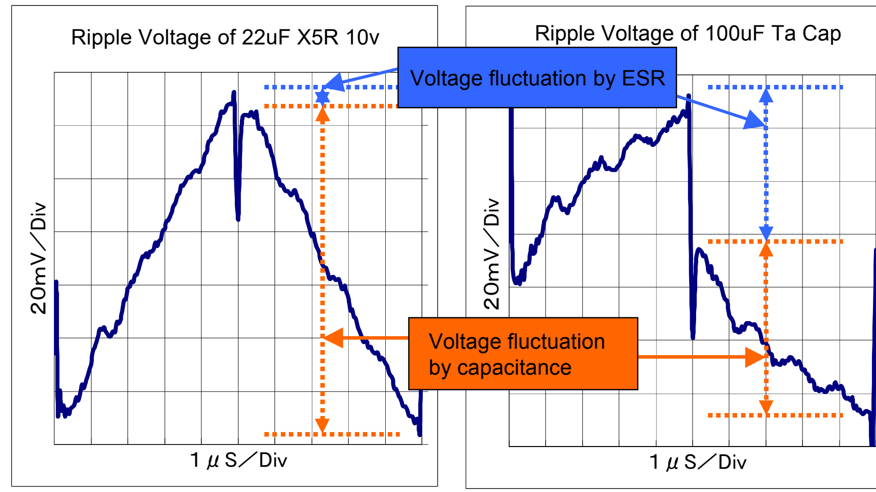
Capacitor and ESR decide the amount of voltage dropped

The Functions of Backup Capacitor

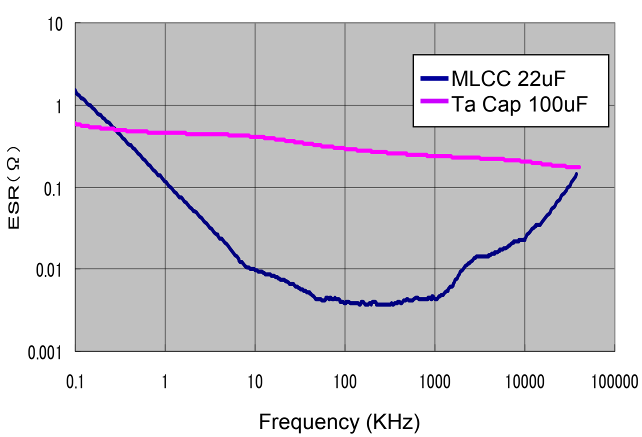
Experimental circuit



Experimental result for Capacitance and ESR



ESR comparison



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

Merits of MLCC

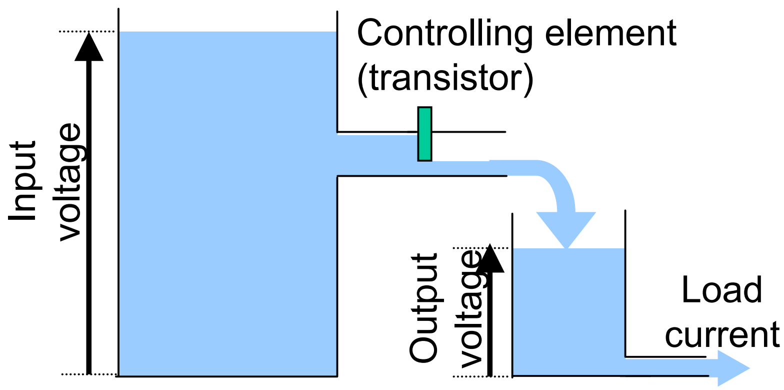
It enables to replace Ta capacitor with a smaller value of MLCC.

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

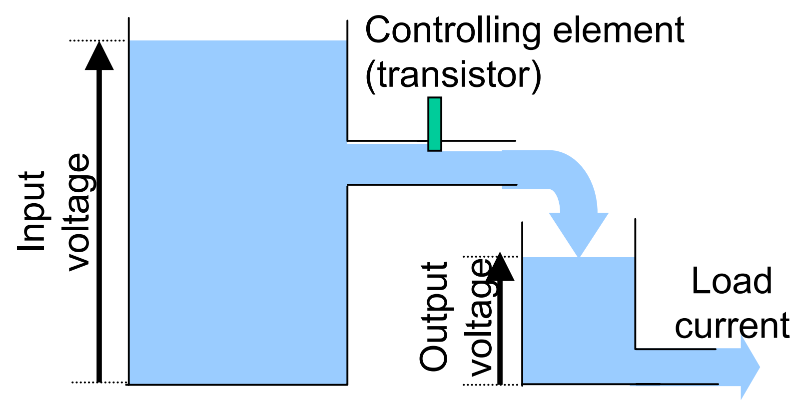
The Basic Knowledge of Power Supply Circuit

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

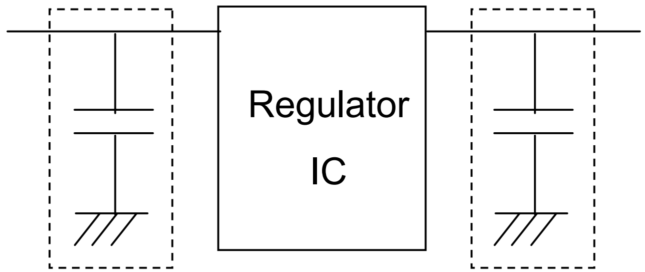
⇩

Output voltage stays constant.

Series Regulator (3 Terminal Regulator)

Circuit structure

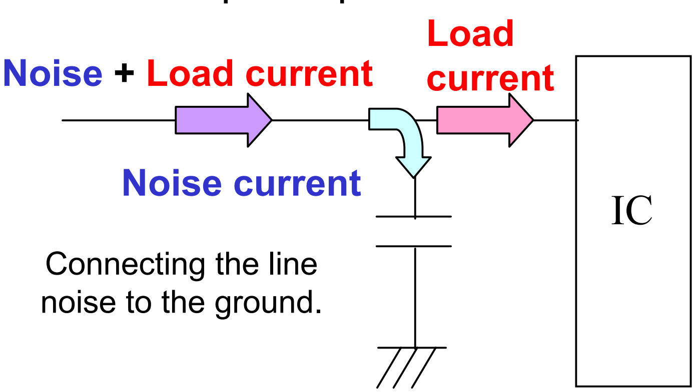
Input voltage > Output voltage



Input Capacitor Output Capacitor

Consisting of IC, input and output capacitors.

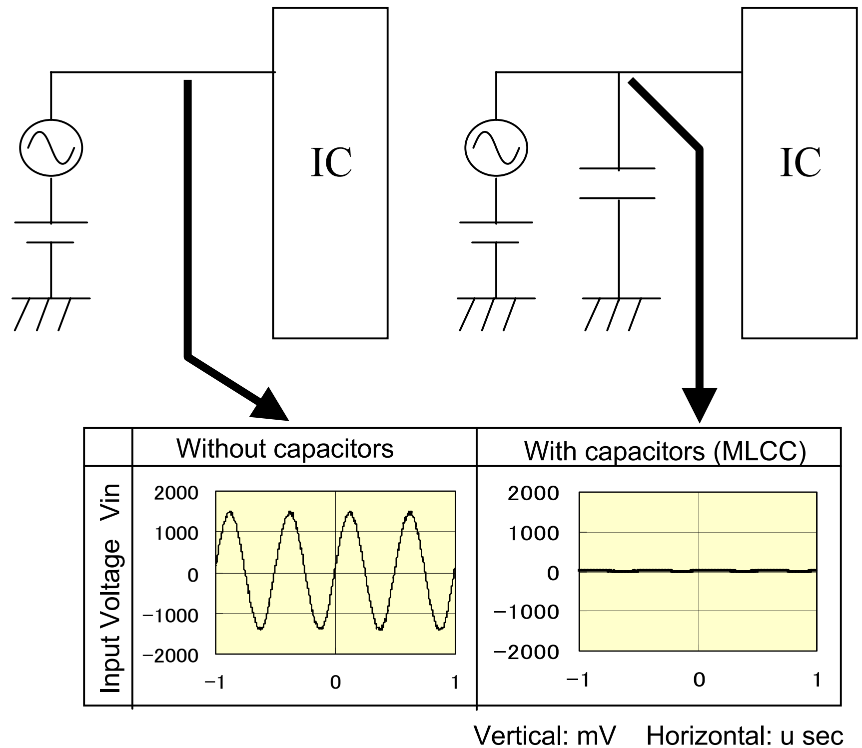
Function of input capacitor



Same as the function of Bypass Capacitor

Effects of input capacitor

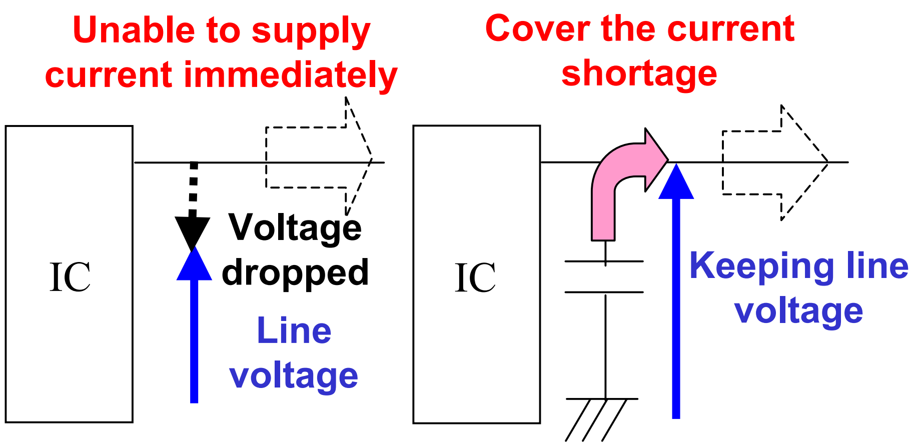
Add alternate current to input voltage purposely to measure input current amount with or without input capacitor



Input voltage is stabilized as input capacitor is connected.

Series Regulator (3 Terminal Regulator)

Function of output capacitor

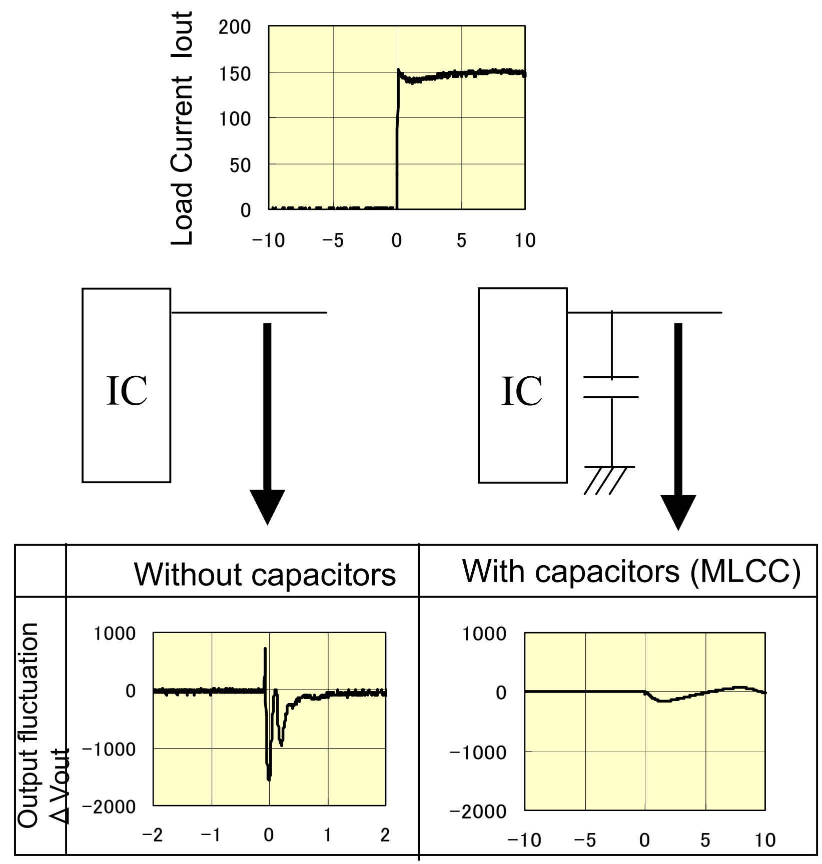


Supply current to control voltage fluctuation for rapid load change

Same as the function of Backup Capacitor

Effects of output capacitor

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

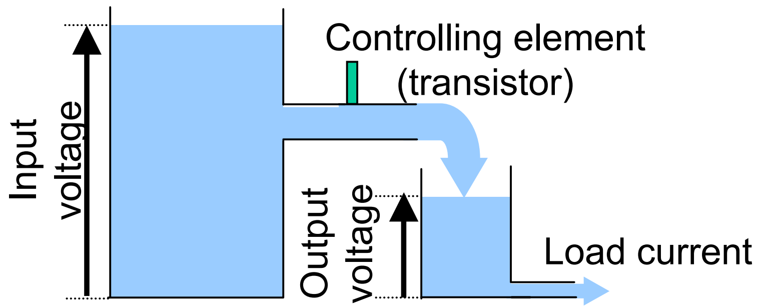


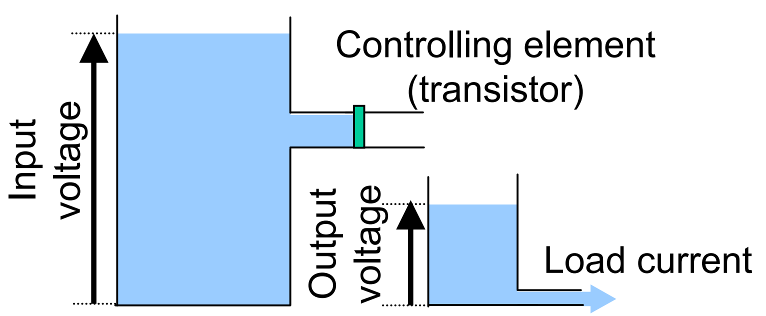
Output voltage is stabilized as output capacitor is connected.

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.

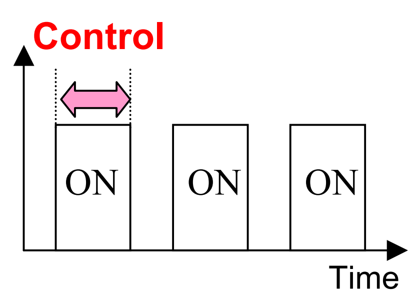
Switching operation

Controlling output voltage by switching

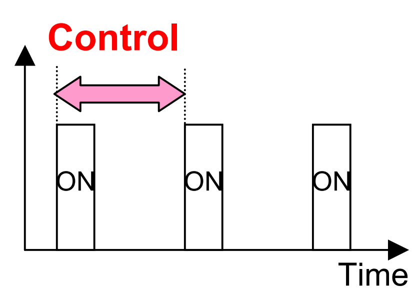
Turn-on cycle → Constant
Time to be ON → Changes
PWM method

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

Turn-on cycle of the switch → Switching frequency



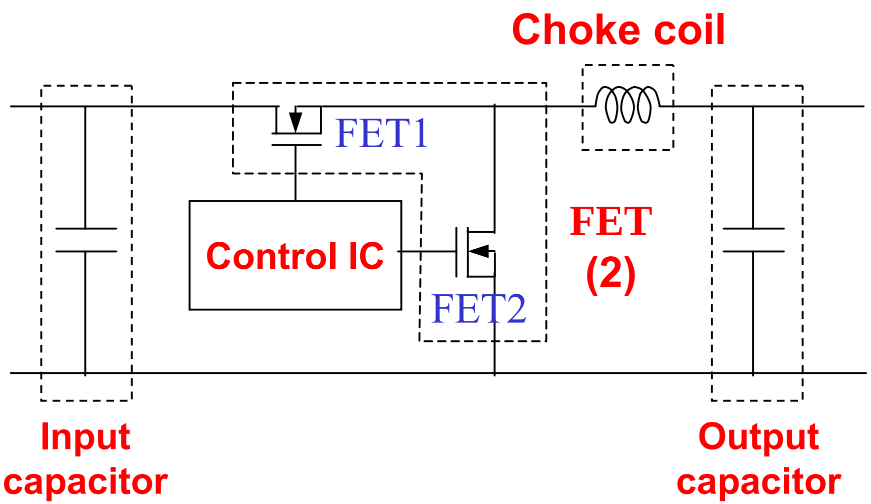
PWM



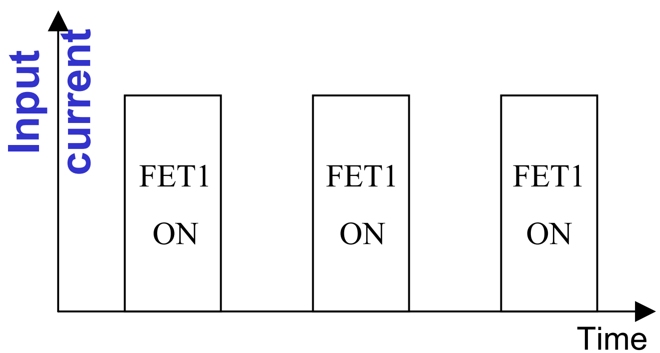
PFM

Step-Down Converter

Circuit structure

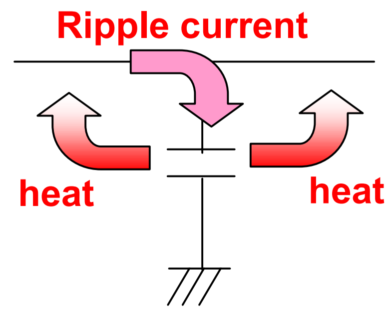


Input side current

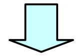


Large amount of alternating current
(ripple current) flows.

Operation of input capacitor



Ripple current flows
into input capacitor.

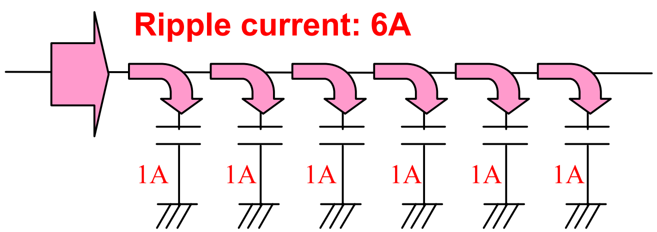


Heat generated by ESR

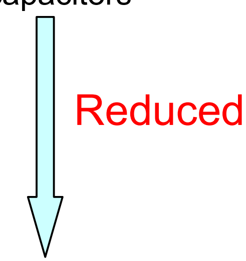
Necessary characteristics of input capacitor

High tolerance for ripple current

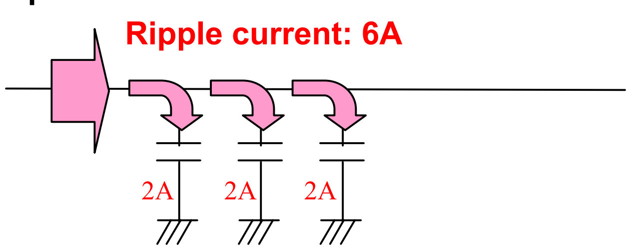
Example: Permissible ripple current of a capacitor is 1A.



6
capacitors



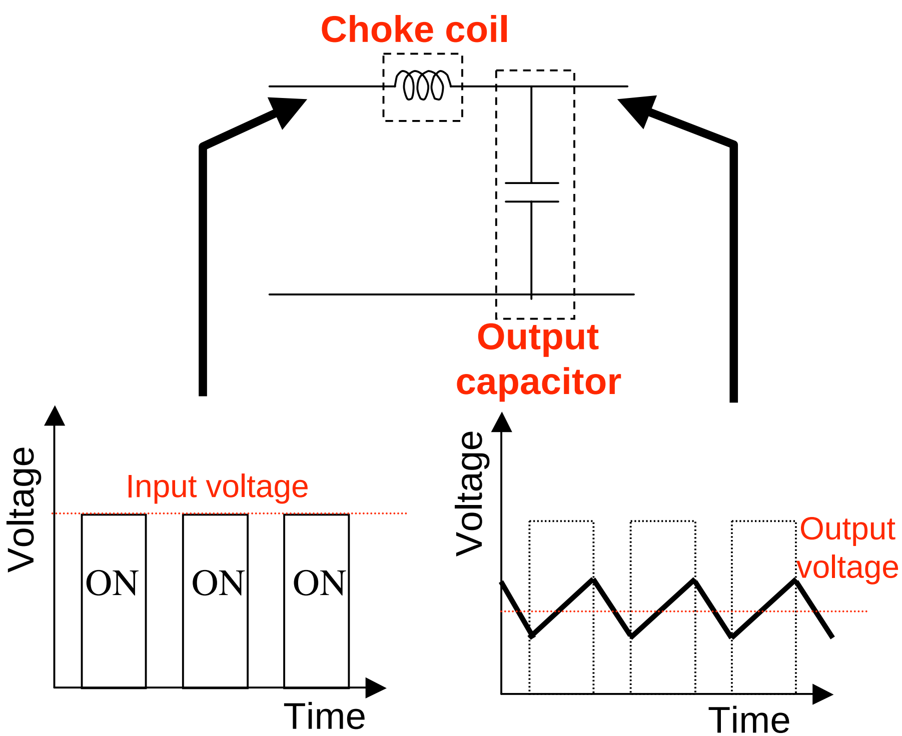
Example: Permissible ripple current of a capacitor is 2A.



3
capacitors

Step-Down Converter

Output side operation



Input voltage is controlled by an on-off switching.

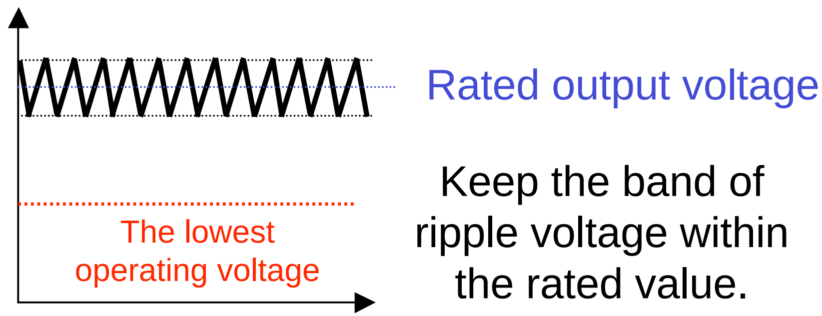
It is smoothed with a choke coil and an output capacitor.

Ripple voltage is included.

Points of output voltage to remember

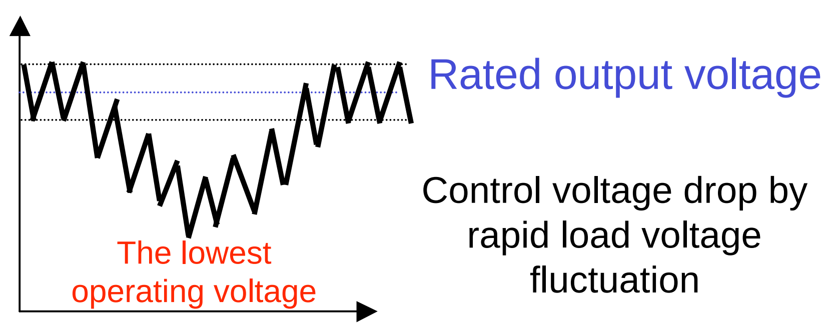
Keeping higher voltage than the lowest operating voltage of load IC.

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

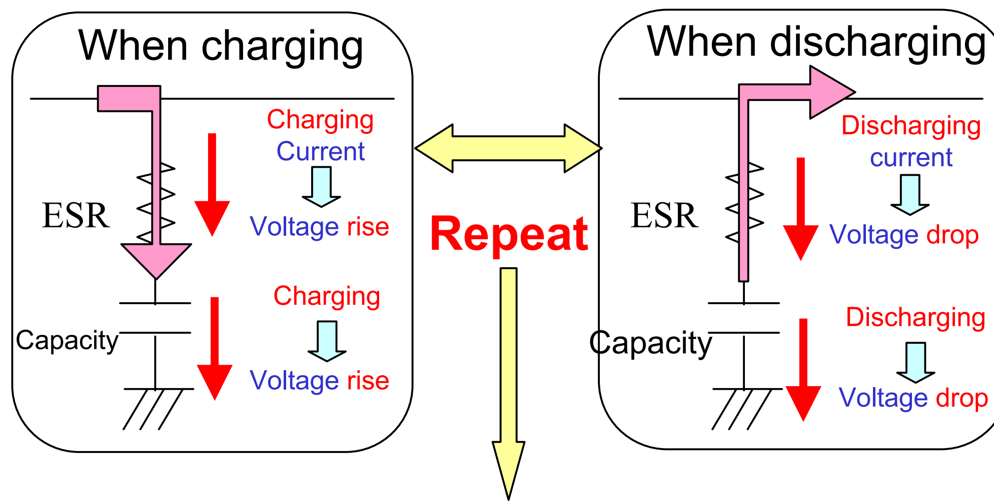
Factor for determining ripple voltage

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

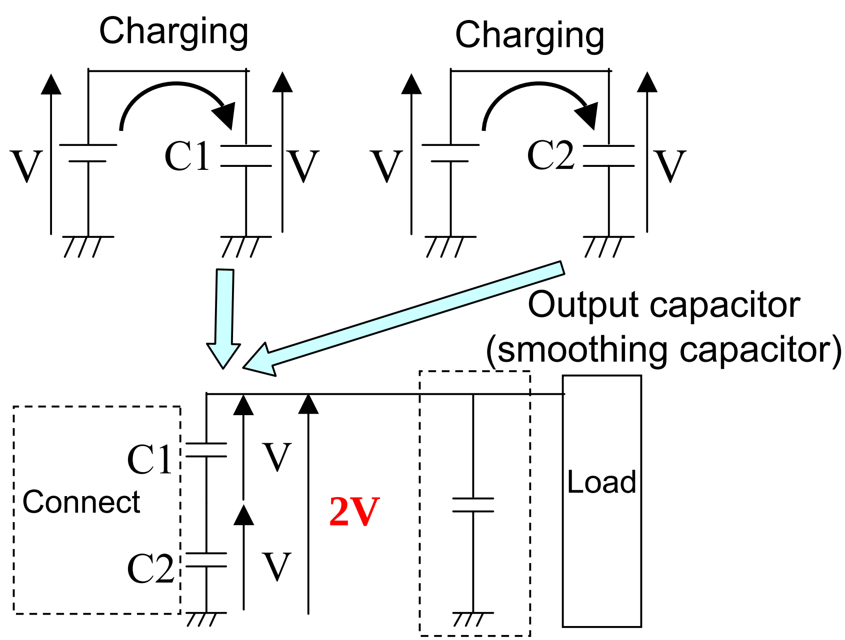


High capacitance and low ESR reduce ripple voltage.

Charge Pump (Boost)

Operation of charge pump (image)

Charging 2 capacitors separately



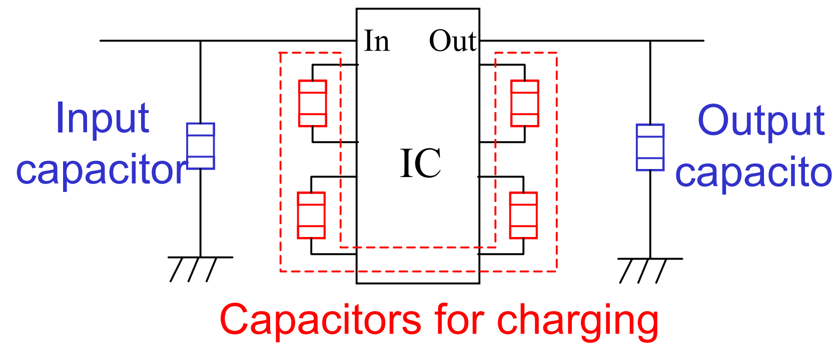
Connecting charged capacitors

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

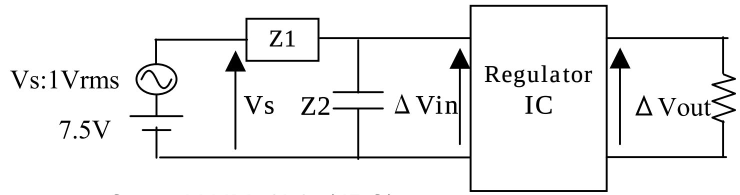
→ Lowering voltage fluctuation occurred by charging/discharging

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:MLCC X5R 1uF 10v, Ta1uF, A11uF

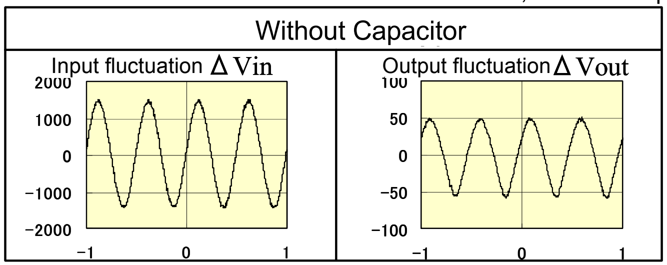
$$\Delta Vin = \frac{Z2}{Z1+Z2} Vs$$ (Z1:Line impedance)

Capacitor (Z2) has low impedance.

→ Effect of noise suppression: large

Constant IC input voltage

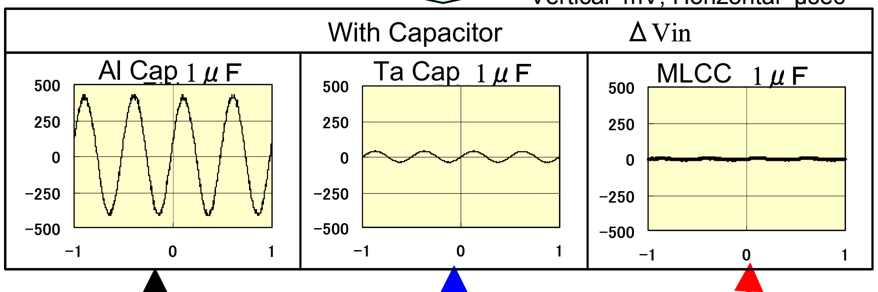
Vertical mV, Horizontal μsec



Input fluctuation of 1Vrms → Output fluctuation of 35Vrms

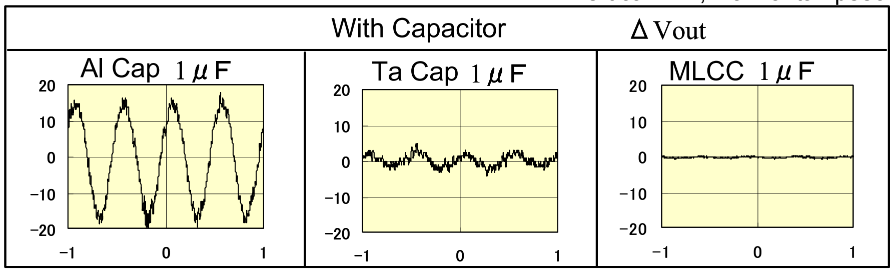
Input capacitor inserted

Vertical mV, Horizontal μsec

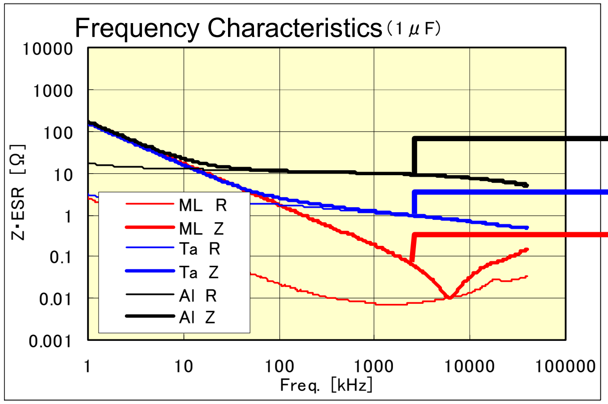


MLCC is excellent in noise suppression (low impedance).

Vertical mV, Horizontal μsec



Output fluctuation becomes smaller as IC input voltage stays constant.

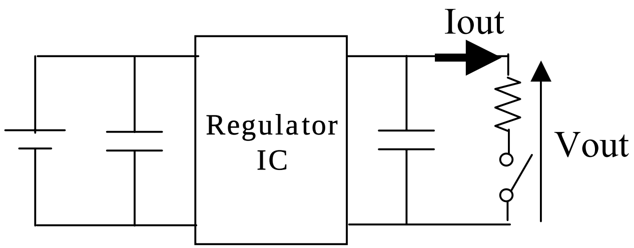


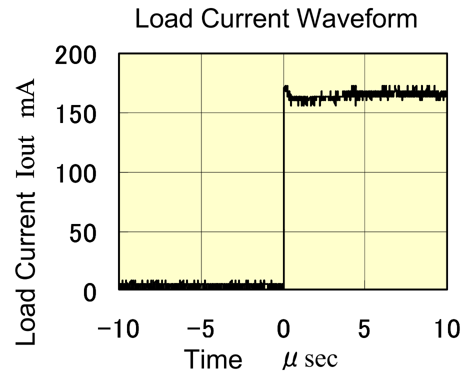
MLCC has lower impedance than that of Ta for a wide range of frequency.

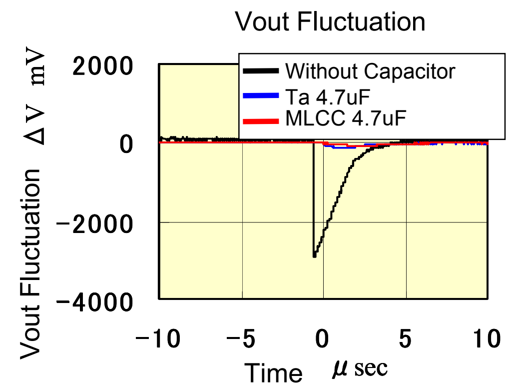
MLCC is suitable for input capacitor.

Summary   Operation Analysis of Output Capacitor

Observation of output voltage fluctuation

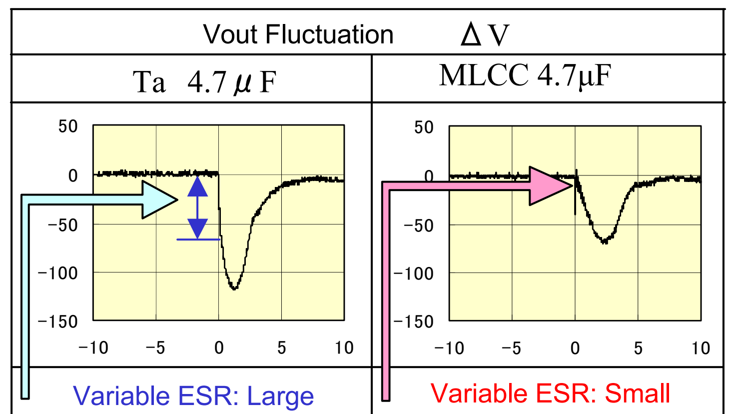




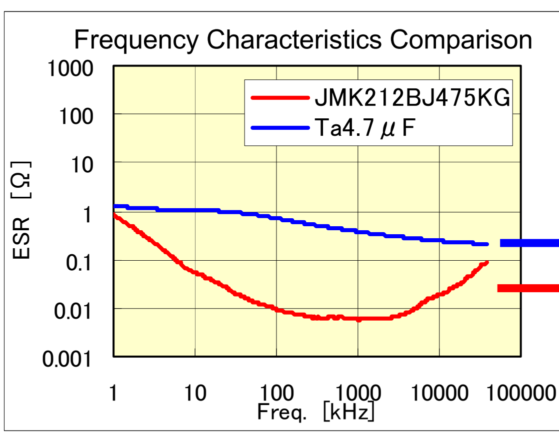


Waveform observation: Iout, Vout
(Observing by the type of output capacitors)

- IC used: R1112N331B (Ricoh)
- Input Cap: MLCC 4.7uF X5R 10v
- Input V: 5V
- Switching frequency: 100Hz
- Load current: 150mA



ESR : Large   ESR : Small   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