Capacitor
Impedance Characteristics of Capacitor

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

<table>
<thead>
<tr>
<th>Elements in Capacitor</th>
<th>Changes in Frequency</th>
<th>Changes in Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESR</td>
<td><img src="image" alt="Graph" /></td>
<td>ESR: Increase</td>
</tr>
<tr>
<td>ESL</td>
<td><img src="image" alt="Graph" /></td>
<td>ESL: Decrease</td>
</tr>
<tr>
<td>Capacitance</td>
<td><img src="image" alt="Graph" /></td>
<td>Cap.: Increase</td>
</tr>
</tbody>
</table>

**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 characteristics vary depended on each element.
Reliabilities of Multi-Layered Ceramic Capacitor

1. Operational condition comparison chart for Circuit

<table>
<thead>
<tr>
<th></th>
<th>Polarity</th>
<th>De-rating</th>
<th>Ripple CU. Limitation</th>
<th>Heat Resistance</th>
<th>Solvent Resistance</th>
<th>Loading Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLCC</td>
<td>No</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
</tr>
<tr>
<td>Ta Cap.</td>
<td>Yes</td>
<td>☑</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☑</td>
</tr>
<tr>
<td>Al Cap.</td>
<td>Yes</td>
<td>☑</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

**Application Problems**
- Layout
- Polarity exam
- Reverse voltage

**Polarity De-rating**
- Have margin for rated voltage (70~50% level)
- Limitation for reflow molding and degrading advancement
- Liquid solution floating except block structure MLCC
- Ta capacitor: diffusion of Ag, short circuit from degrading of insulating layer
- Al capacitor: decreasing in capacitance from electrolysis loss

**Loading Test**
- MLCC: No
- Ta Cap.: Yes
- Al Cap.: Yes

**Ceramic Capacitor**
- Dielectric: Barium Titanate
- Electrode: Ni

**Breakdown Voltage (V)**
- Breakdown voltage level comparison: rated voltage 10V

**Graph**
- Breakdown Voltage (V)
  - MLCC
  - Ta Capacitor
  - Al Capacitor

**Note**
- Capacitor selection requirements for operational conditions
- Material properties and characteristics for each type of capacitor

**What's Electrolytic Capacitor?**
- Electrolytic paper
- Electrolysis solution
- Dielectric (MnO2)

**Ta Capacitor**
- Electrolytic paper
- Dielectric (MnO2)
- Graphite
- Argentum paste
- Solder
- La, Ca: positive/negative pole cap. Da, Dr: rectification from negative pole's oxidization coating
- Ra, Rk: inside resistance of forward direction from +, - poles' oxidization coating
Characteristics Comparison for the Different Type of Capacitors

Ripple Current Characteristics

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°C. There is no limitation of allowed ripple current for MLCC.

Operational recommendation of heat release value for electrolytic capacitor is within 5°C. Allowed ripple current is regulated by makers.
The Basic Knowledge of Circuits
The Functions of Bypass (decoupling) Capacitor

The Role of Bypass Capacitor

Power supply line → Noise + Load current → Load Current → Noise Current → To connect the noise current to the earth (grounding) → IC

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.

<table>
<thead>
<tr>
<th>Impedance</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise effect of decreasing</td>
<td>More effective</td>
<td>Less effective</td>
</tr>
</tbody>
</table>
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.

- Load current: small
  - Operating at low-speed

- Load current: large
  - Operating at high-speed

Power line for high-speed load changing
Large load current is quickly needed.

- The current can’t flow to IC quickly enough.

- Line voltage

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

- Voltage dropped
  - Circuit voltage, Load current

- Line voltage decreases below the required operational voltage for IC.

- The IC stops its operation.

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

- Load current
  - Low-speed operation
  - High-speed operation

- Time
The Functions of Backup Capacitor

The Role of Backup Capacitor

- Electric current delays
- Making up for electric current shortage
- Maintaining Line voltage

Capacitor's actual (considering equivalent circuit)

*This is a simplified version, so disregard ESL

- Voltage dropped by electric current
- Voltage dropped by discharge current
- Voltage risen by capacitor charging
- Voltage risen by ESR

Line voltage dropped

Capacitor and ESR decide the amount of voltage dropped

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

Low-speed operation

High-speed operation

Minimum required operational voltage for IC

Voltage fluctuation occurs when capacitor charging

Line voltage, needed load current, discharge current from Capacitor
The Functions of Backup Capacitor

Experimental result for Capacitance and ESR

Experimental circuit

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)

- Input voltage
- Output voltage
- Controlling element (transistor)
- Load current

Producing output voltage by lowering certain amount of input voltage

Step-down power supply

Load current fluctuation

- Input voltage
- Output voltage
- Controlling element (transistor)
- Load current

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

Noise + Load current  Noise current  Load current
Connecting the line noise to the ground.

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.

Function of input capacitor:

- **Noise + Load current**: Represents the combination of noise and load current.
- **Load current**: Connects noise to the ground.
- **Noise current**: Connects noise to the ground.

Same as the function of Bypass Capacitor.
Series Regulator (3 Terminal Regulator)

Function of output capacitor

Unable to supply current immediately

Cover the current shortage

Voltage dropped
Line voltage

Keeping line voltage

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.

<table>
<thead>
<tr>
<th>Load Current (Iout)</th>
<th>Without capacitors</th>
<th>With capacitors (MLCC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10 -5 0 5 10</td>
<td>-2000 -1000 0 1000</td>
<td>-2000 -1000 0 1000</td>
</tr>
<tr>
<td>-2 -1 0 1 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Control

PWM

Time

ON ON ON

Control

PFM

Time

ON ON ON

Load current

Controlling element (transistor)

Output voltage

Input voltage
**Step-Down Converter**

**Circuit structure**

- Input current flows through FET1 and FET2.
- Choke coil is used to reduce ripple current.
- Control IC regulates the operation of FETs.

**Operation of input capacitor**

- Ripple current flows into the input capacitor.
- Heat is generated by ESR.

**Necessary characteristics of input capacitor**

- High tolerance for ripple current.

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

- For a ripple current of 6A, using 6 capacitors in parallel can be reduced to 3 capacitors.

**Input side current**

- Large amount of alternating current (ripple current) flows.

**Time**

- Input current FET1 ON, FET1 ON, FET1 ON.
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

Rated output voltage
Keep the band of ripple voltage within the rated value.

Rapid load voltage fluctuation

Rated output voltage
Control voltage drop by rapid load voltage fluctuation.

The lowest operating voltage

Input voltage

ON ON ON

Time

Voltage

Output side operation

Choke coil

Output capacitor

.time

Voltage

ON ON ON

Time

Rated output voltage

The lowest operating voltage

Input voltage

ON ON ON

Time

Ripple voltage

Ripple voltage is included.
Step-Down Converter

Factor for determining voltage drop by rapid load voltage fluctuation

Operation at rapid load change

Same as Backup Capacitor

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

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

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

\[ \Delta V_{in} = \frac{Z_2}{Z_1 + Z_2} V_s \]  
(Z1: Line impedance)

Capacitor (Z2) has low impedance.  
Effect of noise suppression: large

Constant IC input voltage

MLCC is excellent in noise suppression (low impedance).

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: \( I_{out}, V_{out} \)  
(Observing by the type of output capacitors)

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

**Frequency Characteristics Comparison**

- **Variable ESR:** Large  
- **Variable ESR:** Small

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

**MLCC with low ESR is well-suited for output capacitor.**
Development Method Direction for ML Lineups and Proposals

Market demand

Circuit segment

- Digital circuit
  - Amplifier
  - Arithmetic
  - Oscillation
  - Modem
  - Digital
  - Power supply
- Analog circuit
  - 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)