Panasonic

Technical Guide

SP-Cap

Conductive Polymer Aluminum Electrolytic Capacitors

2015.11 http://industrial.panasonic.com/ww/products/capacitors/polymer-capacitors/sp-cap

Contents

1. Features of SP-Cap

●Super low ESR (Equivalent Series Resistance) characteristics

SP-Cap has super low ESR characteristics which allows it to have rapid current discharge or charge capability: This makes the SP-Cap an excellent choice as a bulk capacitor in CPU applications.

●Very low impedance characteristics

●Stable capacitance characteristics

SP-Cap has stable capacitance characteristics versus changes in the operating frequency and applied voltage, unlike MLCC.

●Stable temperature and applied voltage characteristics

SP-Cap has stable characteristics versus changes in the operating temperature and applied voltage.

●Benign Failure Mode full advantage of the material

More difficult to ignite and "smoke" than a tantalum electrolytic capacitor.

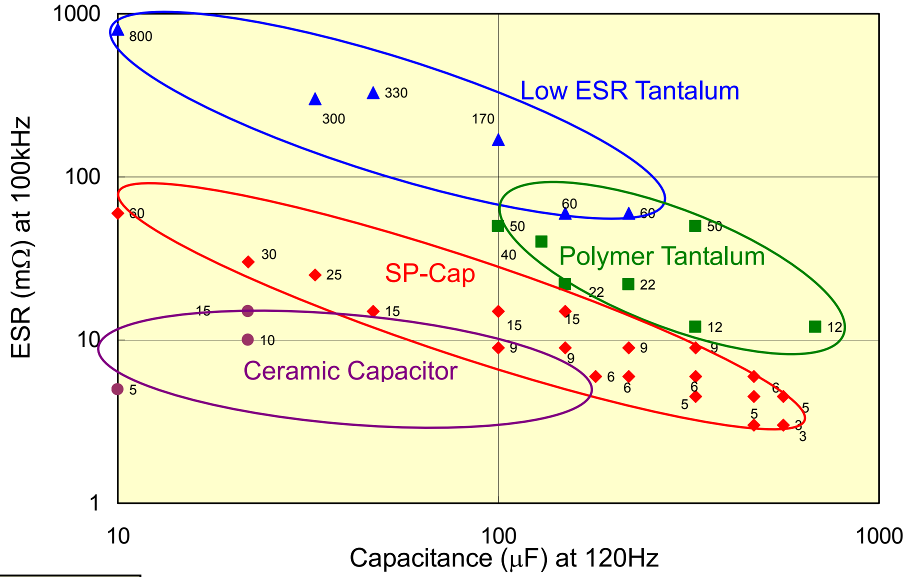
●Surface mounting and low profile

With the adoption of our exclusive new structure, surface mounting and a reduction in height have been achieved.

Comparison with other types of capacitors

■ Super low ESR and large capacitance

ESR: Approx. 1/10 or less that of a tantalum capacitor
Capacitance: Approx. 5 times or more that of a ceramic capacitor



■ Very low impedance

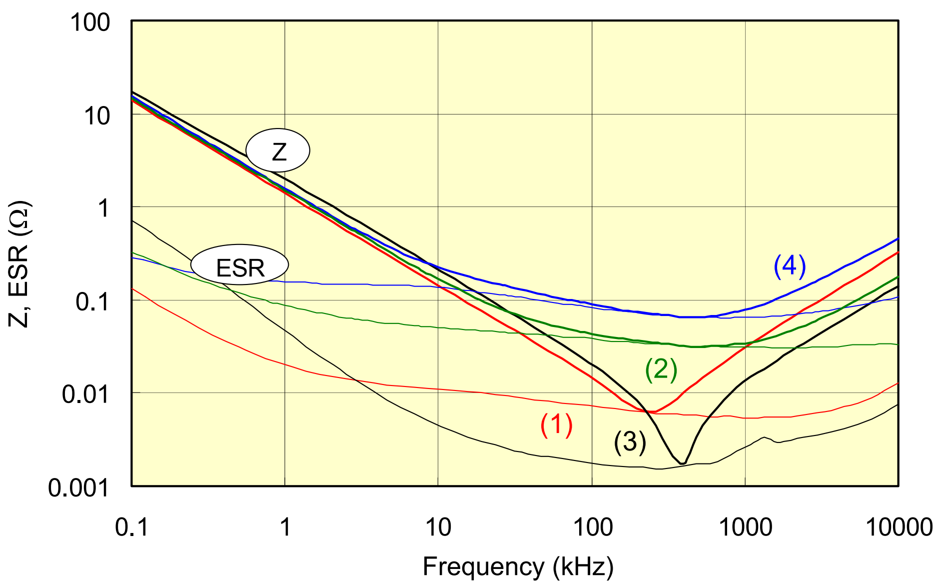
Lowest impedance among electrolytic capacitors

(1) SP-Cap (SX series)
4V100µF (7.3 x4.3 x1.9)

(2) Polymer Tantalum capacitor
4V100µF (7.3 x4.3 x2.8)

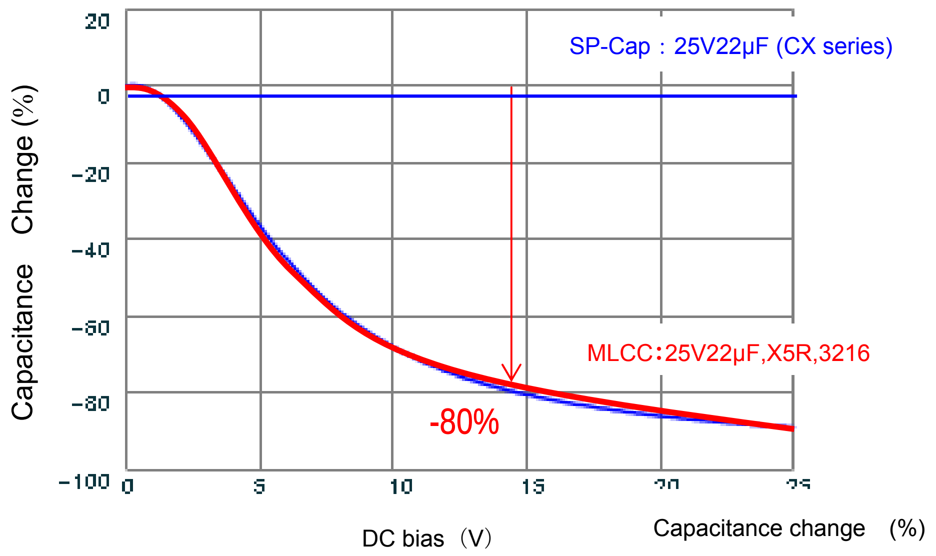
(3) Ceramic capacitor
6.3V100µF (4.5 x3.2 x3.2)

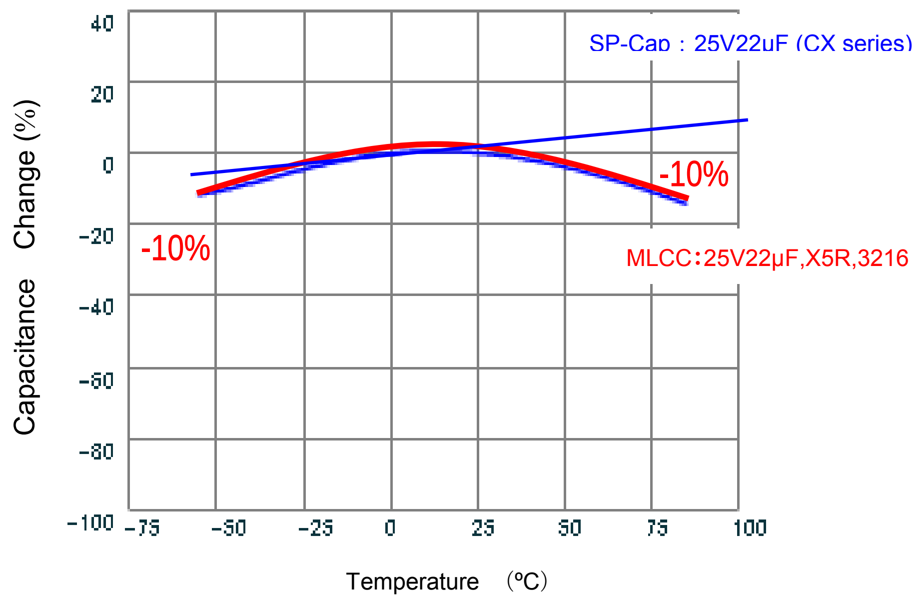
(4) Low ESR Tantalum capacitor
10V100µF (7.3 x4.3 x2.8)



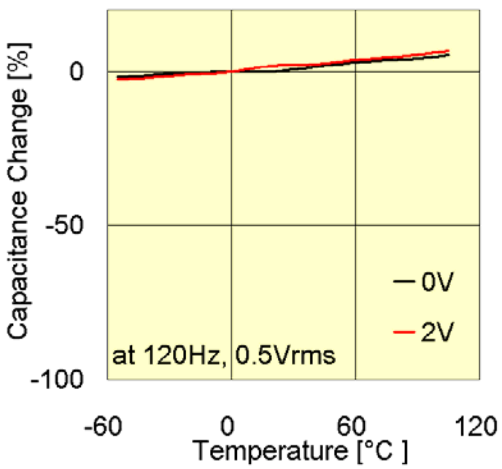
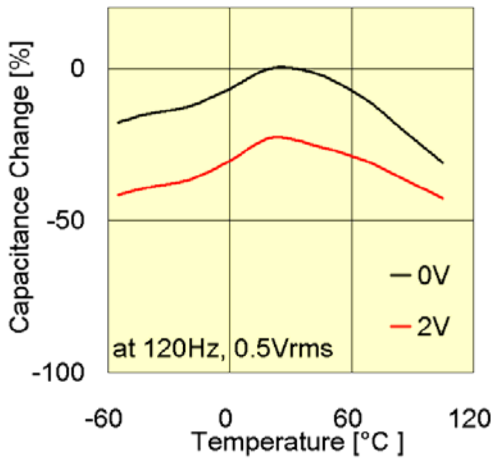
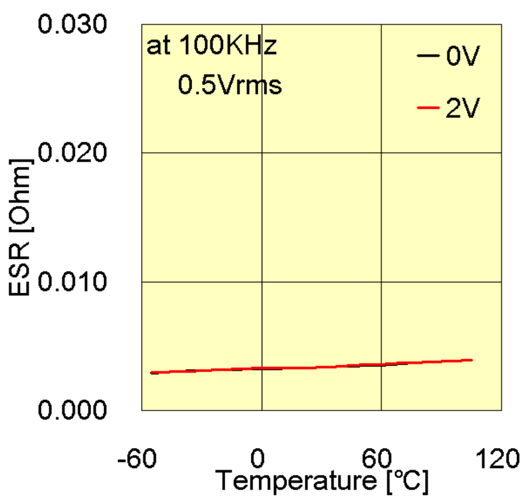
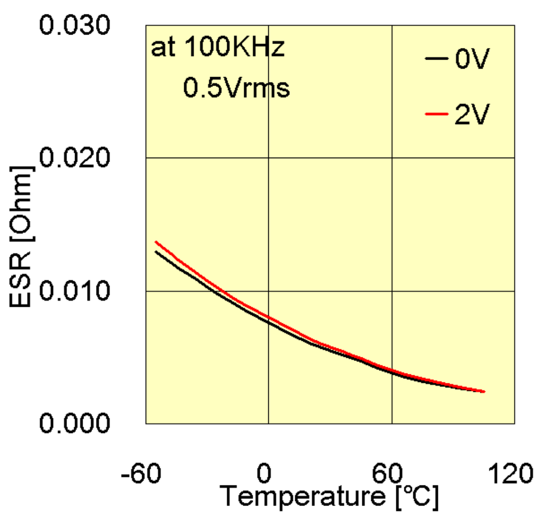
■ Stable capacitance

MLCC reduction capacity in the "voltage application" + “Low Temp.-High Temp."



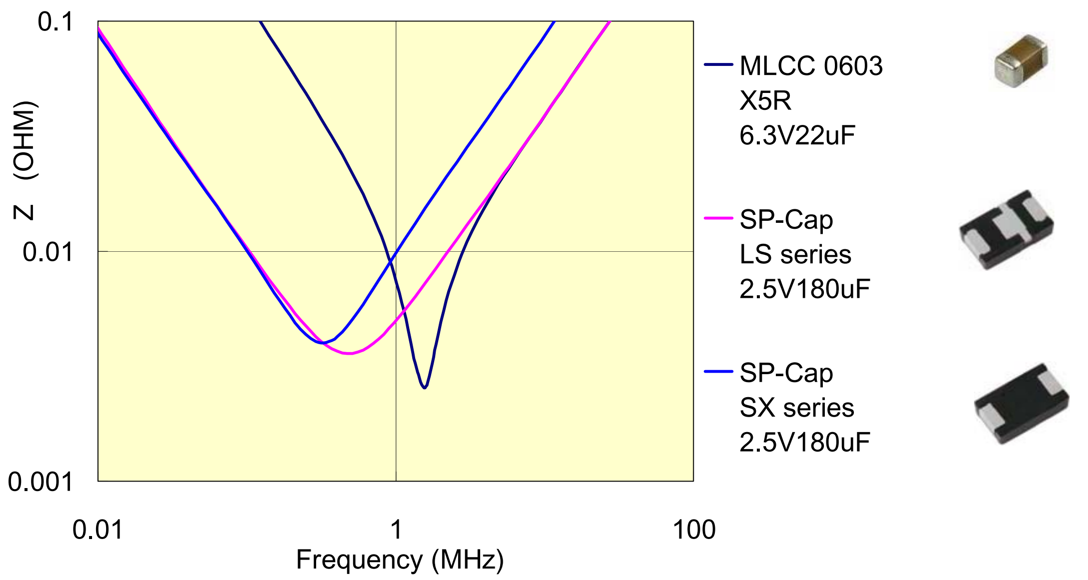


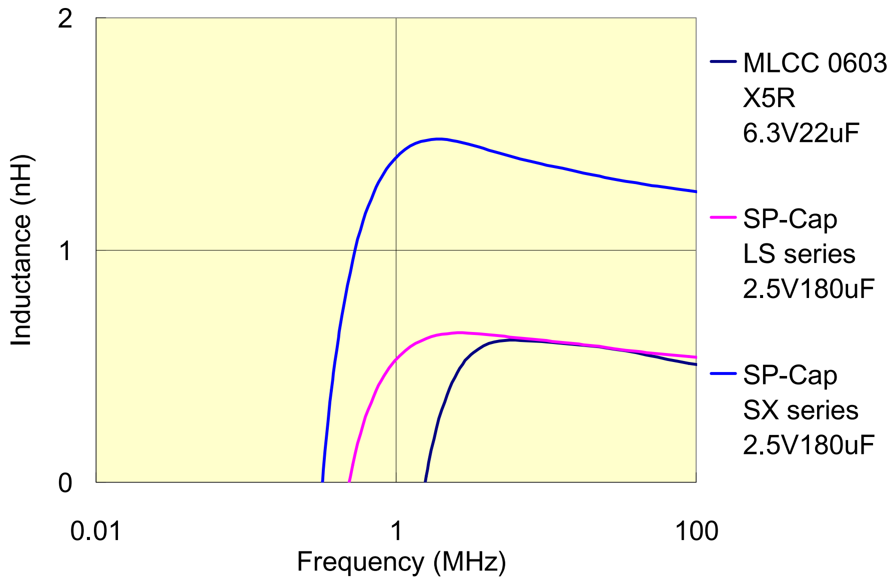
■ Stable temperature and applied voltage characteristics

	SP-Cap (SX series) 2.5V180μF	Ceramic capacitor (MLCC 0805 X5R) 6.3V22μF
Capacitance Change (%)	 	 
ESR (Ohm)		

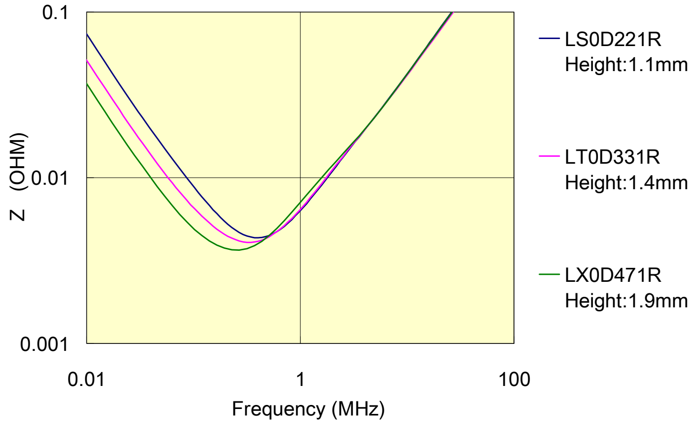
■ Very low impedance at high frequency by low ESL

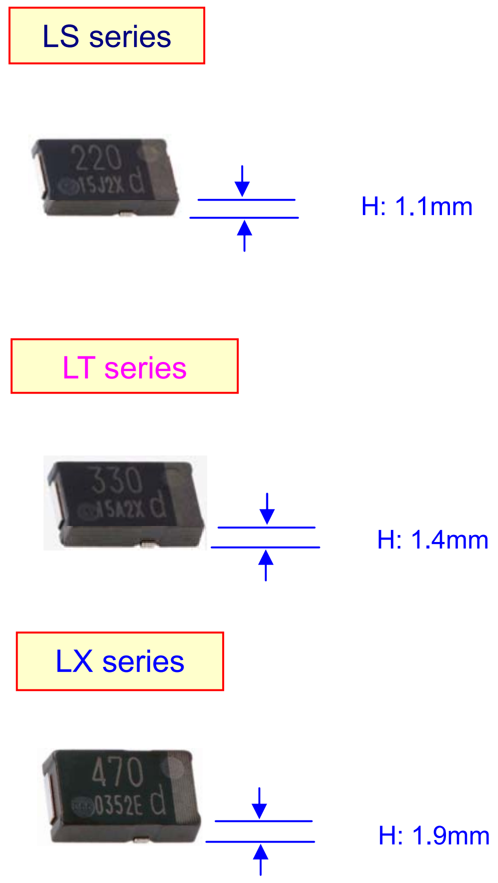
3 Terminal SP-Cap (L* series) has very low impedance equivalent to MLCC at high frequency.

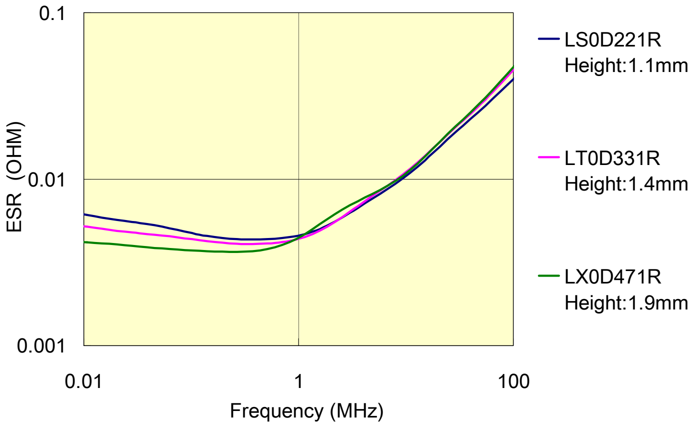


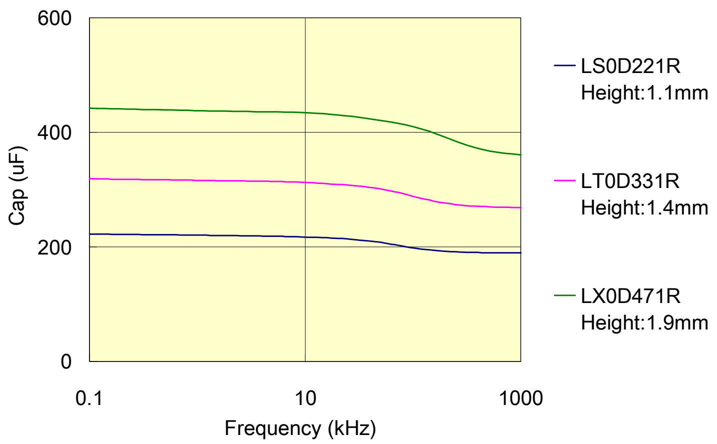


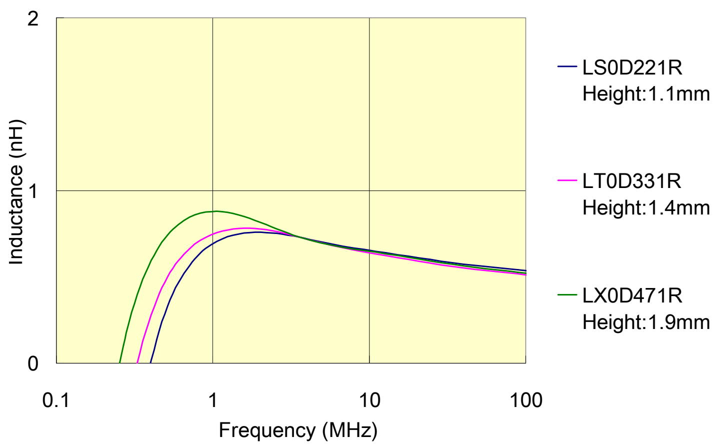
■ Large capacitance & Low profile











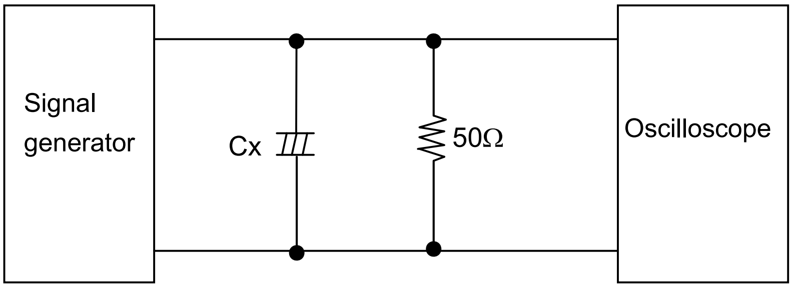
2. Features of application circuit

Excellent noise reduction

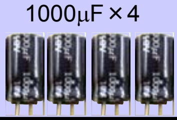
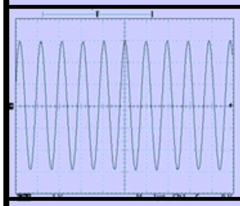
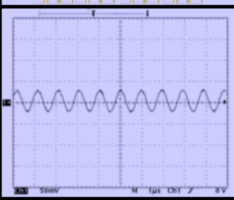
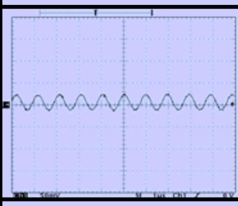
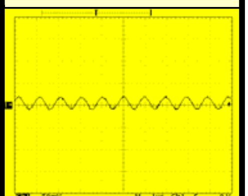
An evaluation of noise reduction compared with that of other types of capacitors is shown below.

Test Circuit

Input voltage : 8Vp-p
Frequency : 1MHz



Comparison of noise reduction capability

Input waveform (1MHz)	Output waveform		
	Aluminum capacitor	Tantalum capacitor	SP-Cap
	1000μF × 4 	100μF × 3 	47μF × 1 
			
8V p-p	54mV p-p	40mV p-p	30mV p-p

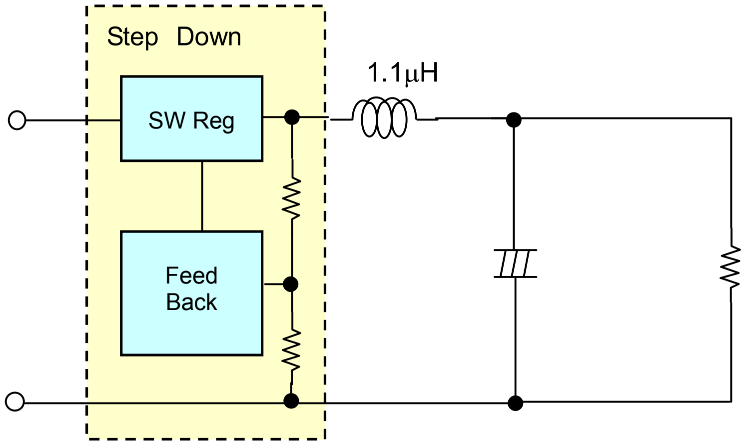
SP-Cap has excellent noise reduction performance.
SP-Cap can realize the quantity reduction and space saving.

Excellent ripple voltage reduction

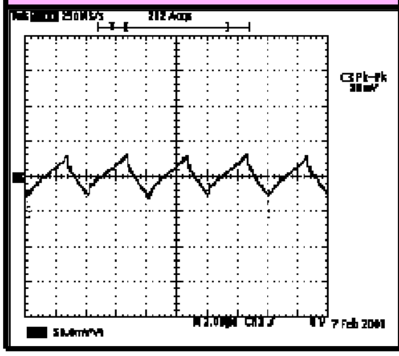
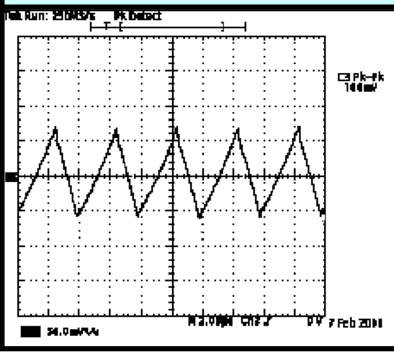
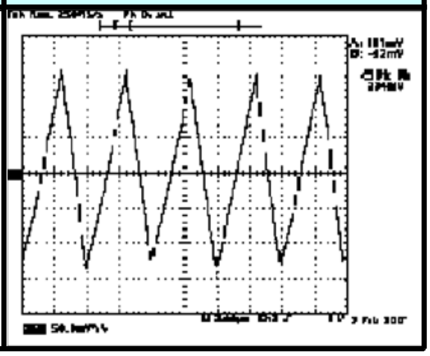
An evaluation of voltage smoothing capability on the switching power output side compared with that of other types of capacitors is shown below.

Test Circuit

Switching frequency: 250kHz



Comparison of ripple reduction capability

SP-Cap	Polymer tantalum	Low ESR tantalum
2.5V 220μF	2.5V 220μF	6.3V 220μF
ESR=10mΩ at 100kHz	ESR=25mΩ at 100kHz	ESR=50mΩ at 100kHz
Ripple voltage:50mVp-p	Ripple voltage:125mVp-p	Ripple voltage:265mVp-p
		

To reduce ripple voltage, SP-Cap with a super low ESR is more suitable.
For the same capacitance, SP-Cap allows the ripple voltage to be reduced to approximately 1/3 that of a polymer tantalum capacitor and approximately 1/5 that of a low ESR tantalum capacitor.

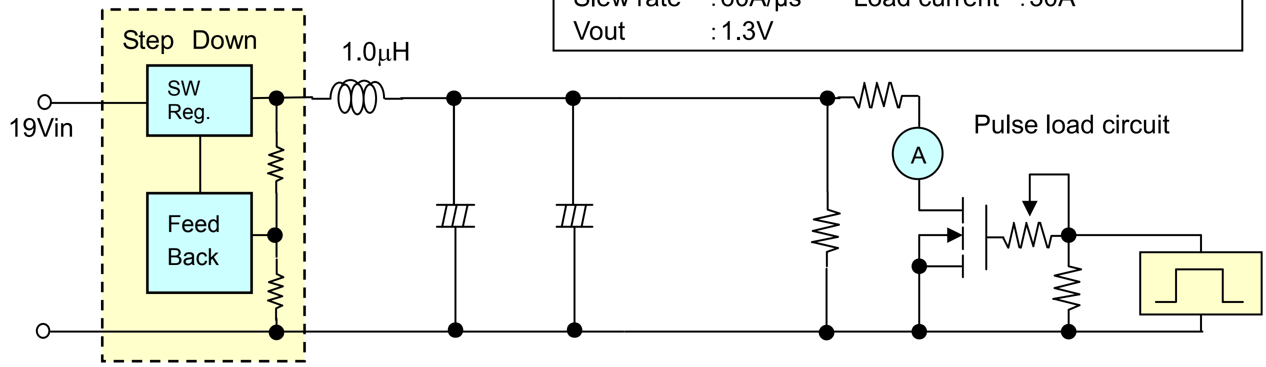
Excellent transient response

An evaluation of the transient response as the load varies in a high speed condition compared with those of the other types of capacitors is shown below.

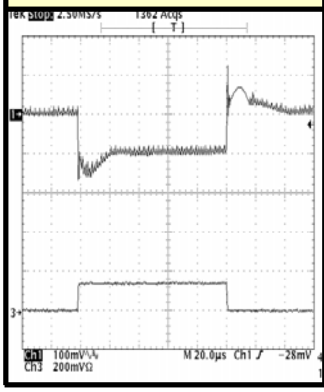
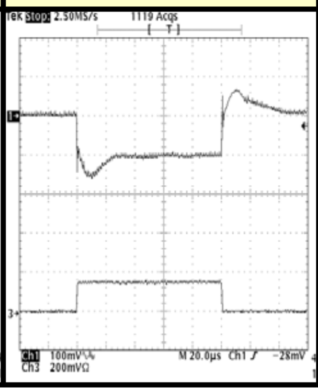
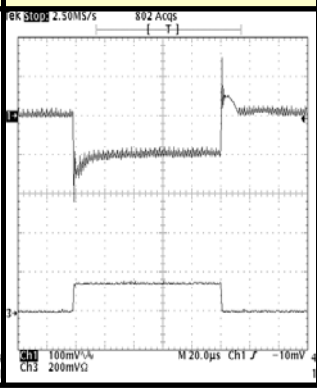
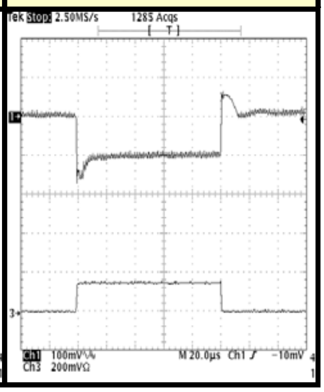
Test Circuit

Load conditions:

Load time	: 100µs	Frequency	: 610kHz/2phase
Slew rate	: 60A/µs	Load current	: 30A
Vout	: 1.3V		



Comparison of transient response capability

Conductive Polymer Aluminum (SP-Cap)		Conductive Polymer Tantalum	
2V 270µF x5 pcs	2V 220µF x8 pcs	4V 470µF x5 pcs	2.5V 330µF x8 pcs
Total Cap. =1350µF at 120Hz	Total Cap. =1760µF at 120Hz	Total Cap. =2350µF at 120Hz	Total Cap. =2640µF at 120Hz
ESR=3mΩmax.at 100kHz	ESR=1.9mΩmax.at 100kHz	ESR=3mΩmax.at 100kHz	ESR=1.9mΩmax.at 100kHz
			

Because SP-Cap provides a super low ESR, the same transient response can be obtained with less capacitance. To obtain the same transient response with polymer tantalum, higher capacitance is required than with the polymer aluminum.

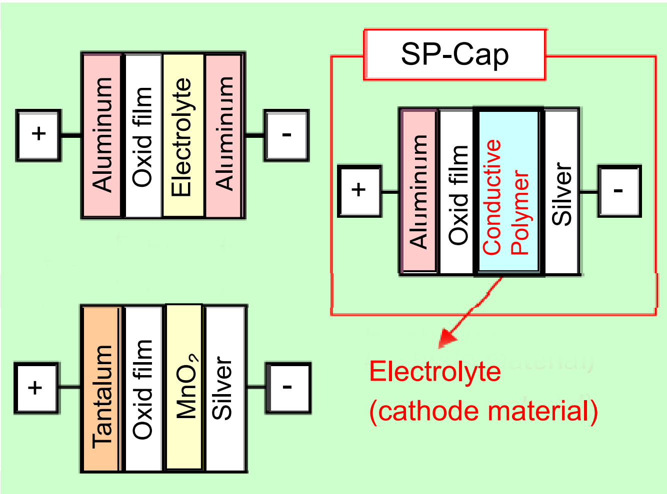
3. Structure

Super low ESR

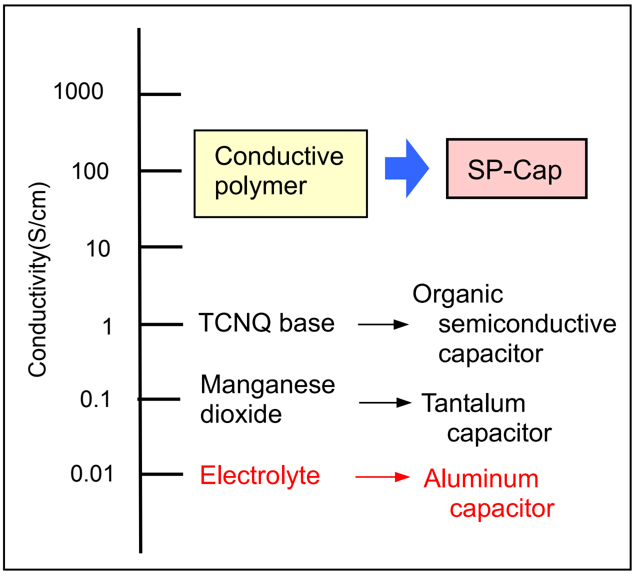
- In order to reduce ESR, the electrical conductivity of the electrolyte (cathode material) must be increased.
- The Conductive polymer electrolyte has a conductivity higher than that of conventional electrolytes

*Approx. 10,000 times that of an aluminum capacitor (electrolyte : liquid)
*Approx. 1,000 times that of a tantalum capacitor (manganese dioxide : solid)

Basic configuration of an electrolytic capacitor

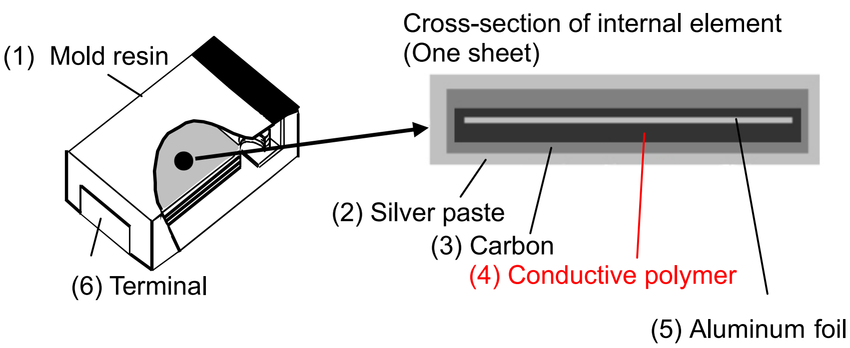


Conductivity of various types of electrolytes



Product structure

With the adoption of our exclusive structure, suface Mounting and reduced height have been achieved.



No.	Component
(1)	Mold resin
(2)	Silver past
(3)	Carbon
(4)	Conductive polymer
(5)	Aluminum foil
(6)	Terminal

Design and specifications are each subject to change without notice. Ask factory for the current technical specifications before purchase and/or use. Should a safety concern arise regarding this product, please be sure to contact us immediately.

4. Transient Response Simulation

Application Example (CPU)

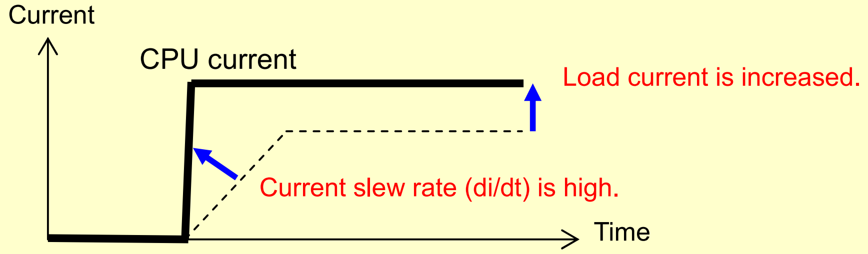
Trend of CPU (Central Processing Unit) used in personal computers

*CPUs continue to follow Moore's Law of doubling operating frequency every 18 months.
Today' CPUs are operating above Ghz frequencies. The Ghz- plus CPUs are characterized by increased power, high operating DC current and current slew rate requirements, and a challenging voltage margin.

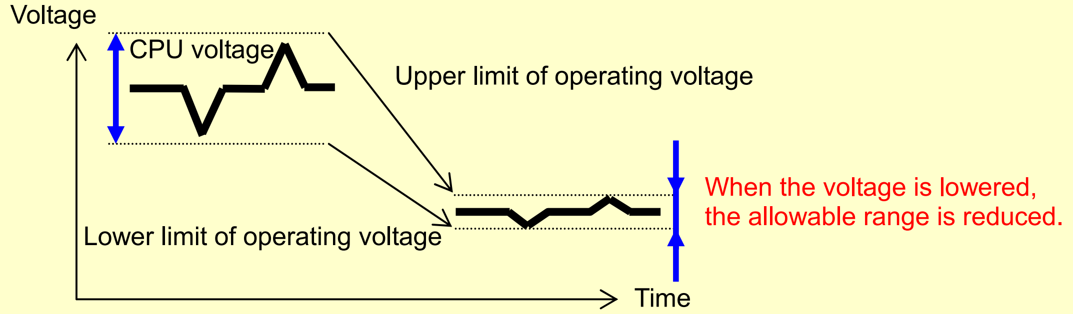
*To reduce energy consumption:
CPU stop clock operation is used.
CPU drive voltage is lowered.

●In order to reduce power consumption, a switching operation (ON and OFF) is repeated frequently by the CPU stop clock operation.
→ A large voltage fluctuation occurs in the CPU drive power line.

●Load current when CPU is operated (ON) is increased.
→ As the CPU computing and operational demand vary, the current demands for the CPU can change very rapidly and require current slew rates of hundreds of amps within a few seconds.



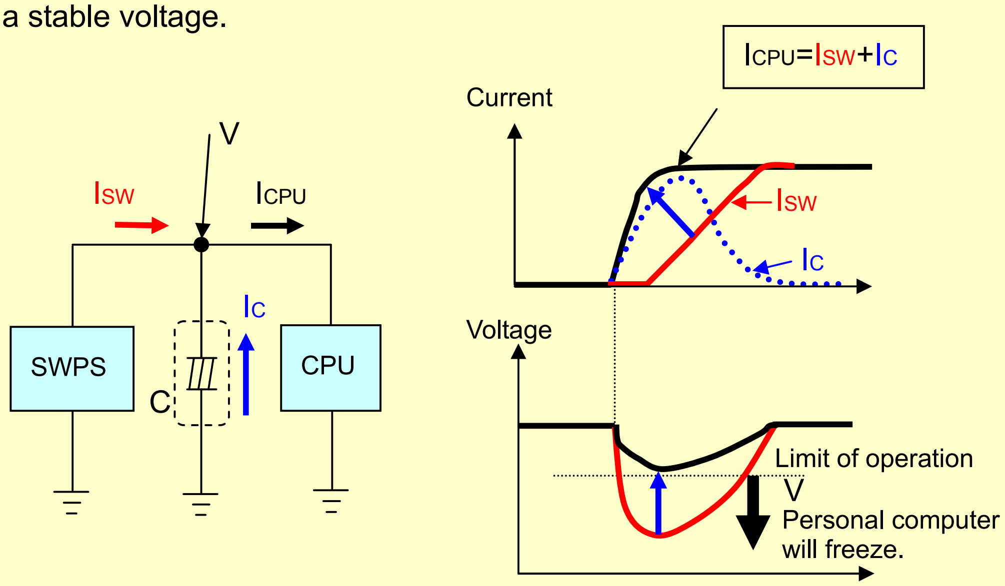
●Reduction in CPU drive voltage
→ The allowable voltage fluctuation range for CPU operation becomes tighter.



Today's CPUs can require current slew rates of hundreds of amps per micro second. The resulting current surge can create unacceptable spikes in the voltage which must be suppressed within the operating voltage margin before any damage is done to the CPU.

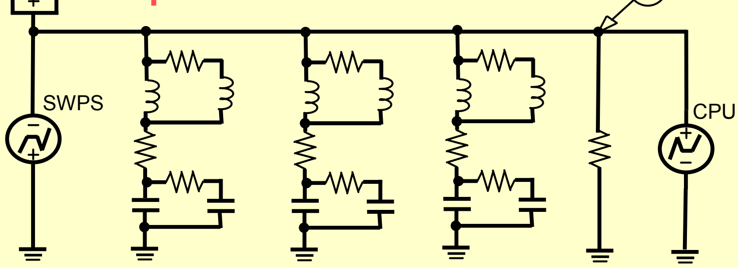
The performance requirement for bulk capacitors have increased due to the increase in the transient response and power requirements of the CPU.

A capacitor functions as a buffer to supply an instantaneous current at a stable voltage.



This transient response simulation presents the optimum idea of capacitor pick up for power supply design.

Spice circuit model



Simulating method

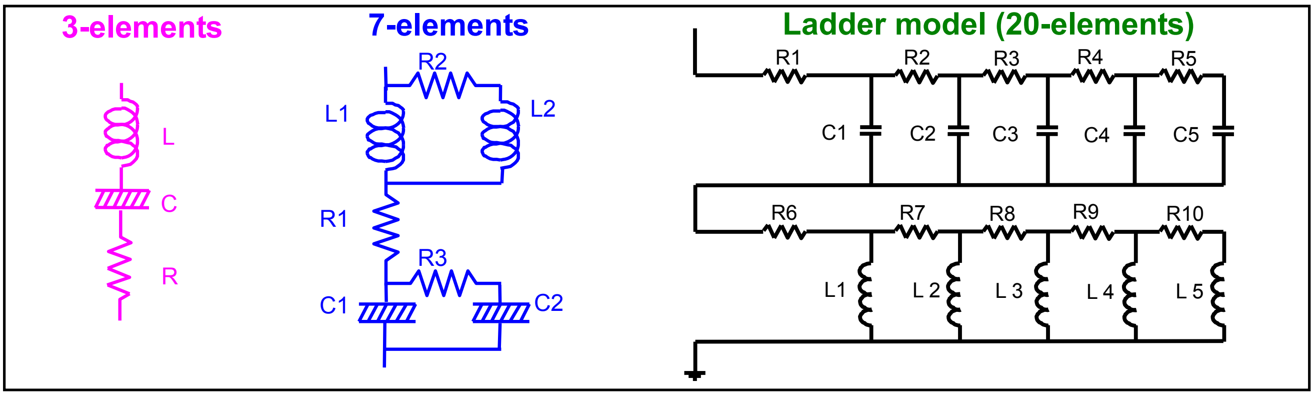
For the simulation of CPU transient response characteristics, a capacitor equivalent circuit model must be created and the circuit conditions must be set up.

In order to simulate the transient response characteristics of a capacitor,
An equivalent circuit model capable of indicating
The variation in ESR* and the reduction in capacity and inductance in the high frequency

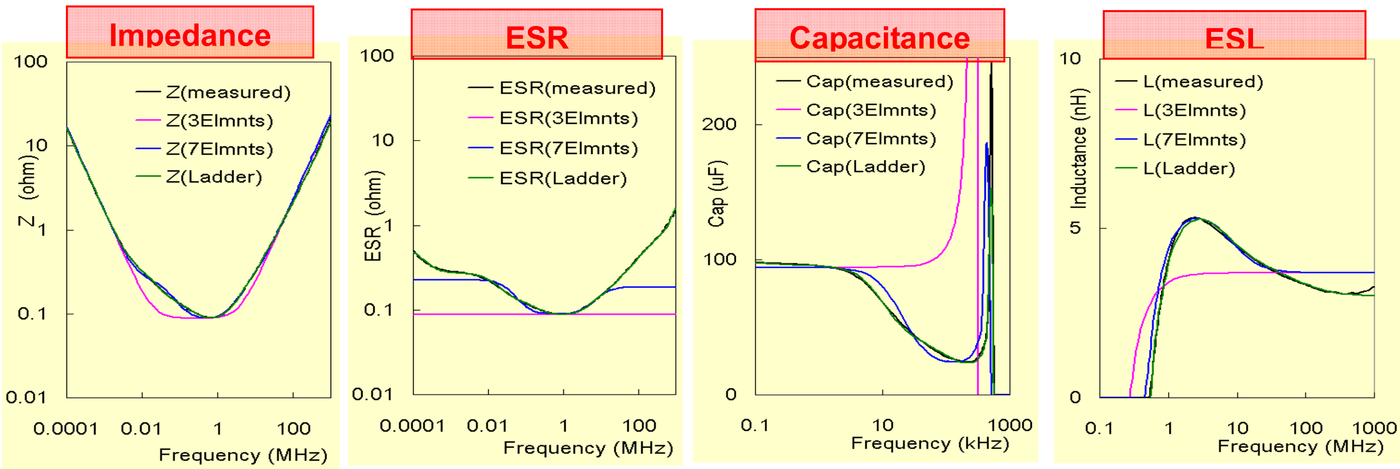
*ESR : Equivalent Series Resistance

Selection of equivalent circuit model

〈Typical equivalent circuit model〉



〈Comparison graph of measured value and simulated value by equivalent circuit model〉



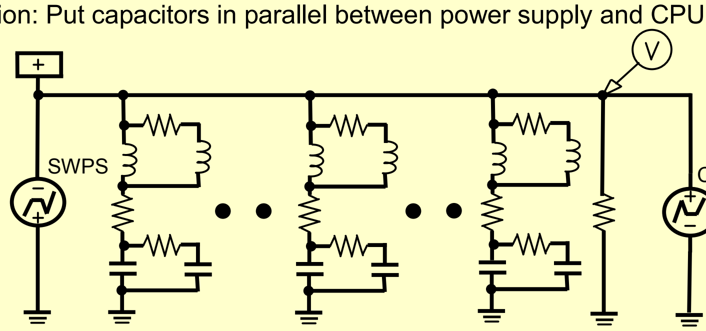
〈Approximation degree by equivalent circuit model〉

Equivalent circuit model	Impedance	ESR	Capacitance	ESL
3 elements	No good	No good	No good	No good
7 elements	Good	No good	Good	Good
Ladder model	Good	Good	Good	Good

Because of its approximation degree to the measured value ladder model is adopted for the simulation.

Setting of circuit conditions

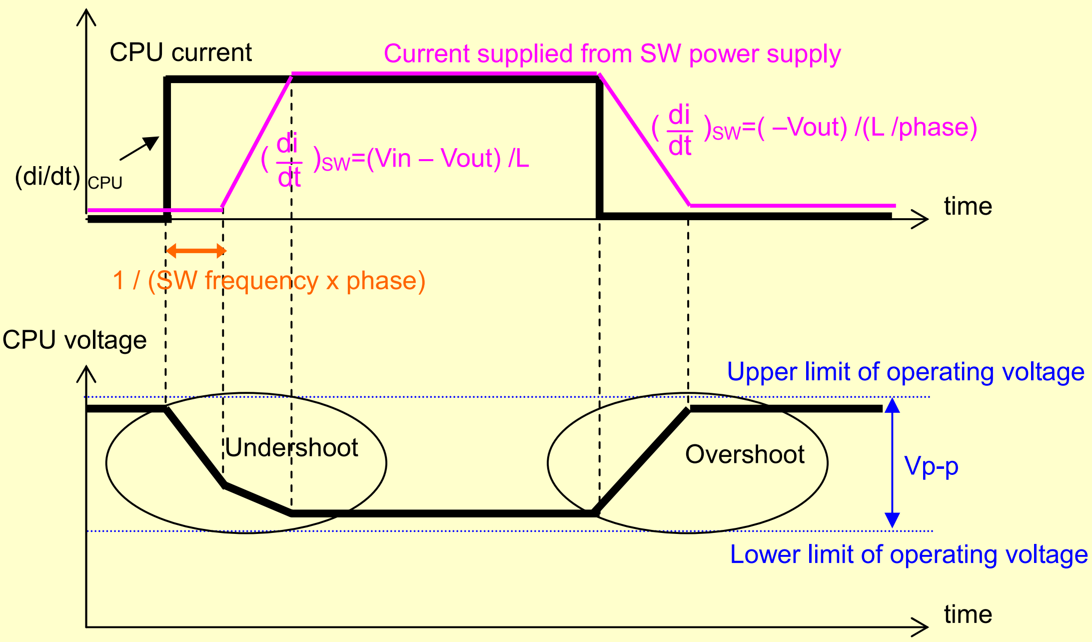
Circuit condition: Put capacitors in parallel between power supply and CPU as described below.



The number of capacitors is calculated using a P Spice circuit simulator under the following conditions of the application.

When CPU voltage varies and current is managed, CPU performance is optimized.

Operating current and ramp up time $(di/dt)_{CPU}$ of CPU conditions.
Operating voltage (Vout) and range of CPU (Vp-p)
Switching frequency and phase of SW power supply
Inductance of PCC (Power Choke Coil) (L) of SW power supply
Min. input voltage (Vin) of SW power supply

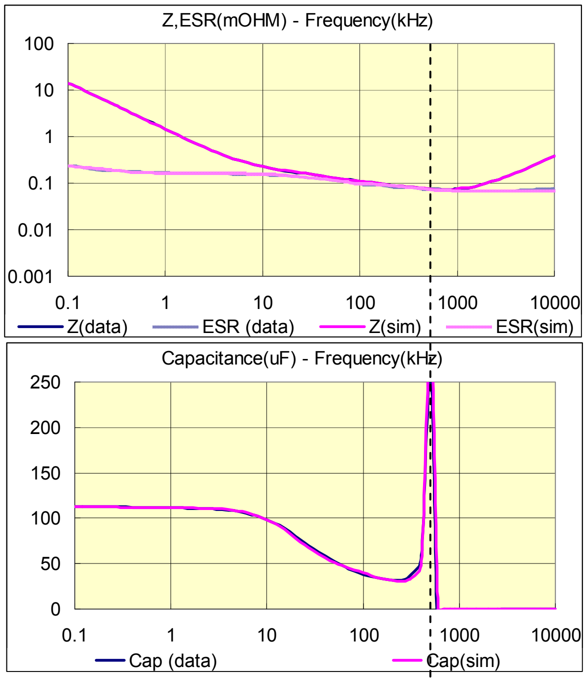


It takes time for the SW power supply to respond to the CPU when it turns on
→ Capacitors are necessary to smoothly transfer the voltage from the CPU start-up.

Estimation of capacitance-frequency characteristics Using the Ladder model

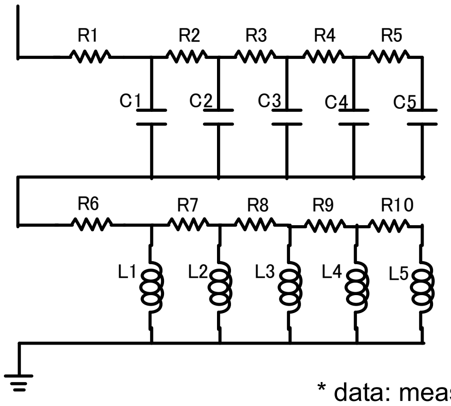
LCR meters are unable to measure capacitance at the resonance point frequencies and above. Using an LCR 20-element ladder model, we propose estimating the behavior of the measured capacitance-frequency characteristics around the point of resonance.

Ref. Low ESR Tantalum (D-size 10V100uF)



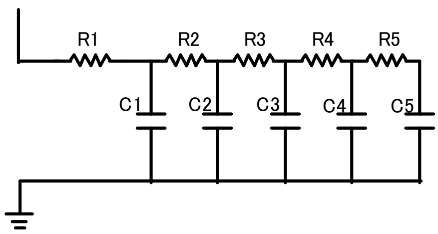
Resonance Point

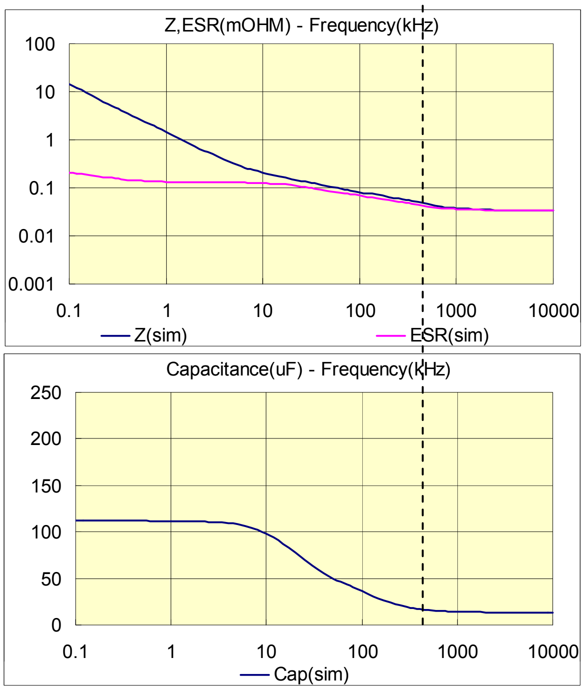
Creation of the capacitance-frequency characteristics excluding the effects of inductance



* data: measured
sim: ladder model

Removal of the R-L circuit





Estimation of capacitance characteristics at high frequency

5. Example of simulation

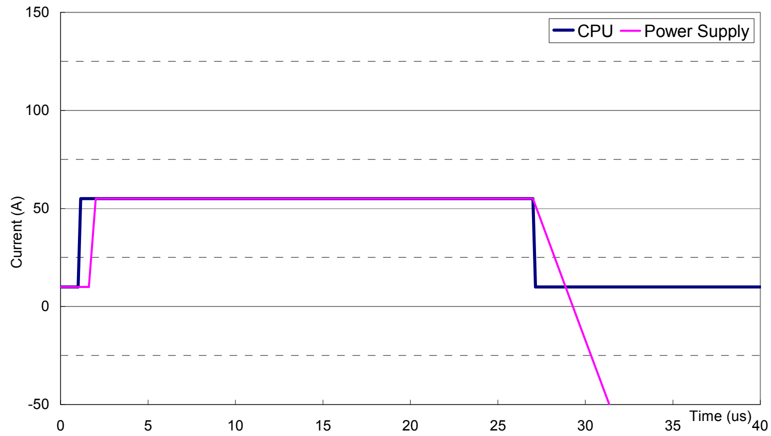
Example of simulation (1)

Circuit conditions

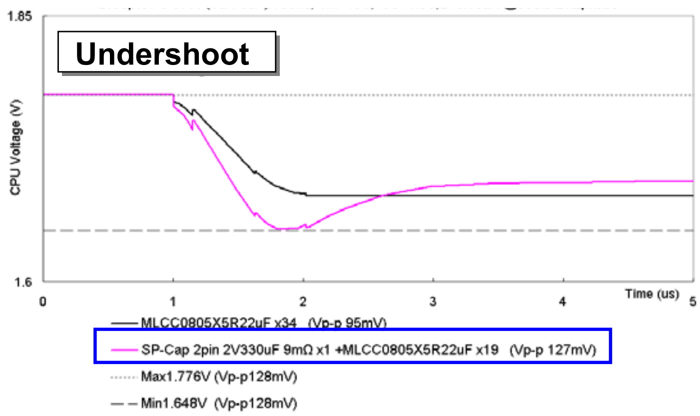
Vin	19V
Vout	1.8V
Load Line Z	2.4mohm

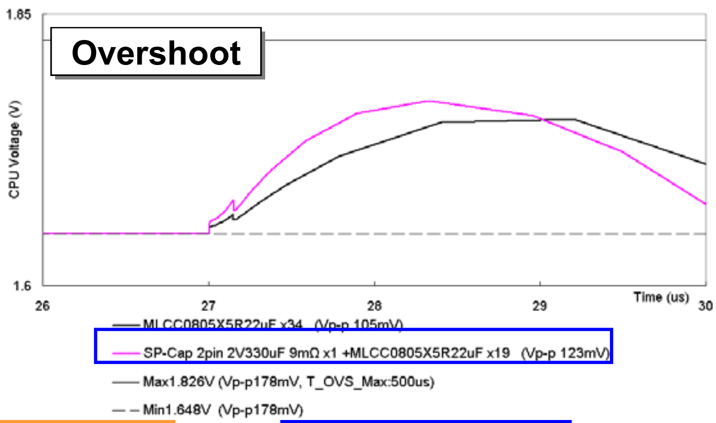
Ipeak (leak)	55A (10A)
CPU Slew Rate	300 A/us
Switching Freq.	800kHz
Phase	2
Inductance	0.15uH

Current behavior of CPU and Power Supply

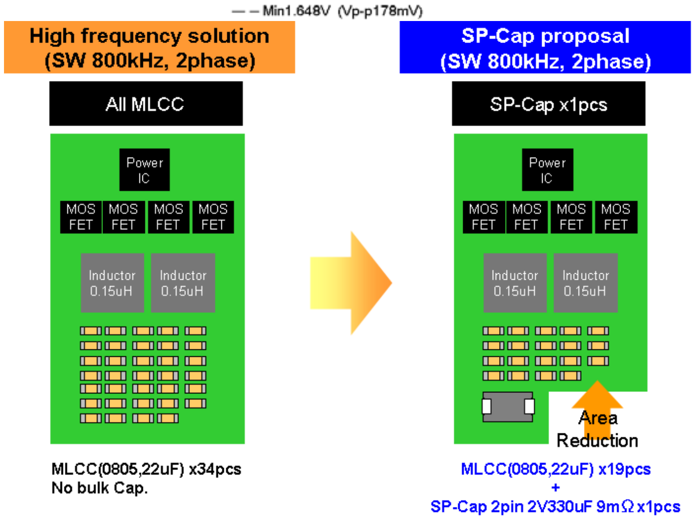


Transient response simulation results





SP-Cap proposal for CPU Vcore



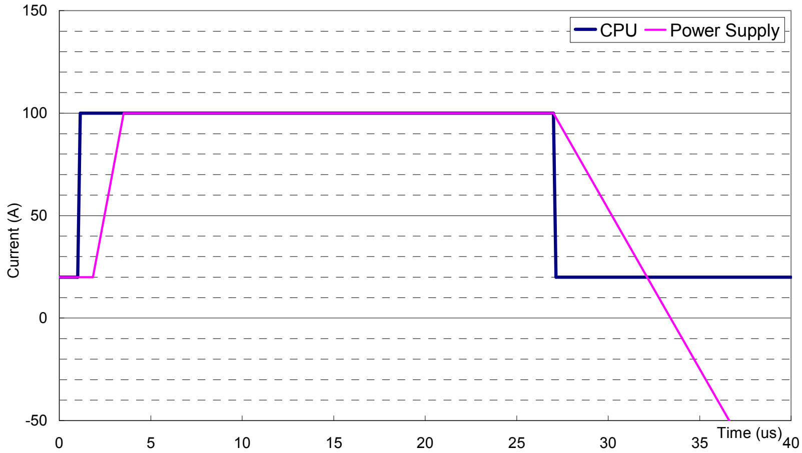
Example of simulation (2)

Circuit conditions

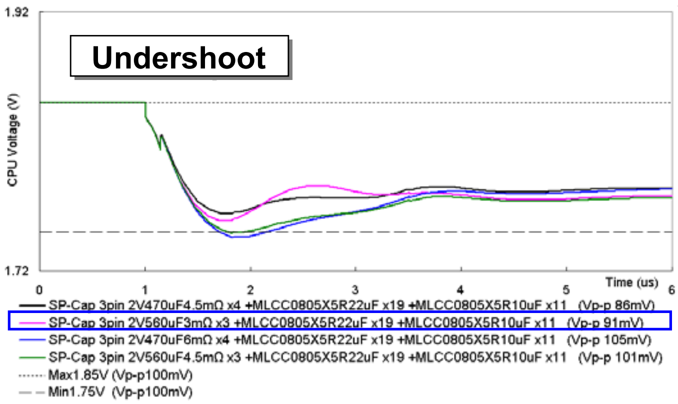
Vin	19V
Vout	1.85V

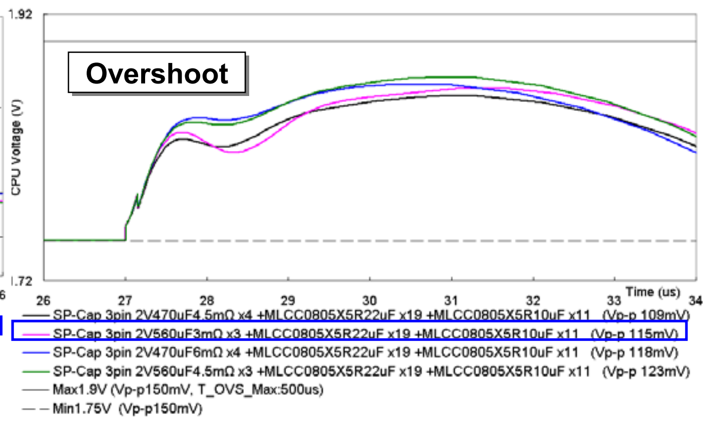
Ipeak (leak)	100A (20A)
CPU Slew Rate	533A /us
Switching Freq.	400kHz
Phase	3
Inductance	0.36uH

Current behavior of CPU and Power



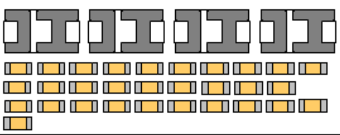
Transient response simulation results





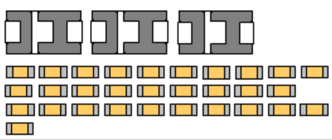
SP-Cap proposal for CPU Vcore

Reference



Capacitor	Q'ty
SP-Cap P/N: EEFLX0D471R4 3pin, 2V470uF, 4.5mΩ	4
MLCC 22uF(X5R,0805)	19
MLCC 10uF(X5R,0805)	11

Our Proposal



Capacitor	Q'ty
SP-Cap P/N: EEFGX0D561L 3pin, 2V560uF, 3mΩ	3
MLCC 22uF(X5R,0805)	19
MLCC 10uF(X5R,0805)	11

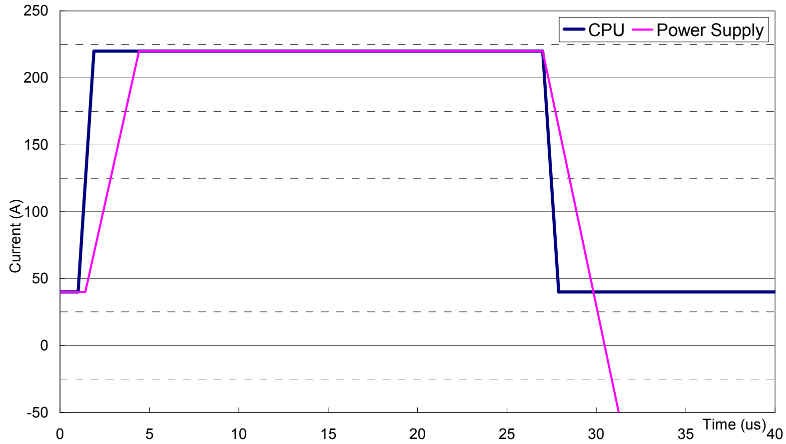
Example of simulation (3)

Circuit conditions

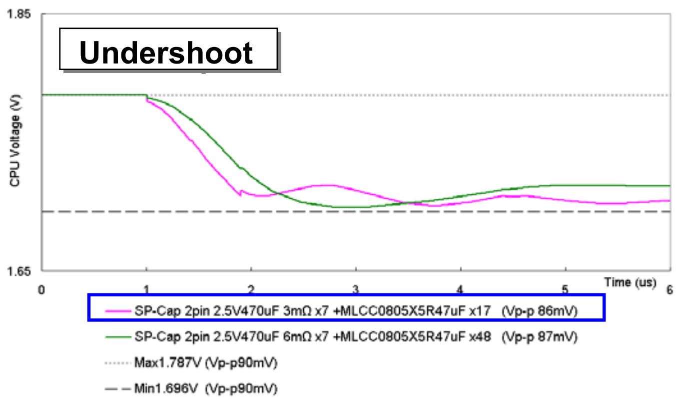
Vin	12V
Vout	1.8V
Load Line Z	0.3mΩ

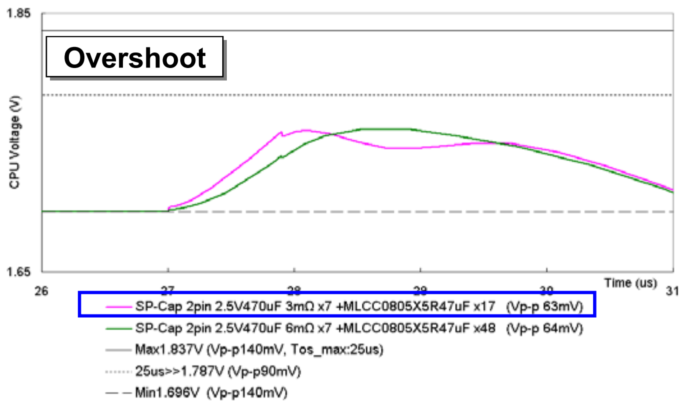
Ipeak (leak)	220A (40A)
CPU Slew Rate	200 A /us
Switching Freq.	400kHz
Phase	6
Inductance	0.17uH

Current behavior of CPU and Power



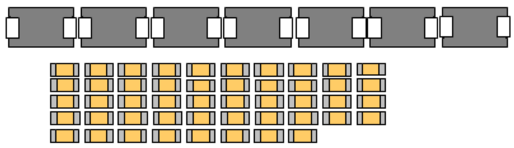
Transient response simulation results





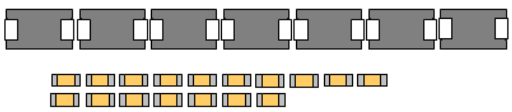
SP-Cap proposal for CPU Vcore

Reference



Capacitor	Q'ty
SP-Cap: 2pin, 2.5V470uF, 6mΩ	7
MLCC 47uF(X5R,0805)	48

Our Proposal



Capacitor	Q'ty
SP-Cap: 2pin, 2.5V470uF, 3mΩ	7
MLCC 47uF(X5R,0805)	17

6. Safety and Reliability

Safety

The Conductive polymer aluminum electrolytic capacitor (SP-Cap) is a capacitor more difficult to"smoke" and ignite than a tantalum capacitor.
The capacitor will not "red-heat" or ignite even if 10A current is applied, even in case of short circuit.

Safety test

A constant current was passed through a short-circuited product, and the product was observed to check for smoking and ignition.

- Test conditions

To short-circuit, an overvoltage of 30 V DC was applied to a capacitor at room temperature, and then a constant current was applied to the capacitor for two minutes.

- Test results

The presence or absence of smoke and the number of capacitors that red-heated and ignited are shown below (unit: piece)

Conductive polymer aluminum electrolytic capacitor 6.3V 100μF (7.3 x 4.3 x 1.9)

Current (A)	Test quantity	Not smoked	Smoked	Red-heated and ignited
1	50	50	0	0
2	50	50	0	0
5	50	35	15	0
7	50	8	42	0
10	50	2	48	0

In the conditions shown above, red-heating and ignition were not identified.

The smoke emitted in the tests above was analyzed.　As a result, harmful substances were not detected.
(Detail: carbon dioxide <0.34mg, carbon monoxide <0.53mg, methane gas < 0.19mg/piece)

Tantalum electrolytic capacitor　6.3V150μF　(7.3 x 4.3 x 2.8)

Current (A)	Test quantity	Not smoked	Smoked	Red-heated and ignited
1	50	50	0	0
2	50	25	25	0
3	50	8	8	34
4	50	N/A	N/A	50
5	50	N/A	M/A	50

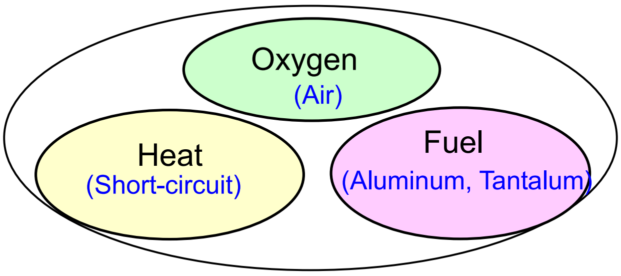
*This test data is simply the results obtained from the reference tests and actual data may vary on actual application.

The Conductive Polymer capacitor is difficult to "smoke" and ignite

It is because:

- *** Aluminum is more difficult to burn than tantalum.**
- *** Conductive polymer emits less oxygen than manganese dioxide.**

Three elements of combustion



∗For substances to burn,
the three elements of combustion - heat, fuel, oxygen - are mandatory. If one of them is not present, burning will not occur.

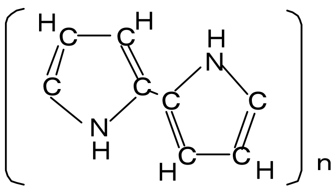
Aluminum is more difficult to burn than tantalum.

	SP-Cap	Tantalum capacitor
Burning reaction	$Al + O_2$	$Ta + O_2$
Reaction start temperature	400ºC ~ 600ºC	250ºC ~ 450ºC
Activation energy	170kJ/mol	115kJ/mol

∗Reaction becomes easier when the activation energy is lower.
→Tantalum is more readily bound to oxygen (O_2), and burns at low temperatures than aluminum.

Conductive polymer does not produce oxygen.

Conductive polymer



Manganese dioxide

MnO_2
Example of the oxygen release reaction of manganese dioxide
$4MnO_2 \rightarrow 2Mn_2O_3 + O_2$

→ Manganese dioxide releases oxygen to cause combustion.

Aluminum is more difficult to bind with oxygen than tantalum, and conductive polymer will release less oxygen than manganese dioxide.

As a result, the SP-Cap is more difficult to "smoke" and ignite than a tantalum capacitor.

Reliability

The Conductive Polymer Aluminum Electrolytic Capacitor (SP-Cap) is a capacitor more difficult to short-circuit than a tantalum capacitor.

Reliability test

Capacitors weretested for possible short-circuiting or burnout when voltage is applied in a high temperature environment.

- Test conditions

Test temperature	: 85 to 145°C
Applied voltage	: Rated voltage (W.V.) x (0.8 to 1.25)
Test time	: 1,000 hours (without protective resistance)
Quantity of specimens	: n = 20 for each condition

- Test results

The number of capacitors short-circuited or burned out are shown below.

Conductive polymer aluminum electrolytic capacitor 6.3V 100μF(7.3 x 4.3 x 1.9)

	0.8 x R.V.	R.V.	1.1 x R.V.	1.25 x R.V.
85℃	0	0	0	0
105℃	0	0	0	0
125℃	0	0	0	0
145℃	0	0	0	0

During the test, short-circuits did not occur under each of all the conditions.

Tantalum capacitor 6.3V 220μF(7.3 x 4.3 x 2.8)

	0.8 x R.V.	R.V.	1.1 x R.V.	1.25 x R.V.
85℃	0	0	0	0
105℃	0	0	0	1
125℃	0	0	0	3
145℃	1	0	0	0

The short-circuited products were all burned out.
Normally, when the atmospheric temperature and voltage become higher, a product tends to short-circuit.

Predicted failure rate of SP-Cap

- As a result of our reliability test, the following data could be obtained.
  Failure rate resulting from the temperature accelerated test: 8.2 Fit or less (Predicted failure rate when the temperature is 105°C and the rated voltage is applied)
- Predicted market failure rate: 0.13 Fit or less (c = 0, predicted failure rate when reliability level is 60%)

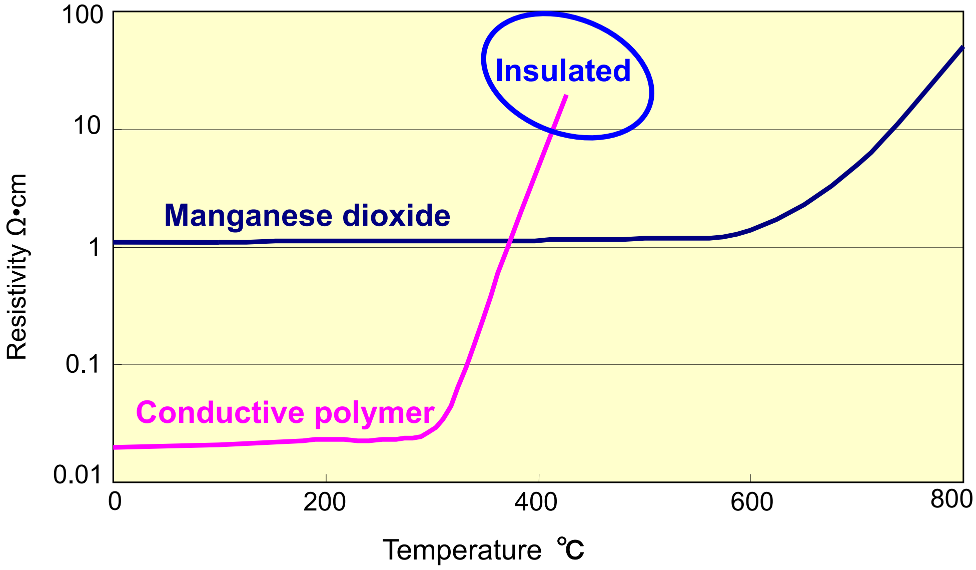
*This failure rate is for reference only. Actual failure rates may vary in actual applications.

The SP-Cap is difficult to short-circuit

The conductive polymer is a substance (electrolyte) whose resistance rises with temperature.

When a defect occurs in the dielectric, the joule heat of the current flowing trough the defect raises the resistance of the polymer to the point that it becomes self-insulating and shuts off the current flow.

Resistivity with respect to temperature



The conductive polymer insulates itself at a low temperature as compared with manganese dioxide.
As a result, SP-Cap is more difficult to short-circuit than a tantalum capacitor.

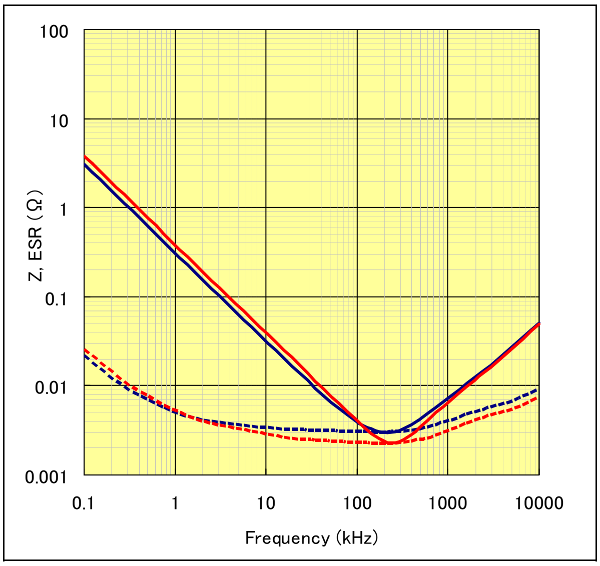
7. Reliability Test Data

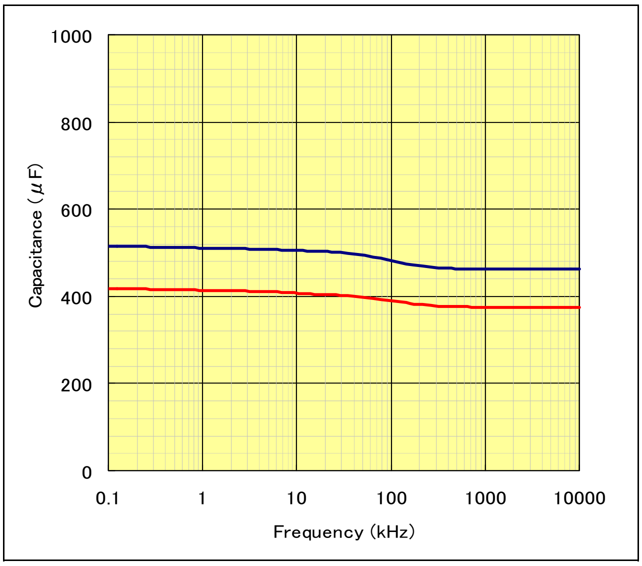
Frequency characteristics*

Z, ESR - Frequency / Capacitance - Frequency

■ SX Series

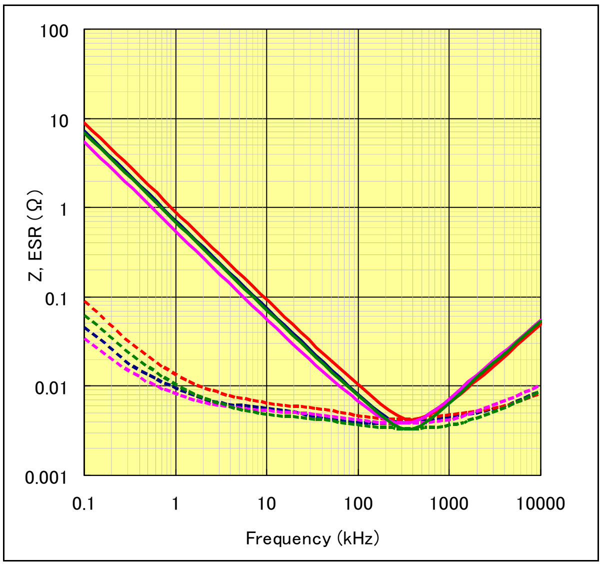
EEFSX0E471E4 **EEFSX0D561E4**

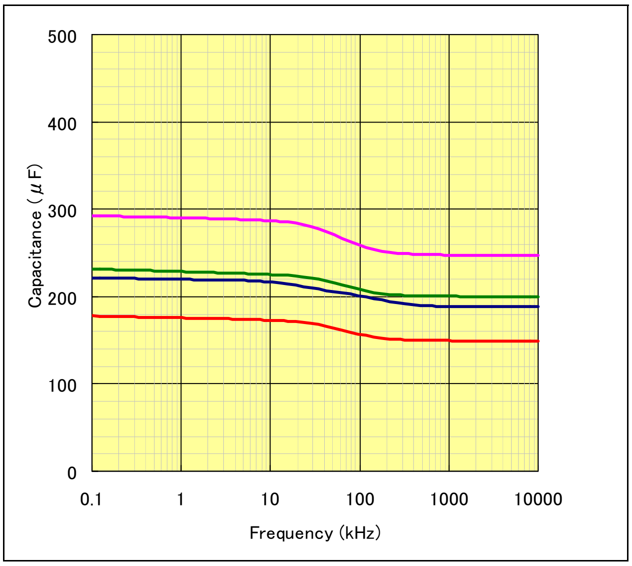




■ ST-SS Series

EEFSS0D221R **EEFSS0E181R** **EEFST0D331R** **EEFST0E271R**





* Please refer to ' Estimation of capacitance-frequency characteristics using the ladder model' on page16.

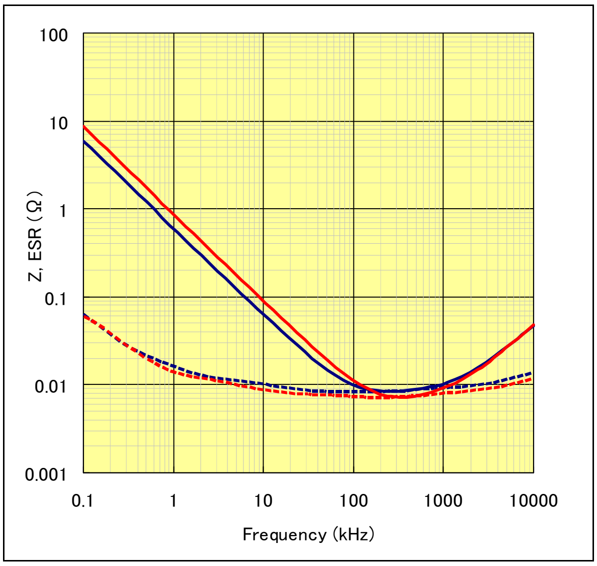
Frequency characteristics*

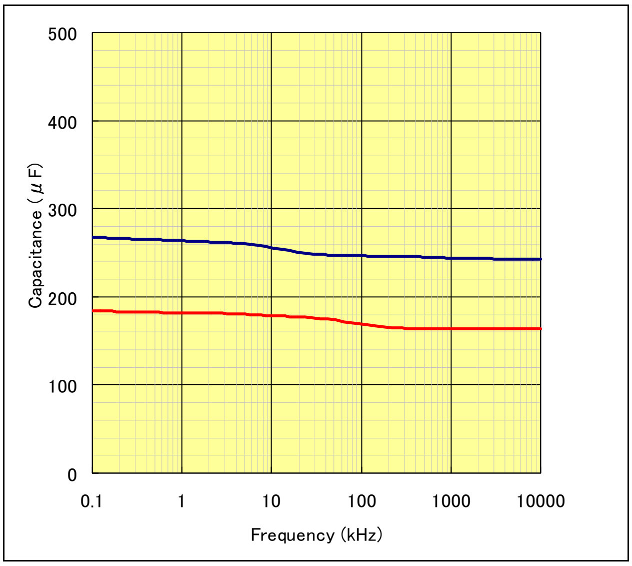
Z, ESR - Frequency

Capacitance - Frequency

■ CX Series

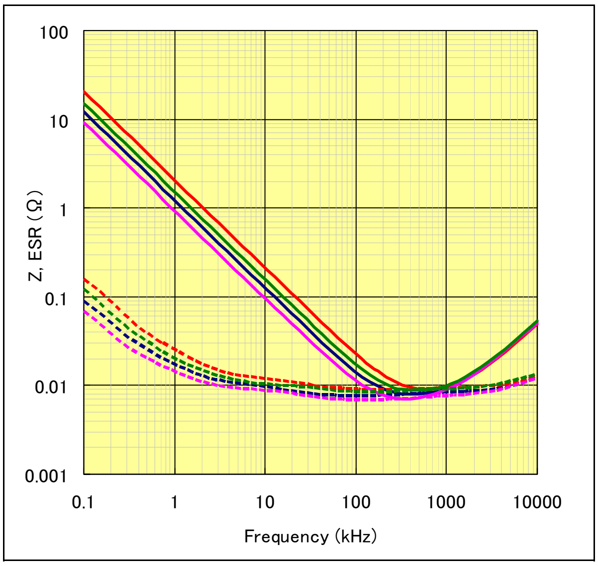
EEFCX0G271R EEFCX0J181R

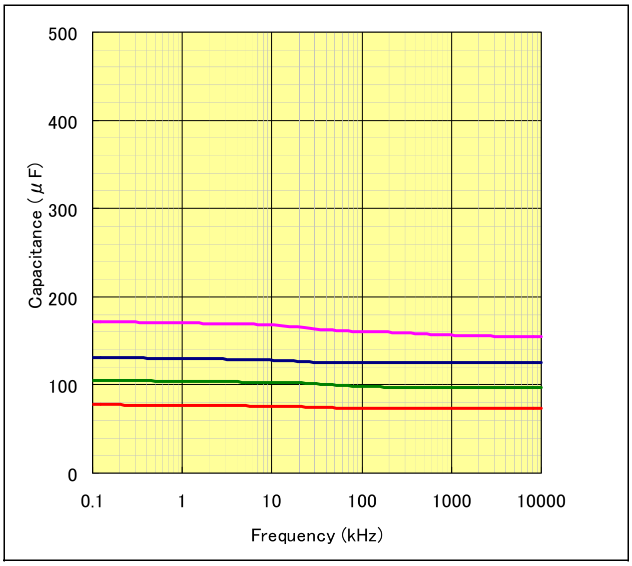




■ CT-CS Series

EEFCS0G121R EEFCS0J680R EEFCT0G181R EEFCT0J101R





* Please refer to ' Estimation of capacitance-frequency characteristics using the ladder model' on page16.

MEMO

Technical Guide of Conductive Polymer Aluminum Electrolytic Capacitors

The first edition : October 1st 2000
The sixth edition : November 1st 2015

Issued by Automotive & Industrial Systems Company Panasonic Co., Ltd.
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