Panasonic

Technical Guide

Conductive Polymer Aluminum Solid capacitors

OS-CON

2017.02 | industrial.panasonic.com/ww/products/capacitors

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OS-CON™ Technical Guide

INDEX

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Feature

”OS-CON” use high conductive polymer to achieve low equivalent series resistance (ESR), excellent noise reduction capability and ideal frequency.

〈 Low ESR by using conductive polymer〉

- ○ Suitable as a decoupling capacitor to remove noises, because its impedance has ideal frequency characteristics.
- ○ Suitable as a smoothing capacitor for switching power supply because it allows large ripple current.
- ○ Suitable as a backup capacitor for the circuits that consumes large current at a

〈 Environmental responsibility 〉

- ○ All models are completely Pb-free and RoHS compliant.

〈 Long lifetime 〉

- ○ The estimated lifetime of OS-CON is 10 times when ambient temperature decreases by 20 ℃ (10 times by 20 ℃ reduction)

〈 Superior temperature characteristics 〉

- ○ ESR has stable characteristics at when operating between -55℃ and 105℃, suitable for applications used at low temperatures (under 0℃).

〈 Wide capacitance range 《3.3 μF～ 2700 μF》 〉

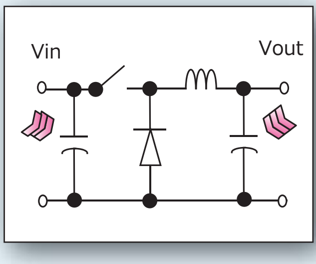
- ○ An array of various series covers wide capacitance range.

〈 High voltage, high reliability 〉

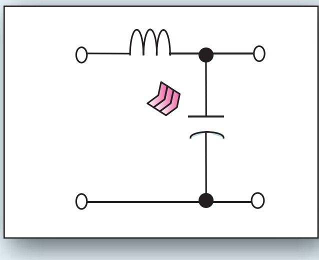
- ○ We have high voltage type 100, 63 V.DC and high reliability products which are available for special purpose such as industrial equipment, automotive etc.

Main use examples

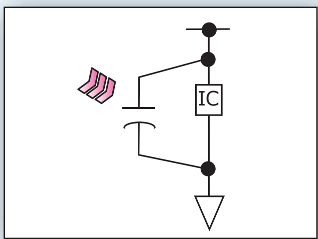
In order to reduce line impedance in circuit designing, various capacitors such as OS-CON are widely used as backup capacitors and bypass capacitors.
Among them, OS-CON characterized with its extra-low ESR can replace general electrolytic capacitors, offering a smaller mounting area, and serves greatly to reduce ripple noise in a smoothing circuit of a switching power supply, which is the most commonly used power supply. OS-CON is also useful in a filter circuit for reducing noise that tends to occur with miniaturizing and digitalizing of electronic systems.
In addition, OS-CON has small characteristics change by temperature. Therefore, in various environments, OS-CON realizes stable operation.These advantages of OS-CON lessen noise-related troubles, and contribute greatly to shortening of circuit designing period and miniaturizing of electronic systems.



◇Smoothing Capacitor in Power Supply Circuit



◇Capacitor in Filter Circuit



◇Backup Capacitor
◇Bypass Capacitor

2-1. Basic structure

2-1.1 OS-CON has a basic construction similar to an aluminum electrolytic capacitor. A distinctive difference lies in electrolyte.

Aluminum electrolytic capacitor	Separator sheet impregnated with electrolytic solution	Liquid electrolyte
OS-CON	Separator sheet impregnated with conductive polymer	Solid electrolyte

2-1.2 Basic structure and sectional view

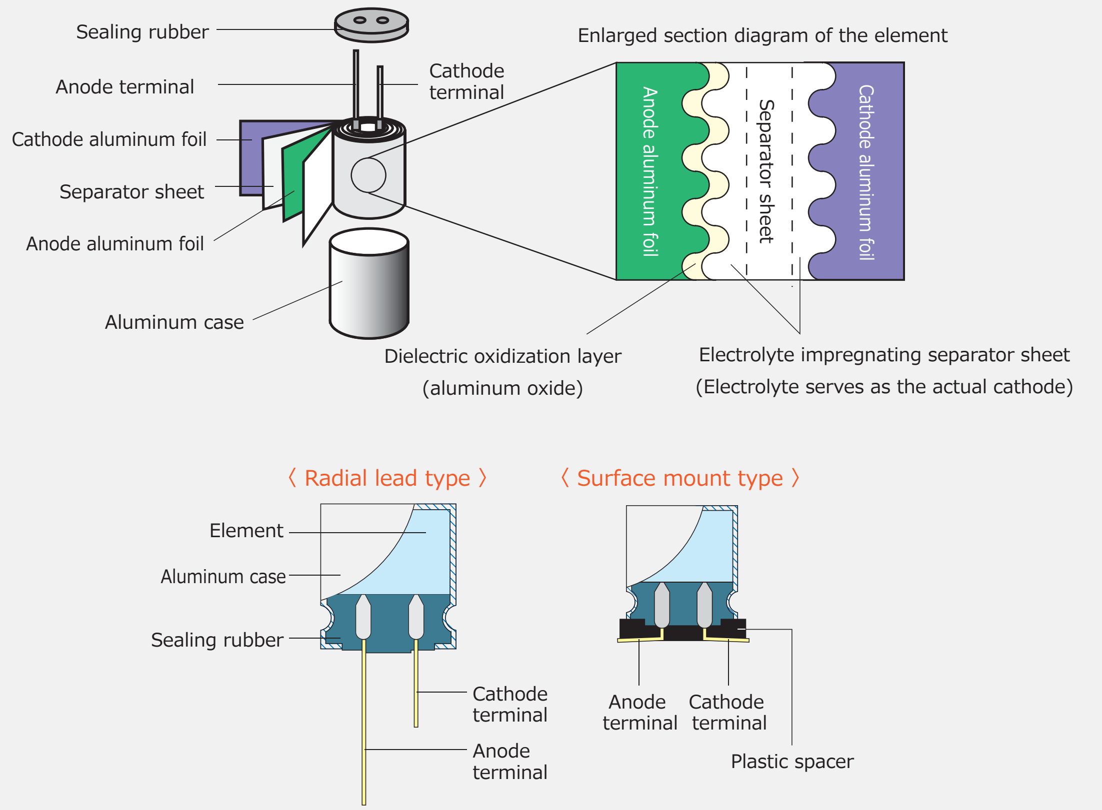


Fig.2-1 Sectional view

2-1.3 Characteristics between OS-CON and aluminum electrolytic capacitor due to a difference in electrolyte

	Aluminum electrolytic capacitor	OS-CON
Conductivity	0.01 S / cm	100 S / cm
	・Difficult to lower ESR due to low conductivity ・ESR augments, in particular, in low temperature conditions	・The highest electronic conductivity, realizing super low ESR. ・ESR is stable in low temperature conditions
Reliability, lifespan	・Liquid electrolyte is evaporable at high temperature ・Static capacitance is on the decline at high temperature ・Limited lifespan resulting from dry-up ・Major fluctuations in temperature characteristics	・Little evaporation due to solid electrolyte ・Little decrease in static capacitance ・Long lifespan even at high temperature ・Very minor fluctuations in temperature characteristics
Temperature coefficient (for lifespan)	2 times by 10℃ reduction	10 times by 20℃ reduction
	105℃ / 2000 h → 85℃ / 8000 h	105℃ / 2000 h → 85℃ / 20000 h

※Please contact us separately if you require life factor of SXV, SXE series.

3-1. Explanation of the rush current suppression methods

When the OS-CON is used in the following circuit as Fig.3-1, a rush current may flow because the ESR is extremely small. Maintain the rush current at 10A or less.
If as long as 10 times of the allowable ripple current of the OS-CON exceeds 10A, reconfigure so that the ripple current does not exceed 10 times.

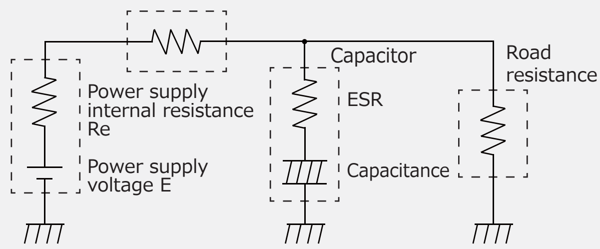


Fig.3-1 Circuit diagram

3-1.1 DC-DC converter input circuits

(a) DC-DC converter circuits are usually a PCB block shape and use a low ESR capacitor in the input section for high performance and miniaturization.
(b) Consideration must be given to the rush current that flows from the equipment when the DC-DC converter is adjusted and inspected.

∗There is the possibility that an extremely large amount of a rush current will flow through the OS-CON during voltage adjustment or inspection of the DC-DC converter 's circuit block when the power impedance supplied from the equipment being adjusted or inspected is exceedingly low and the current suppression function of the current limiter and such is provided. (Refer to Fig.3-1)

∗A rush current suppression measures must be taken for DC-DC converter adjustment and inspection equipment.

3-1.2 Circuits driven by chargeable batteries

Circuit power lines equipped with batteries or rechargeable batteries use capacitors such as the OS-CON with extremely low ESR to increase performance and facilitate miniaturization.

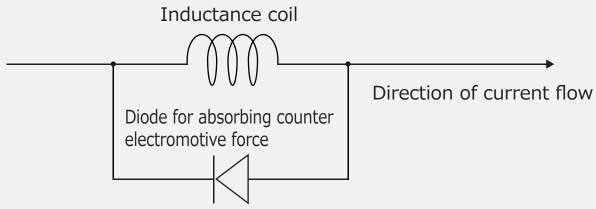


Fig.3-2

∗There is the possibility of an extremely large amount of a rush current flowing through the low ESR capacitors arranged along the power line when the power is turned on for circuits driven by nickel cadmium chargeable batteries etc. That have a very low internal resistance. (Refer to Fig.3-1)

∗A protection circuit like that is Fig.3-2 is usually used to suppress rush current of charging battery.

∗The main points.
The peak current value of the diode when absorbing counter electromotive force.

3-1.3 A rush current without protection resistor

When there is no protection resistor Z as shown in Fig.3-1 and the power supply has Re nearly = 0 Ω, The OS-CON rush current is as follows.

$$\text{A rush current (A)} = \frac{\text{Supplied DC voltage (E)}}{\text{ESR} + \text{Re} + \text{Z}\ (\Omega)}$$

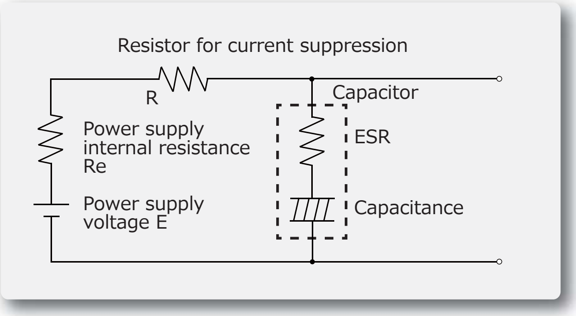
Example : For 25SVPD10M

ESR=65 mΩ or less / Supplied voltage=20 V.DC

$$\frac{\text{20 V.DC}}{\text{less than 0.65 }\Omega} = \text{300 A or more}$$

3-2. Example of rush current suppression methods

3-2.1 Resistor method



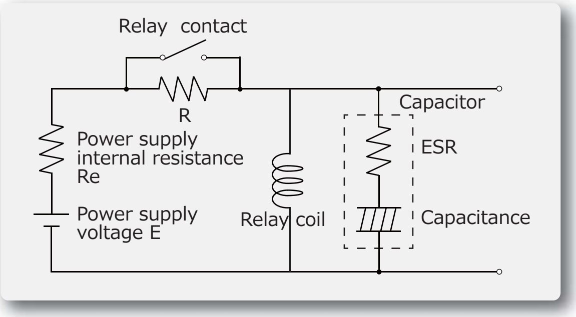
(a)Rush current is as shown below.

$$\text{Rush current (A)} = \frac{\text{E (V.DC)}}{\text{Re + ESR + R }(\Omega)}$$

(b)Rush current is usually determined mainly by R as Re and ESR are low.

(c) Although the current is simply and clearly suppressed with this method, resister R for suppressing current causes the voltage to drop.

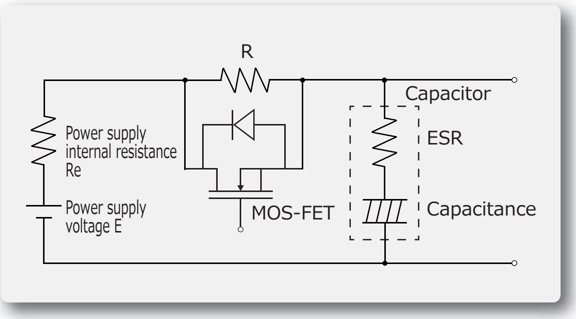
3-2.2 Resistor and relay method



(a) A rush current is exactly the same as in the resistor method. There is almost no voltage drop caused by the current suppression resistor from the time the relay contact goes on.

(b)Note:
After the capacitor has finished recharging, it may take some time or setting of voltage to turn the relay ON.

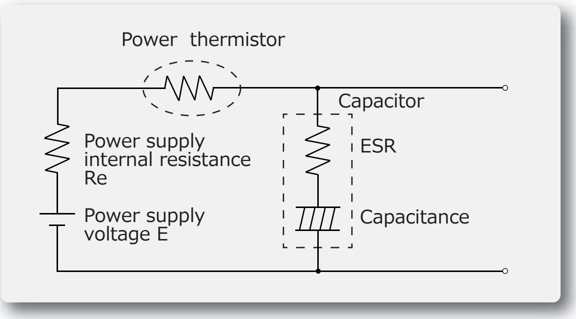
3-2.3 Resistor and MOS-FET method



(a)Resistor method is exactly the same to using suppressed resistor R to suppress a large current rush. There is almost no voltage drop caused by suppressed resistor after MOS-FET is on.

(b)Note:
As with the resistor and relay method, after the capacitor has finished recharging, it may take some time or setting of voltage to turn the MOS-FET ON.

3-2.4 Power thermistor



(a)Taking an example of a common power thermistor, the value is 8Ω at 25℃, but becomes 0.62Ω at 130℃.

(b)When the power thermistor is connected as shown in the above diagram, rush current is suppressed due to the large resistor value at the moment the switch is turned on.
The output loss (voltage drop) is reduced after this.

(c)The power thermistor has a heat constant, meaning that the large resistor value in the initial state cannot be regained the moment the switch is turned off.
As a result, the ability to suppress current is lost when the switch is turned off and on quickly.

3-3. Sudden discharge current suppression

OS-CON has an exceedingly low ESR. When the load impedance during discharge is extremely low, there is the chance that it allows a large amount of discharge current to flow for an instant.
There is the chance an extremely large amount of discharge current will flow when electric charge is discharged with 0Ω loading.

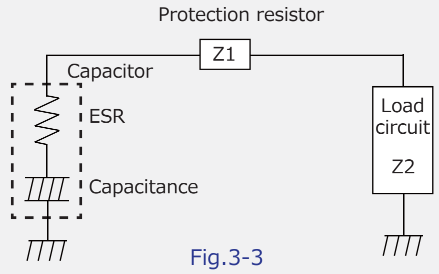


Fig.3-3

*The discharge equivalent circuit is as shown to the Fig.3-3.
*The formula for estimating discharge current is given below.

$$\text{Discharge current (A)} = \frac{\text{Charging voltage (E)}}{\text{ESR} + \text{Z1} + \text{Z2}\ (\Omega)}$$

Example : For 25SVPD10M
・ESR : 65 mΩ or less
・Charging voltage : 20 V.DC
・Z1、Z2 : 0 Ω

$$\text{Discharge current (A)} = \frac{\text{Charging voltage 20 V.DC}}{\text{ESR 0.65 }\Omega\text{ or less}} = \text{300 A or more}$$

When the OS-CON is to be used in sudden discharge operations, configure the circuit so that the peak discharge current becomes 10A or less, using the above mentioned rough estimate expression as a guide. However, if 10 times the allowable ripple current of the OS-CON exceeds 10A, reconfigure so that 10 times the allowable ripple current is not exceeded.

3-4. Precautions when connecting an OS-CON and an aluminum electrolytic capacitor in parallel

Aluminum electrolytic capacitors and OS-CON are often connected in parallel to improve circuit density an cost performance of ripple absorbing capacitors as follows.

(a) Ripple current flowing through each parallelly connected capacitor can be found by using the values symbolized in the reference equivalent circuit in Fig.3-4.
(b)The equivalent circuit in Fig.3-4 can be simplified as shown in Fig.3-5 when it is to be used for frequencies between 100kHz and a few MHz. (Assuming the capacitor's capacitance is more than 10μF.)

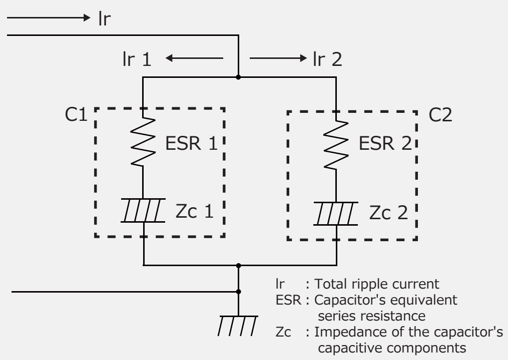


Fig.3-4

Since impedance becomes exceedingly low when the capacity is more than 10μF. And frequencies higher than 100 kHz, each Zc in Fig.3-4 can be omitted changing the actual ripple current value to that shown in Fig.3-5.

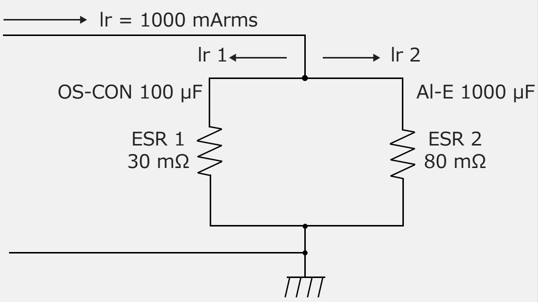


Fig.3-5

【Formula for calculating the ripple current value】

$$\text{Ir1} = \text{Ir} \times \frac{\text{ESR 2}}{\text{ESR 1} + \text{ESR 2}} = 1000\ \text{mA} \times \frac{80\ \text{m}\Omega}{30\ \text{m}\Omega + 80\ \text{m}\Omega} \fallingdotseq 727\ \text{mArms}$$

(c)As shown here, although the OS-CON has 1/10th of the capacitance that of the mated capacitor, it allows 73% of the total ripple current to flow.
(d)When OS-CON and an aluminum electrolytic capacitor are to be used in parallel connection, select the appropriate type of OS-CON that has an extra margin of capacity since a large amount of ripple current flows through it.

4-1. Temperature acceleration test (Endurance)

The decrease in capacitance of the OS-CON depends on temperature.
Fig.4-1 shows the speed of capacitance decrease at each temperature.
This graph indicates that temperature coefficient of the OS-CON lifetime is 10 times by 20℃ reduction.

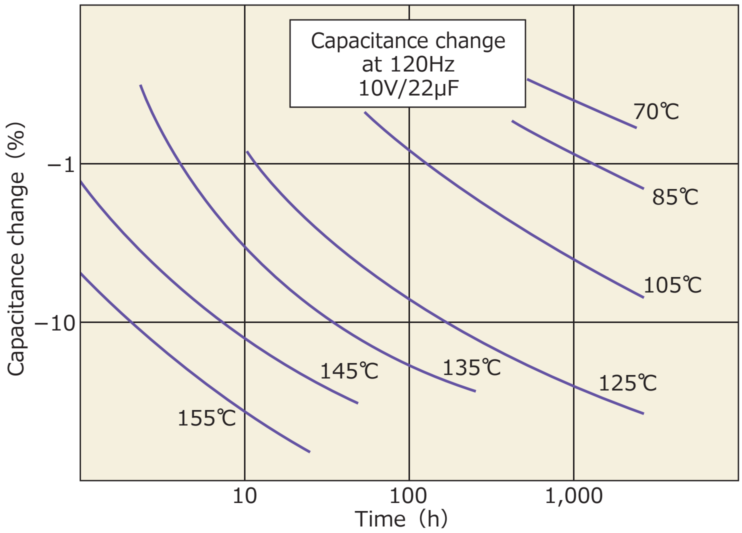


Fig.4-1

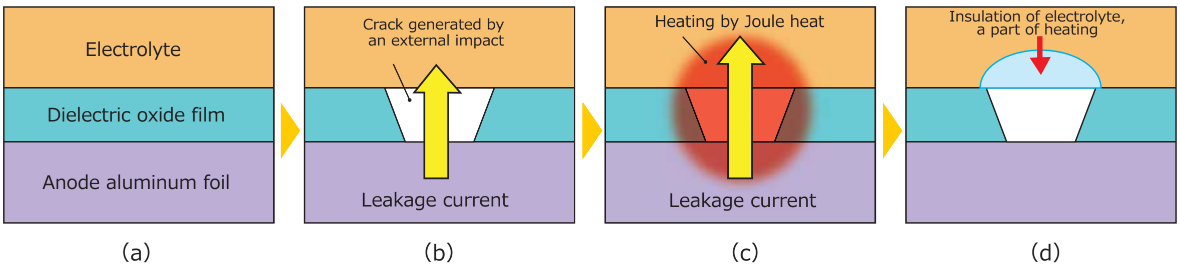
OS-CON	Aluminum electrolytic capacitor
105℃ ⇒ 2000 h	105℃ ⇒ 2000 h
95℃ ⇒ 6324 h	95℃ ⇒ 4000 h
85℃ ⇒ 20000 h	85℃ ⇒ 8000 h
75℃ ⇒ 63245 h	75℃ ⇒ 16000 h

※Time is an estimate, not guaranteed.

Though the OS-CON and an aluminum electrolytic capacitors are guaranteed on 2000 hours at 105℃, the life span results in differences as temperature drops.
The OS-CON has a longer life span compared with an aluminum electrolytic capacitor.

4-2. Self-Healing Mechanism

The dielectric substance of the OS-CON is a non-conductive oxide film that has formed on the surface of an anode aluminum foil.
Since the oxide film is solid and thin, leakage current may temporarily increase if micro cracks are generated by external stress (i.e. mechanical, thermal, electrical).
When this happens, the leakage current generates Joule heat and with this heat the electrolyte turns non-conductive and insulates the outlet of the leakage path. The leakage current from the micro cracks is thus suppressed through this function.
This is known as "self-healing mechanism."



4-3. Presumption of life

The capacitance of the OS-CON is getting smaller as time goes with endurance test.
This means wear-failure of the OS-CON is open mode, which is a main failure factor.
The life time is different by each operating temperature and self-heating by ripple current.

4-3.1 Calculating formula for the presumtion of life

$$Lx = Lo \times 10^{\frac{To - Tx}{20}}$$

Lx : Life expectance (h) in actual use (temperature Tx)
Lo : Guaranteed (h) at maximum temperature in use
To : Maximum operating temperature (℃)
Tx : Temperature in actual use (ambient temperature of the OS-CON) (℃)

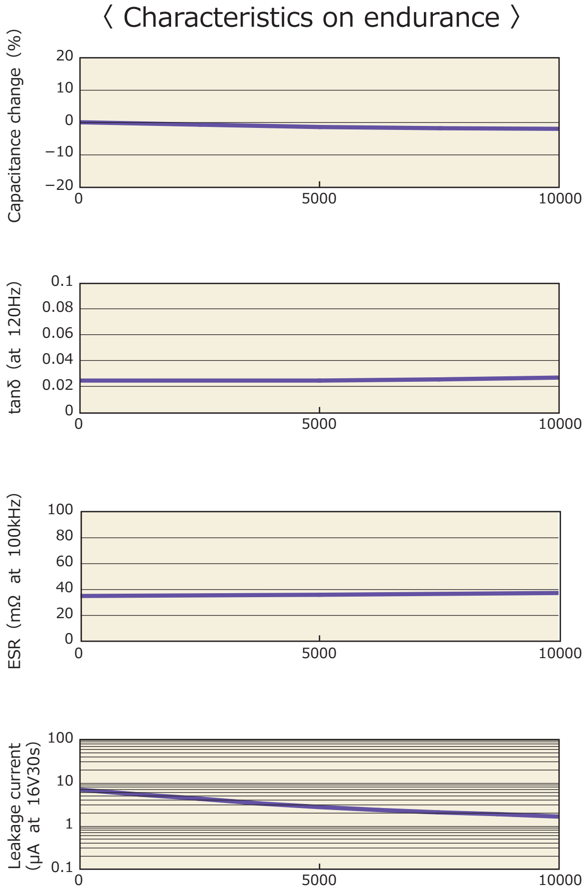
Please contact us separately about estimated life expectancy of “SXV, SXE series” and “SVQP, SVPD, SEQP series” guaranteed at 125℃.

*The estimated life expectancy of conductive polymer electrolyte type can be calculated without consideration of self-heating under application of the ripple current.

4-4. Reliability test（16SVP39M）

4-4.1 Endurance（105℃、16 V.DC applied）

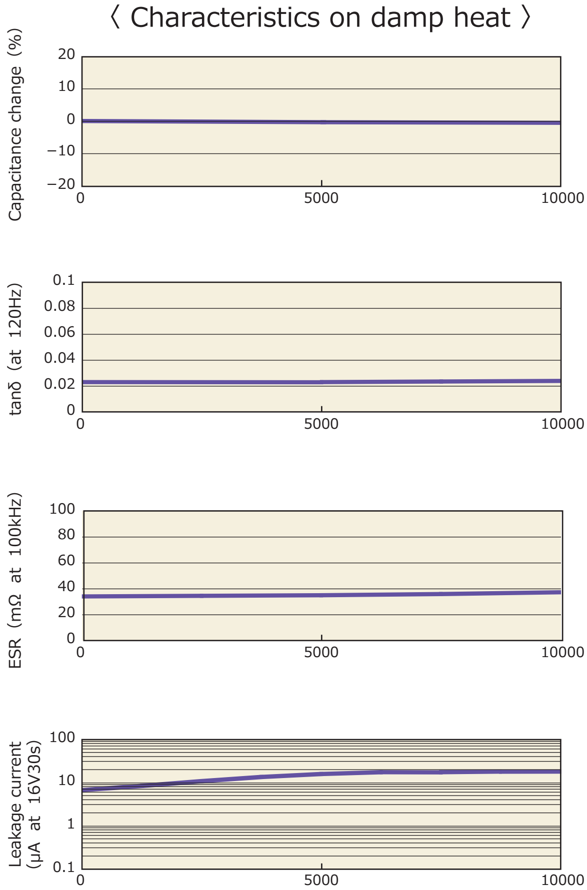
〈 Characteristics on endurance 〉



Little change in characteristics can be seen after 10000 hours because of adoption of conductive polymer that excels in thermal stability.

4-4.2 Damp heat（60℃ 90%RH、without load）

〈 Characteristics on damp heat 〉



Little change in characteristics can be seen after 10000h hours in a high temperature and damp heat environment because of the excellent thermal stability of conductive polymer.

5-1. Frequency characteristics

Fig.5-1 Impedance frequency characteristics
(OS-CON vs other types)

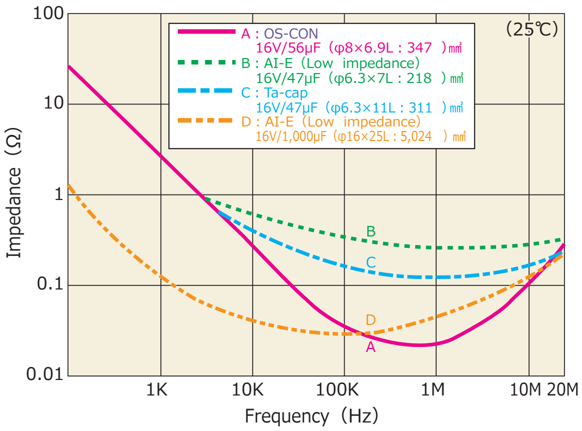
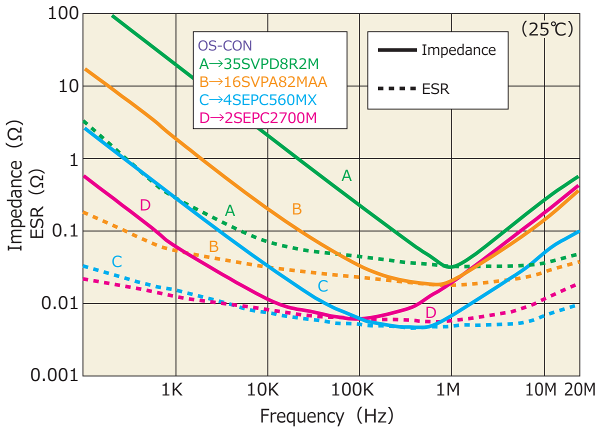


Fig.5-2 Impedance & ESR frequency characteristics
(several OS-CON models)



The OS-CON is an electrolytic capacitor that has excellent frequency characteristics.
It improves ESR greatly, and provides the excellent frequency characteristics because the OS-CON uses a high conductive polymer as electrolyte.

Fig.5-1 : The OS-CON's frequency characteristic shows a nearly ideal curve.
When compared at 100kHz, The OS-CON 56μF, and low impedance aluminum electrolytic capacitor 1000μF nearly have the same feature.

Fig.5-2 : The resonance point of the OS-CON is at 100kHz to 10MHz. The ESR is an extremely small value approximately 5mΩ at 100kHz of 560μF.

5-2. Characteristics at high temperature and low temperature

Fig.5-3 ESR temperature characteristics
(OS-CON vs other types)

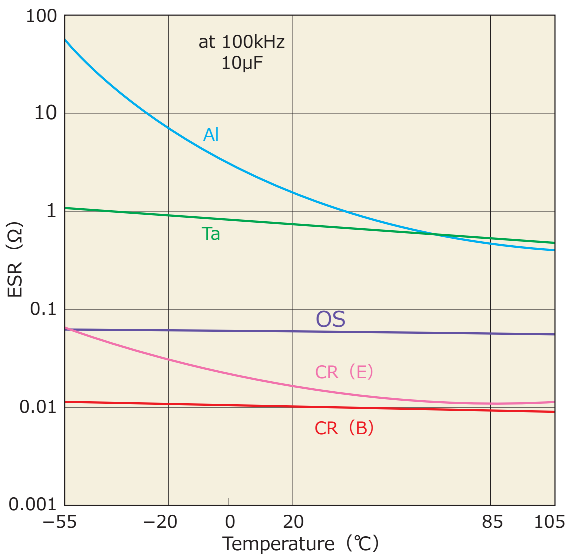
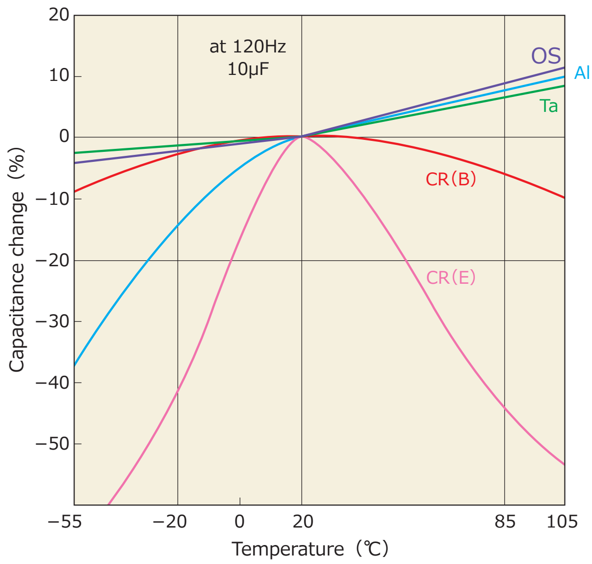


Fig.5-4 Capacitance temperature characteristics
(OS-CON vs other types)

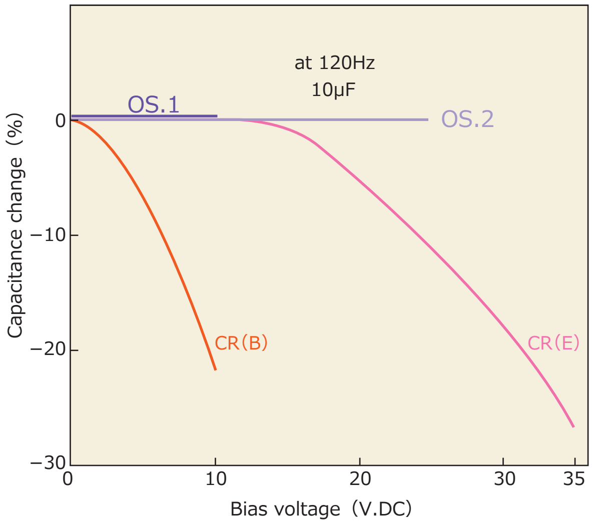


OS-CON's Characteristics at high temperature and low temperature is that it features little change in temperature for the ESR.
What ESR changes a little against temperature means that noise clearing ability changes a little against temperature as well. The OS-CON is suitable for outdoor apparatus.

OS = OS-CON ——— Purple
Al = AL-E. Cap ——— Blue
Ta = Tantalum Cap. ——— Green
CR（B）= Cera Cap. (X5P Type) ——— Red
CR（E）= Cera Cap. (X5U Type) ——— Pink

5-3. Bias characteristics

(a) Capacitance

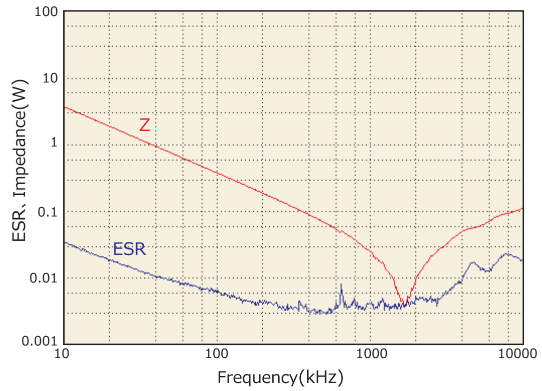


O S.1＝OS-CON(10SVP10M) ——— Purple
O S.2＝OS-CON(25SVPD10M) ——— Light Purple
CR(B)＝Cera cap. ——— Red
(X5P Type ; 10V / 10μF)
CR(E)＝Cera cap. ——— Pink
(X5U Type ; 50V / 10μF)

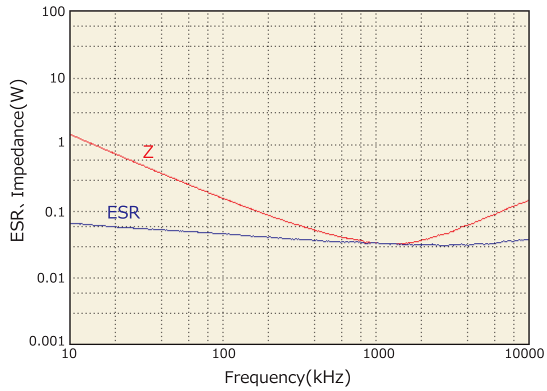
When voltage is applied to ceramic capacitors, they show a bias characteristics where static capacitance is reduced.
Our OS-CON product, however, will show no reduction in capacitance for applied voltage within its rating.

(b) Impedance, ESR (Bias characteristics of OS-CON & ceramic capacitors)

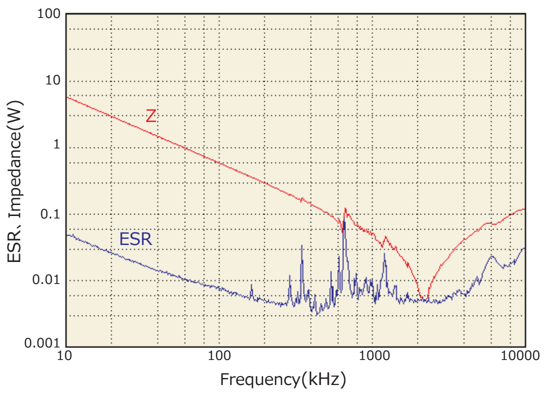
Multi-layer ceramic capacitor (25 V.DC / 4.7 μF)
0 V.DC Bias



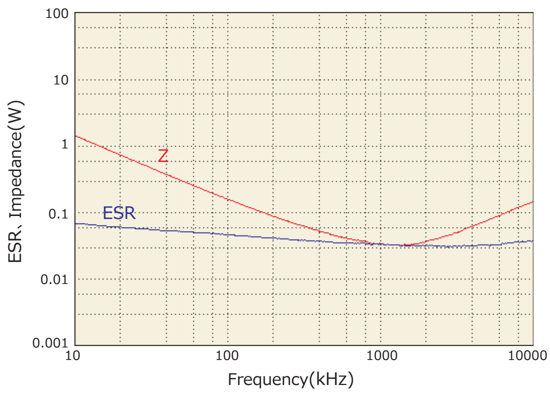
OS-CON (25SVPD10M)
0 V.DC Bias



Multi-layer ceramic capacitor (25 V.DC / 4.7 μF)
20 V.DC Bias

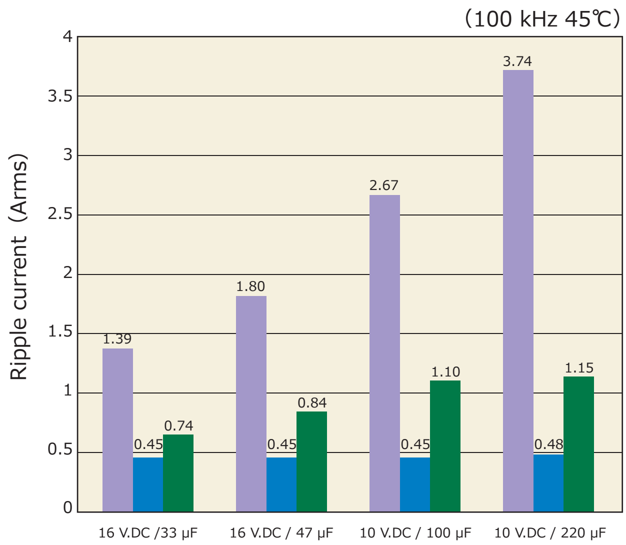


OS-CON (25SVPD10M)
20 V.DC Bias



ESR & impedance of ceramic capacitors change largely between 300kHz to 1MHz.
As for OS-CON, neither ESR nor impedance changes.

5-4. Allowable ripple current



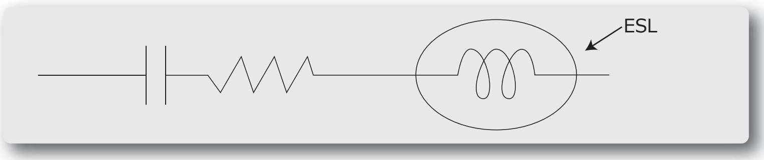
OS-CON (SVP series) ———— Light purple
Al cap. (Low impedance) —— Blue
Ta cap. (Low ESR) ———— Green
※Samples of SVP series are approximate models.

When selecting smoothing capacitors for power supply, the allowable ripple current of a capacitor is one of criterion.
The allowable value of ripple current is decided by the generated heat of a capacitor, this heating is due to the ESR. Since a large ESR capacitor generates larger heat value, it can not make the flow of ripple current greater.
Compared to other electrolytic capacitor, ESR of OS-CON is so small that it can allow far more ripple current.

5-5. ESL Characteristics

The OS-CON is a capacitor of high performance with low ESR and large capacitance.
Recently in circuit technologies, the constituent of ESL is important in the domain of the high frequency with that of electronic equipment.

(a) Eqivalent series circuit of capacitor



(b) Approximate ESL values of SEPC series

(unit : nH)

Size code	at 10 MHz	at 40 MHz
B9	1.6	1.5
C55	2.4	2.3
C6	2.6	2.5
C7	2.3	2.3
C9	2.2	2.1
E7	2.9	2.8
E9	2.7	2.6
E12	4.3	4.1
E13	4.3	4.1
F13	6.0	5.8

※Measuring position: root of lead terminal
※Measuring method: Based on JEITA RC-2003
※All values on left figure are not guaranteed but reference.

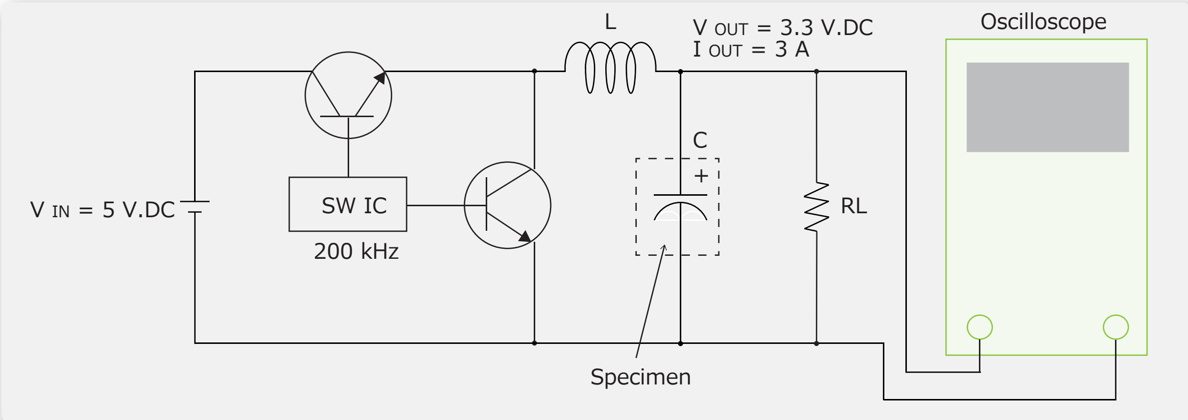
6-1. Ripple voltage reduction capability

While there is a tendency to downsize switching power supplies capacitors still remain one of the parts occupying large areas of circuit boards. The working temperature is an important consideration when selecting a capacitor, since it generally results in widely varying capacitor characteristics. The following experiment shows the superior ripple removal capability of the OS-CON at higher frequencies in wide range of working temperature.

6-1.1 The number of capacitors needed to keep the same ripple voltage level

(a) Experiment content

A general chopper switching power supply was used to test the OS-CON against two alternatives. OS-CON, low-impedance aluminum electrolytic capacitor, and low ESR tantalum capacitors were each connected as the capacitor in the output side smoothing circuit at working temperature range of -20℃, 25℃ and 70℃ to compare the output ripple voltage.



① Initially OS-CON・100 uF / 6.3 V.DC (6SVP100M・φ6.3 × L6.0 mm) was used as the output side smoothing capacitor (C) in the above test circuit, the ripple voltage was measured at ambient temperature of each temperature. (Tab.6-3)
② Low-impedance aluminum electrolytic capacitors and Low-ESR tantalum capacitors were selected for measurement at each temperature so that the ripple voltage became equal to that achieved when the OS-CON・100 uF / 6.3 V.DC was used. (Tab.6-3)
③ The ripple voltage was measured at each temperature (-20℃ to 70℃) with an equal number of side smoothing capacitors to the 25℃ conditions, and the rates of change in the ESR of the smoothing capacitors were calculated from the amounts of change. (Tab.6-2)

(b) Experiment result

Ambient temperature	OS-CON	Aluminum Electrolytic capacitor	Tantalum capacitor
25 ℃	1	7.15	1.46
−20 ℃	1	16.7	1.46
70 ℃	1	4.77	1.46

Tab.6-1 On-board area ratios of capacitors at each temperature

Ambient temperature	OS-CON	Aluminum Electrolytic capacitor	Tantalum capacitor
25 ℃	1	1	1
−20 ℃	1.14	3.03	1.27
70 ℃	0.952	0.587	0.85

Tab.6-2 Rates of change in ESR on the basis of 25℃*

$$* : \text{Rate of change in ESR} = \frac{\text{Ripple voltage at ambient temperature X Oscillation frequency at ambient temperature}}{\text{Ripple voltage at 25℃ X Oscillation frequency at 25℃}}$$

From the above results, it can be seen that OS-CON excels in temperature characteristics.

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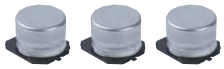
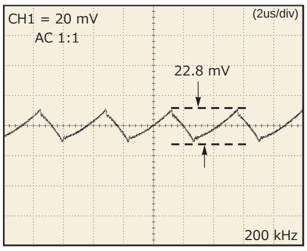
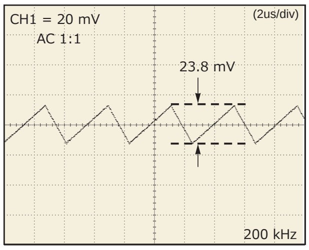
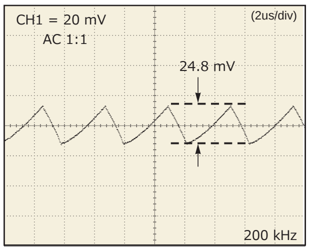
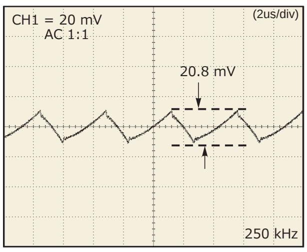
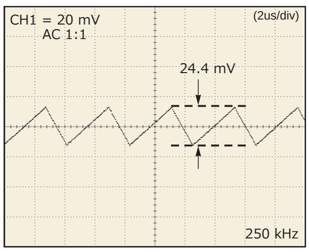
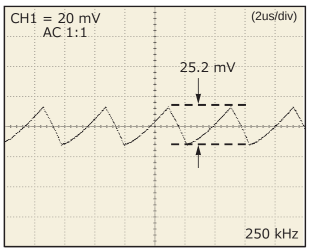
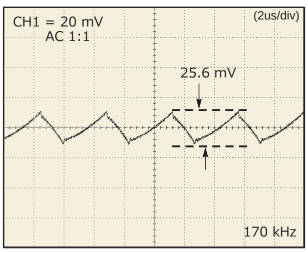
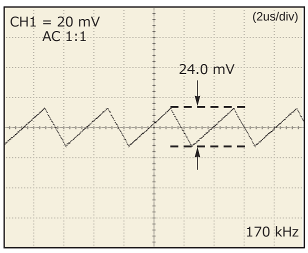
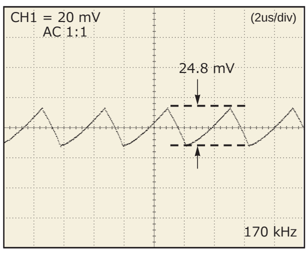
Tab.6-3 Comparison of the measurement of each capacitor

Ambient temperature	Capacitor type	OS-CON	Aluminum electrolytic capacitor	Tantalum capacitor
	Capacitance/voltage	100 μF / 6.3 V.DC	680 μF / 6.3 V.DC	100 μF/ 10 V.DC
	Size (mm) *	6.6 X 6.6	10.5 X 10.5	7.5 X 4.5
25 ℃	Quantity			
	On-board area ratio	1	7.15	1.46
	Oscillation frequency	200 kHz		
	Ripple voltage	22.8 mV	23.8 mV	24.8 mV
	Fig	Fig4 	Fig5 	Fig6 
– 20 ℃	Quantity			
	On-board area ratio	1	16.7	1.46
	Oscillation frequency	250 kHz		
	Ripple voltage	20.8 mV	24.4 mV	25.2 mV
	Fig	Fig4 	Fig5 	Fig6 
70 ℃	Quantity			
	On-board area ratio	1	4.77	1.46
	Oscillation frequency	170 kHz		
	Ripple voltage	25.6 mV	24.0 mV	24.8 mV
	Fig	Fig4 	Fig5 	Fig6 

* The base plate dimensions were taken as the maximum dimensions except for Ta.

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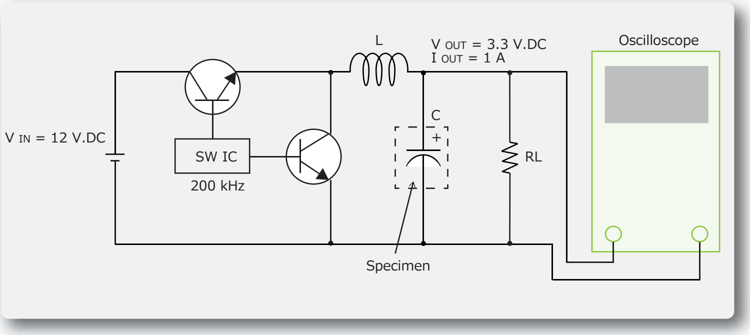
6-1.2 Ripple voltage removal capability before and after endurance test

(a) Experiment content

OS-CON and low-impedance aluminum electrolytic capacitors were respectively connected to the output side of chopper switching power supply, as soothing capacitors.
Output ripple voltage made by the two kinds of capacitor was respectively measured before and after endurance tests (125℃ × 1000 h, rated voltage applied) of the capacitors.
The ripple voltage measurement was done at the ambient temperatures of 25℃, 0℃, and -20℃.



〈Sample〉
OS-CON 56 µF /10 V.DC(10SVPD56M φ6.3×L6 mm) and low-impedance aluminum electrolytic capacitor 330 µF / 10 V.DC (φ10×L10 mm) were used for this experiment.
Measured ESR value of the OS-CON was 38 mΩ, while that of the aluminum electrolytic capacitor was 180 mΩ.
To match the equivalent ripple voltage one OS-CON brings, four pieces of the aluminum electrolytic capacitor were used.

① Specifications of test samples

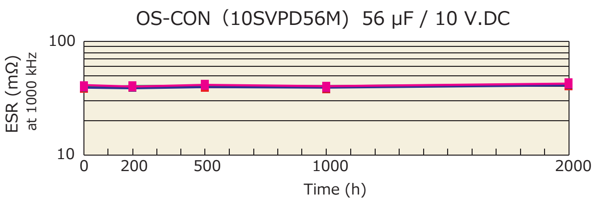
	OS-CON	Aluminum electrolytic capacitor
Capacitance/voltage	56 µF / 10 V.DC	330 µF / 10 V.DC
ESR	45 mΩ	300 mΩ
Category temperaturerange	−55 ℃ to +125 ℃	−40 ℃ to +125 ℃
Endurance	125 ℃ 2000 h	125 ℃ 2000 h
Size (mm)	 φ6.3 x L6	 φ10 x L10

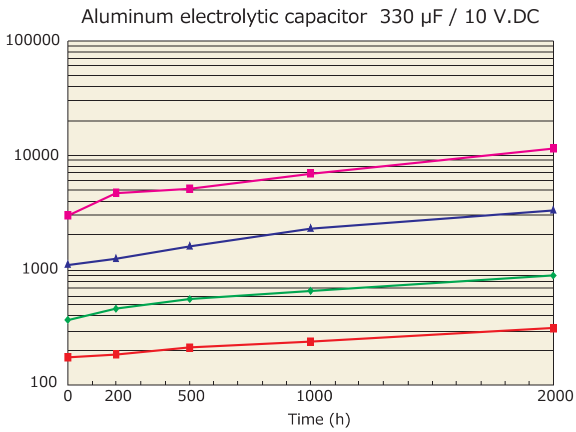
② ESR change of test samples

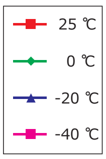
Ambient temperature in measuring	OS-CON		Aluminum electrolytic capacitor	
	Initial value	Value after 125℃ × 10 V.DC applied × 1000 h	Initial value	Value after 125℃ × 10 V.DC applied × 1000 h
25 ℃	38 mΩ	40 mΩ	180 mΩ	231 mΩ
0 ℃	39 mΩ	41 mΩ	369 mΩ	663 mΩ
-20 ℃	38 mΩ	40 mΩ	907 mΩ	2212 mΩ

③ Endurance（125℃ × 10 V.DC applied）

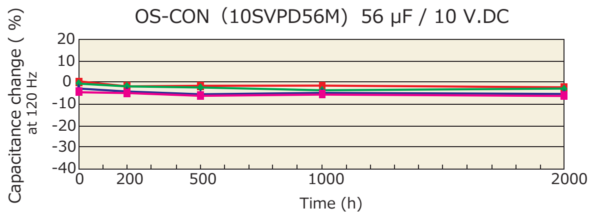
〔ESR〕

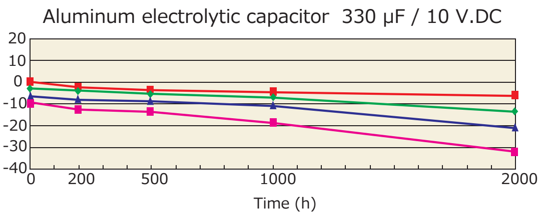






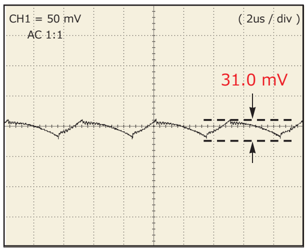
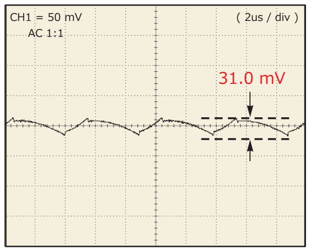
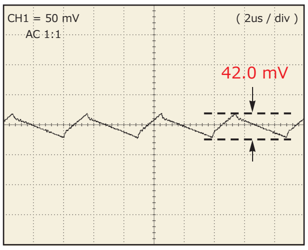
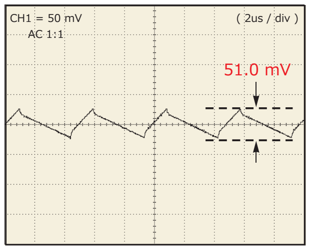
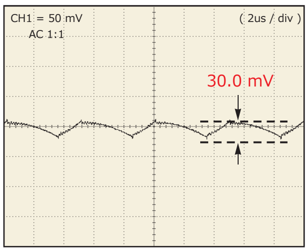
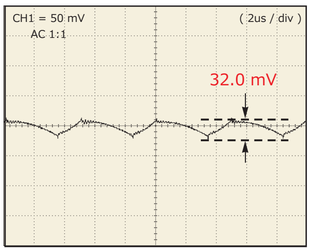
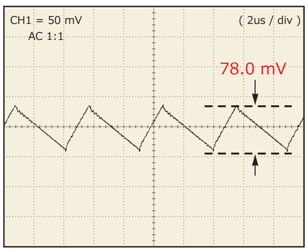
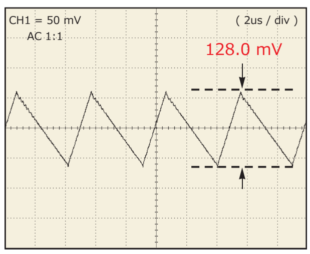
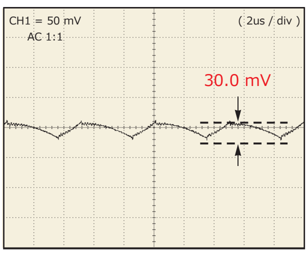
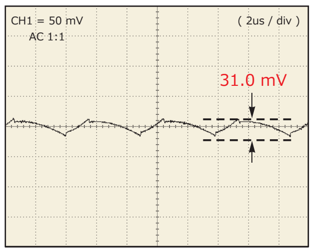
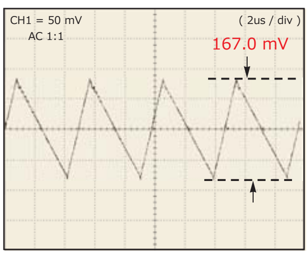
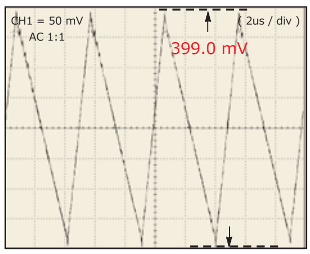
〔Capacitance〕





(b) Experiment result

Comparison of ripple voltage waveform under each temperature

		nitial	After endurance test (125℃×10V applied×1000h)
25 ℃	OS-CON 56 μF / 10 V.DC 		
	Aluminum electrolytic capacitor 330 μF / 10 V.DC 		
0 ℃	OS-CON 56 μF / 10 V.DC 		
	Aluminum electrolytic capacitor 330 μF / 10 V.DC 		
-20 ℃	OS-CON 56 μF / 10 V.DC 		
	Aluminum electrolytic capacitor 330 μF / 10 V.DC 		

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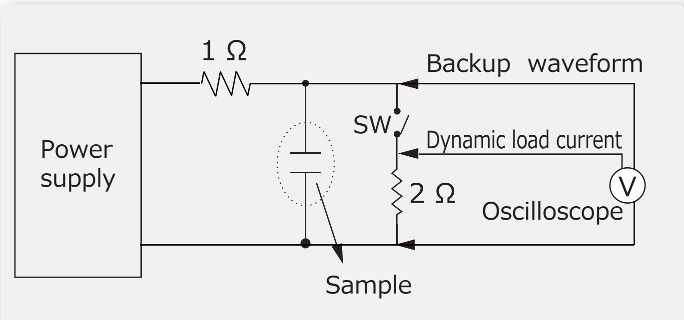
6-2. High speed back-up performance (Back-up capacitor for dynamic load)

IC, especially MPU that are lately used in electronic devices operate at very high processing speed. PCB' s are able to be more densely populated by lowering voltage and getting narrow pattern space. Involved in changing to lower voltage, load current is increasing with a development of new MPU.A sudden change of load current with larger dynamic load at high speed causes the voltage fluctuation of power supply line, and it makes MPU work wrong.

Capacitors with low ESR and large capacitance are necessary for high-speed load current transients.
The OS-CON can provide the largest capacitance among low ESR capacitors, and in this regard, the OS-CON is a suitable back-up capacitor.Let us explain the excellent back-up performance of OS-CON compared to that of other electrolytic capacitors.

6-2.1 Test condition



Test circuit

Load condition

Item	Condition
Load width	5 μs
Cycle	12.5 μs
Rising time	20 ns
Dynamic load current	2 A
Voltage	4 V.DC
Power supply impedance	1 Ω

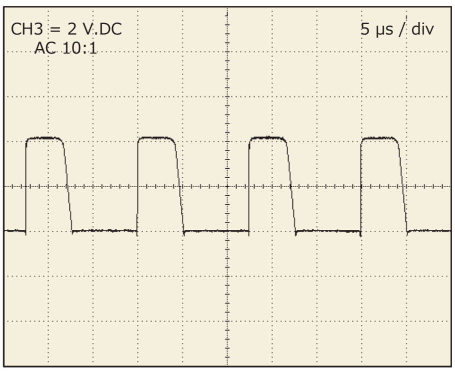
Suitable back-up capacitor for an AC volt tolerance can be estimated from the following equation:

$$\Delta V = \frac{\Delta I \times \Delta t}{C} \times \frac{T - \Delta t}{T} + \Delta I \times ESR$$

ΔV : AC volt tolerance (V)
ΔI : Dynamic load current (A)
Δt : Load width (s)
C : Capacitance (F)
ESR : ESR (Ω)
T : Cycle(s)

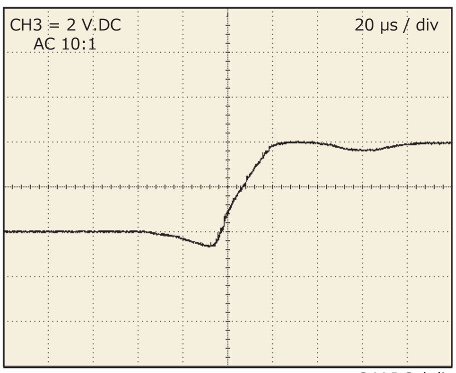
(a) Switching wave form

Whole wave form



2 V.DC / div
5 ms / div

Rising wave form



2 V.DC / div
20 ns / div

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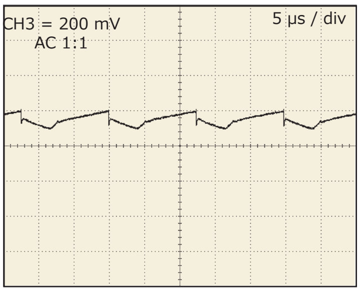
6-2.2 Result

(a) Comparison between OS-CON and other capacitors with same capacitance

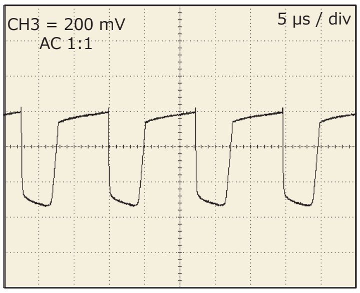
Compared with same capacitance, OS-CON voltage change of supply line is 104 mV, but low-impedance aluminum electrolytic capacitor indicates 548 mV (5.3 times of OS-CON), and low ESR tantalum electrolytic capacitor indicates 212 mV (2 times of OS-CON).

OS-CON
16SVP100M、ESR : 21 mΩ



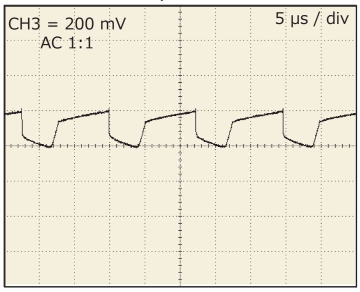
ΔV = 104 mV 200 mV / div 5 μs / div

Low Z Aluminum capacitor
10 V.DC / 100 μF、ESR : 245 mΩ



ΔV = 548 mV 200 mV / div 5 μs / div

Low ESR Tantalum capacitor
10 V.DC / 100 μF、ESR : 85 mΩ

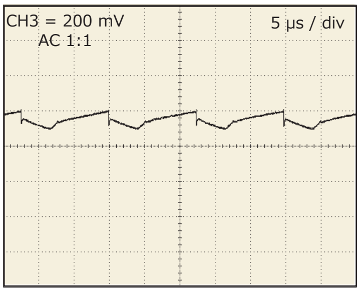


ΔV = 212 mV 200 mV / div 5 μs / div

(b) Examination of same level variable load

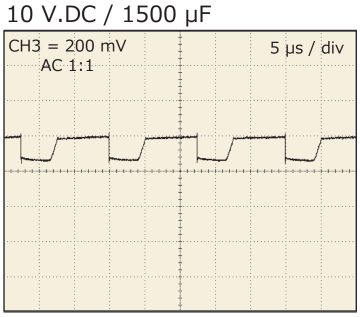
To obtain similar level of voltage change to 10SP100M, Low Z aluminum electrolytic capacitor needs 1500 μF or more.
Low ESR tantalum electrolytic capacitor needs 220 μF X 2 pcs or more.

OS-CON
16SVP100M



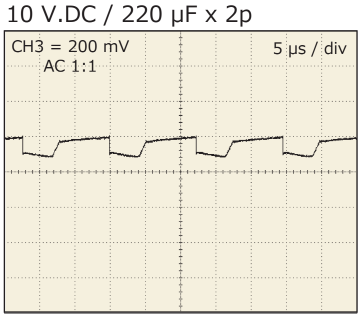
ΔV = 104 mV 200 mV / div 5 μs / div

Low Z Aluminum capacitor
10 V.DC / 1500 μF



ΔV = 128 mV 200 mV / div 5 μs / div

Low ESR Tantalum capacitor
10 V.DC / 220 μF x 2p

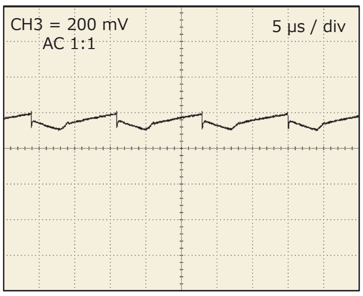


ΔV = 116 mV 200 mV / div 5 μs / div

(C) Comparison with lower temperature (-20℃) of (b)

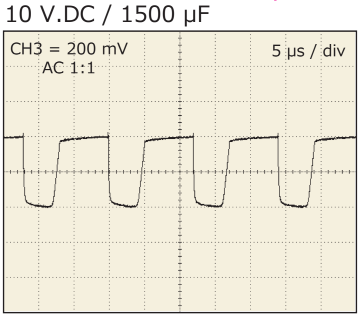
Compared them under the lower temperature, OS-CON is able to keep stable, while the low Z aluminum capacitor has 3.2 times larger drop of the voltage and the low ESR tantalum capacitor has 1.2 times larger change of the voltage.

OS-CON
16SVP100M



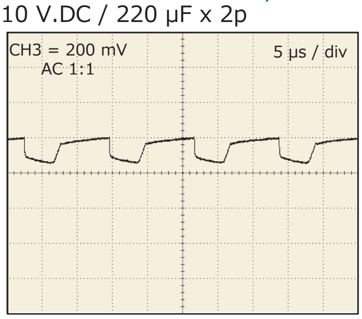
ΔV = 104 mV 200 mV / div 5 μs / div

Low Z Aluminum capacitor
10 V.DC / 1500 μF



ΔV = 404 mV 200 mV / div 5 μs / div

Low ESR Tantalum capacitor
10 V.DC / 220 μF x 2p



ΔV = 144 mV 200 mV / div 5 μs / div

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6-3. Image effect caused by power line noises

Let’ s see how capacitor differences affect an image, in other words, how digital noises affect analog signals.

(a) Effect on a security camera image

OS-CON and low Z aluminum electrolytic capacitors were respectively mounted on the filter circuit of a security camera’ s power line. Then the recorded images in both cases were compared at normal and low temperatures. Since no differences were seen at initial recordings, compared them that after endurance test.

- OS-CON : SVP series

20 V.DC / 22 μF
Size Φ6.3 x L6.0 mm

	25 ℃	-20 ℃
Initial ESR	42 mΩ	42 mΩ
ESR after endurance	45 mΩ	45 mΩ

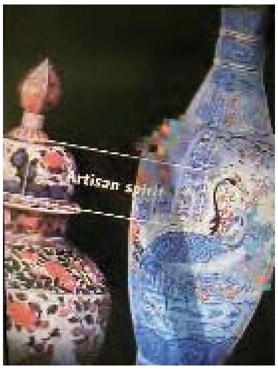


Image 1 25 ℃

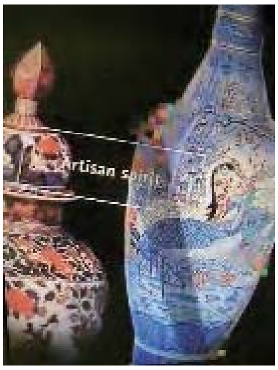
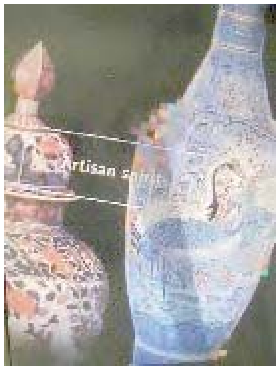


Image 2 -20 ℃

→


Gamma adjusted (3.0)

- Low Z aluminum electrolytic capacitor

16 V.DC / 100 μF
Size Φ6.3 x L6.0 mm

	25 ℃	-20 ℃
Initial ESR	303 mΩ	1080 mΩ
ESR after endurance	418 mΩ	1640 mΩ

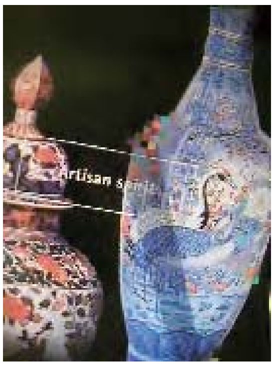


Image 3 25 ℃

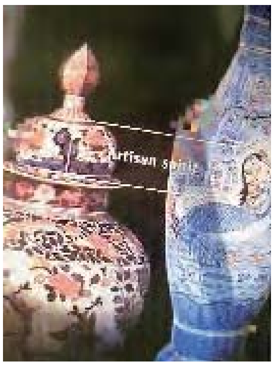


Image 4 -20 ℃

→


Gamma adjusted (3.0)

(b) Summary

① With OS-CON
: No image defects were seen at both 25℃ and − 20℃. (Image 1, Image 2)

② With low Z electrolytic capacitors
: The capacitor’ s deteriorated ESR (1640 mΩ) caused an image distortion (pale and striped effect) at − 20℃.
See the gamma adjusted images for easier distinction.
The red-circled part best shows the striped effect.

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6-4. Equivalent circuit model

Using a circuit simulation increased for shortening the circuit design in recent years. A resistance and inductance element of the pattern are simulated considerately due to CPU's voltage accuracy is severe. Concerning a backup capacitor, the simulation model that characteristic is close to actual measurement is required

6-4.1 Current equivalent circuit's issue

In the simulation of a power supply circuit, the simulation is done in the equivalent circuit of the ideal capacitor as Fig. 6-1.
There has rarely problem for the purpose to confirm a ripple voltage and a ripple current. But it cannot satisfy that higher accuracy simulation such as the load changes of CPU. There might be a large difference between a real circuit and the simulation result. This is because ESR & capacitance frequency characteristic are not reflected.

6-4.2 Equivalent circuit for more accurate simulation

We made the equivalent circuit as shown in Fig. 6-2.
As a result, capacitor has the frequency characteristics which are close to the measurement result and it is useful for a simulation near the real operation in circuit.

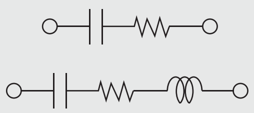


Fig. 6-1 Current equivalent circuit

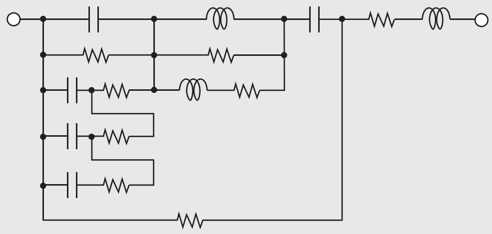
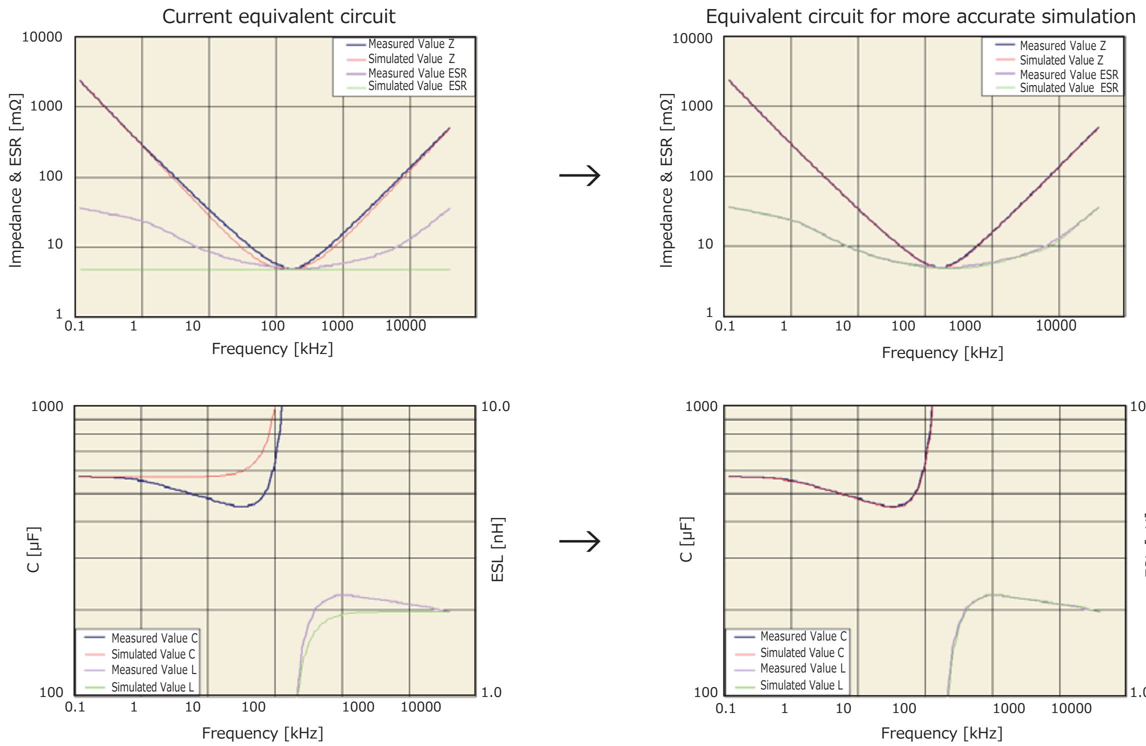


Fig. 6-2 Equivalent circuit for more accurate simulation

● Comparison of frequency characteristics of measurement and simulation

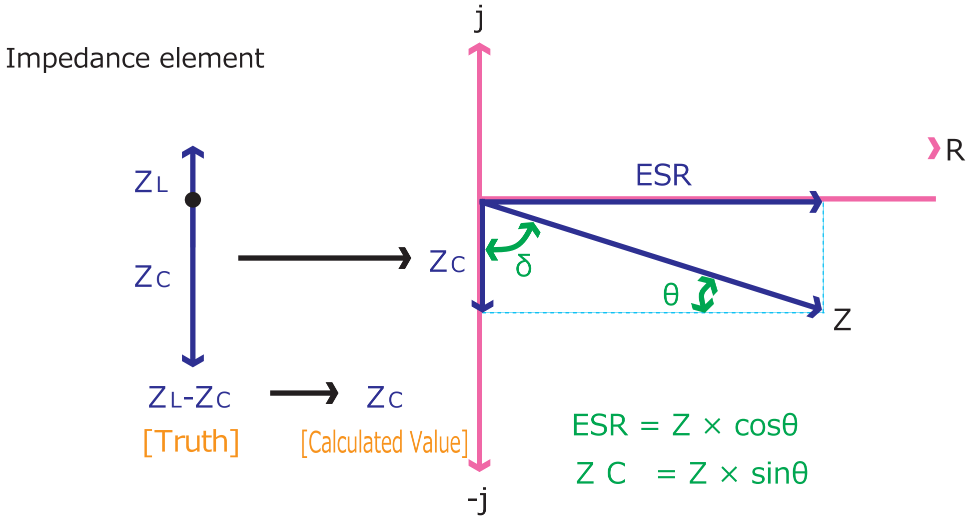
Model : 2SEPC560MW (2.5 V.DC / 560 μF)



6-4.3 Frequency characteristics of capacitance

The frequency characteristics of capacitance cannot show a normal value around the resonance point when a capacitor is measured.
This is because measuring instruments that impedance analyzer or LCR meter, etc. Impress the voltage signal, and capacitance is calculated from the phase lag with the current.This phase lag is decided by the difference between impedance Zc of capacitance and impedance ZL of inductance.
It becomes "Zc＞＞ZL" when the frequency is lower, and inductance hardly influences it. It comes to receive the influence of ZL as the frequency rises. The phase lag decreases around the resonance point (Zc≒ZL). The direction changes and capacitance cannot be measured.

However, it becomes possible to guess the capacitance frequency characteristics with this equivalent circuit (Fig.6-3).
Capacitance frequency characteristics can be shown by assuming all inductance of an equivalent circuit to be zero. Below figure shows graphing of the calculation result. The resonance point of the capacitor is at 190kHz.
It is influenced by ZL from the 1/10 frequency.



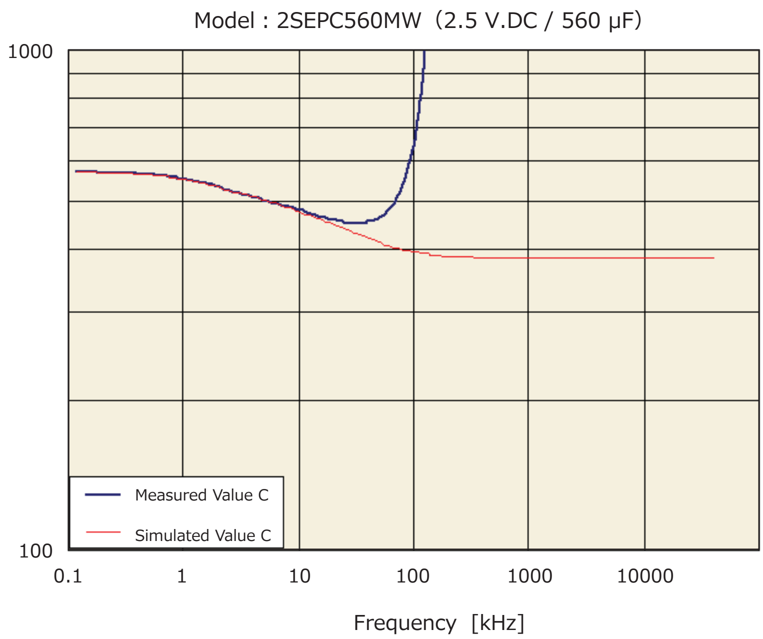
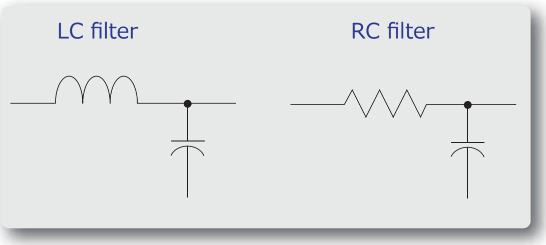


Fig. 6-3

6-5. Application to low-pass filter circuits

As a means of removing noise from power supply lines, a low-pass filter such as shown below may be used.In recent years, switching power supplies have been become a main power sources, that are compact and highly efficient, but its make a large noise sources. Also, digital circuits make noise easily, and in most of the devices with mixed noise-sensitive analog circuits, entry of high-frequency noise into the analog circuits is prevented by connecting these low-pass filters to the power supply lines of the analog circuits.



①The damping effect of the filter gets closer to an ideal damping rate as capacitor has lower ESR.
② Capacitance and ESR have 0 point frequency (fz), when the frequency is higher than 0 point frequency, +20dB/dec cancel the damping effect.
③ LC filter : -40dB/dec is to be -20dB/dec
RC filter : -20dB/dec is to be 0 (non-damping effect)
④Even if capacitance is increased, there has no effect of noise cutting, it is influenced by the 0 point frequency. OS-CON is most effective in low-pass filter because of low ESR.

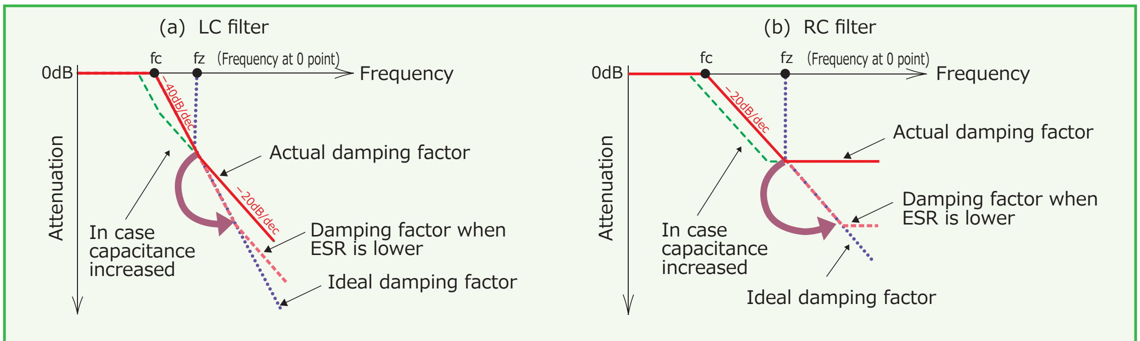
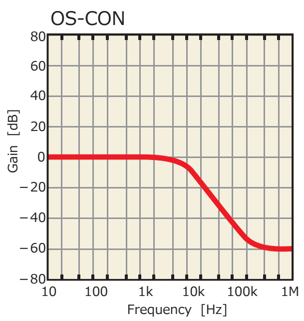


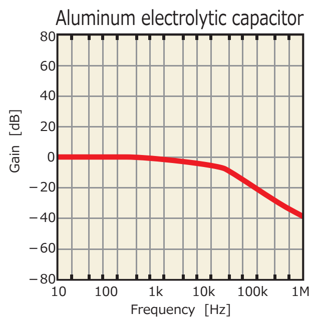
Fig. 6-4 Actual damping factor

●Compare the actual damping factor of the following OS-CON with an aluminum electrolyte capacitor

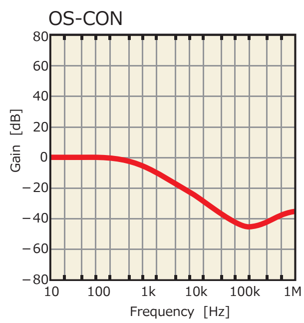
OS-CON（20SEP33M）	Aluminum electrolytic capacitor
20 V.DC / 33 μF、ESR = 37 mΩ (The actual measurement)	10 V.DC / 33 μF、ESR = 1410 mΩ (The actual measurement)

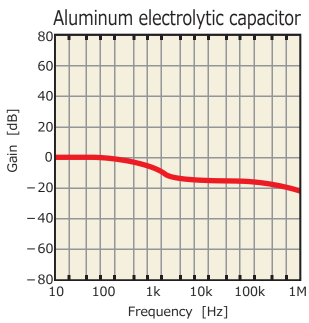
6-5.1 LC filter（L=10 μF）





6-5.2 RC filter（R=5.6 Ω）





OS-CON shows a damping effect in higher frequency regions comparing with an aluminum electrolytic capacitor.
These measurements were made at room temperature.
The difference in damping effect will be larger when the temperature is under 0℃, because ESR of an aluminum electrolytic capacitor will extremely increase.
Oppositely OS-CON has little increase that dose not affect the damping effect of the filter.

6-6. Application of switching power supply for smoothing capacitor

For restraining output ripple current, the output smoothing capacitor of the switching power supply is need to use low ESR capacitor. However the lower ESR capacitor makes the phenomenon sometimes occurs, which is called the abnormal oscillation of output voltage. The abnormal oscillation of output voltage varies depending on the regulator method or the topology such as buck type, boost type, etc. We explain the mechanism and the treatment method of output voltage oscillation with the sample of the Buck style switching regulator under the voltage control mode.

6-6.1 Abnormal oscillation of output voltage

The switching power supply usually has the negative feed-back circuit to stabilize output voltage. The difference between output voltage and standard voltage Vref are amplified with the error amplifier and convert to the digital signal with the PWM comparator and flip on and flip off switch Q1. Input voltage Vin becomes a square wave form by Q1, and you obtain DC output voltage Vout by make it smooth with coil L and capacitor Cout. L and also Cout assumed that they form the second low pass filters.

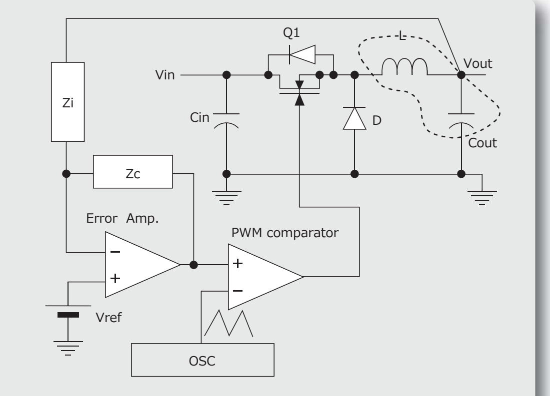
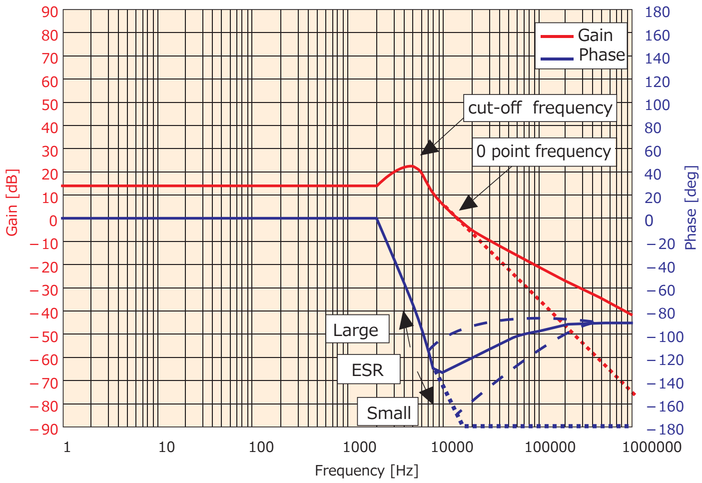


Fig. 6-5 Control block of switching power supply

The frequency characteristics of the output LC filter is expressed with the Bode diagram like Fig.6-6. The phase is delayed 180 degrees originally, because the error amplifier is a negative feedback circuit. Therefore, the phase delay of the output LC filter and the error amplifier occur at the same time, and when 360 degrees delay occur, the output voltage oscillates.

The damping rate of the LC filter is -40dB/dec and the cut-off frequency becomes $\frac{1}{2\pi\sqrt{LC}}$, and become Gain and Phase like the dotted line of Fig.6-6.With an ideal filter the output voltage oscillates because it is delayed 180 degrees. But more than some frequency that is called zero frequency, damping rate of Gain becomes -40dB/dec to -20dB/dec. Furthermore the Phase returns to delay 90 degrees from delay 180 degrees. This is because the first order Phase lead network is formed by the capacitance value and ESR of Cout.

Fig. 6-6 Frequency characteristic of LC filter



Because, after the zero point frequency $\frac{1}{2\pi \text{Cout ESR}}$, the Gain damping rate goes on the Phase of +20dB, +90 degrees. However, when the low ESR capacitor is used, it works as a LC filter up to high frequency band, and the phase delay to nearly 180 degrees and it becomes easy to oscillate.
30 degrees to 40 degrees or more of Phase margin is thought as a necessity to inhibit the oscillation of output voltage with a general negative feed-back circuit. The Phase margin is numerical value how much the minimum value of the Phase is distant from-180 degrees.
The smaller the Phase margin gets, the higher the possibility to oscillate by the characteristic dispersion and temperature change of the component will be.

6-6.2 Inhibition method of oscillation

By doing Phase compensation with the feed-back circuit of the error amplifier the oscillation of output voltage can be inhibited. There are various kinds in Phase compensation.
It is most effective to use the Phase compensation circuit like the following in the switch power supply of the voltage control mode.

Fig. 6-7 : ② & ④ form first order Phase lead network. ① & ③ form first order Phase lag network. By adjusting these values, it does the Phase compensation by which Phase will occur and improve Phase delay of the whole negative feed-back circuit by the frequency characteristic of output LC filter at the frequency band which the Phase indicates the lowest.

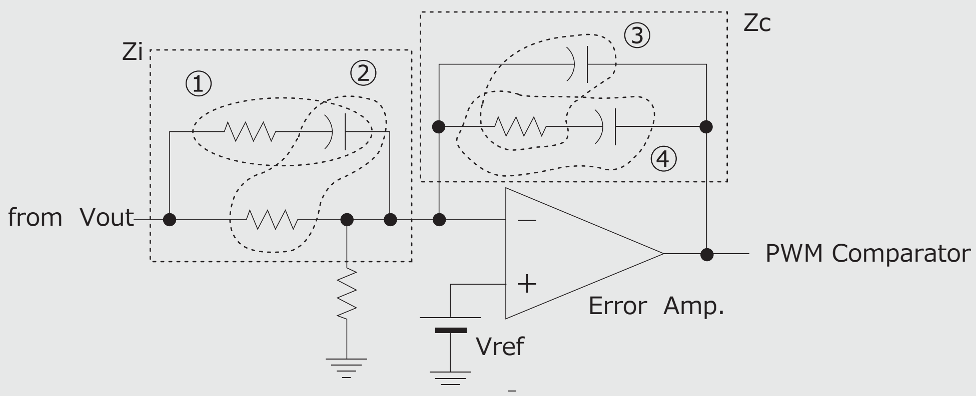
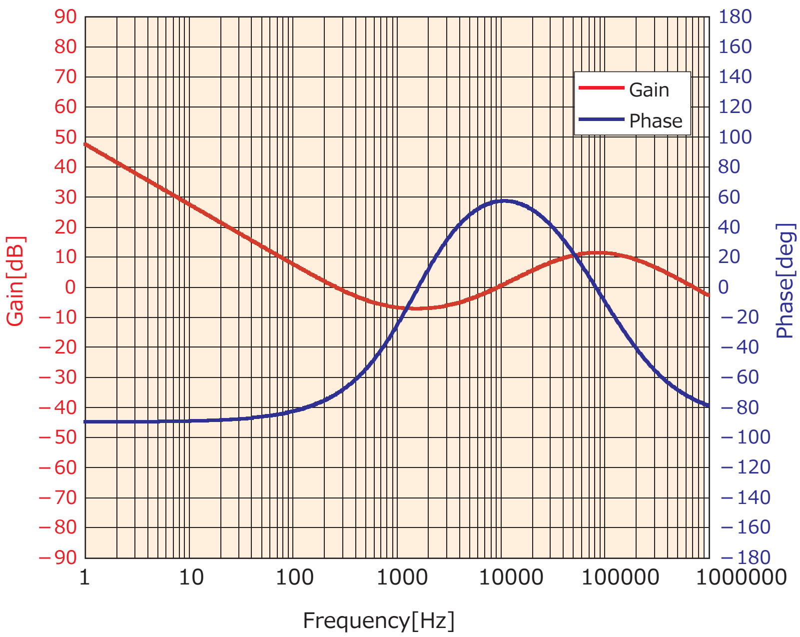


Fig.6-7 Phase compensation network of Voltage Control Mode

Fig. 6-8 : Example. As the Phase of the output LC filter of Fig.6-6 becomes a lowest point at around 10kHz, it has about 30 degrees of Phase lead around that frequency.
Because of this, it can secure the Phase margin of 30 degrees even if the Phase delay of LC filter becomes 180 degree nearly, the oscillation of output voltage can inhibited.

Fig.6-8 requency characteristic of Phase Compensation Network


6-6.3 Concrete design examples of prevention oscillation

The ESR of the output capacitor necessary to make an output ripple voltage of 20mVp-p can be obtained as follows:ESR < Vripple / ((Vin-Vout) / L*Vout / Vin / fosc) = 35.7mΩ
Consequently, the following capacitors have been selected.

- OS-CON 6SVP100M
  1-parallel φ6.3 × L6 mm ESR＝32 mΩ ※ESR is an actual measurement.

- Aluminum electrolytic capacitor 6 V.DC ／ 680 μF
  3-parallel φ10 × L8 mm ESR＝128 mΩ /pcs ⇒ Total ESR＝43 mΩ

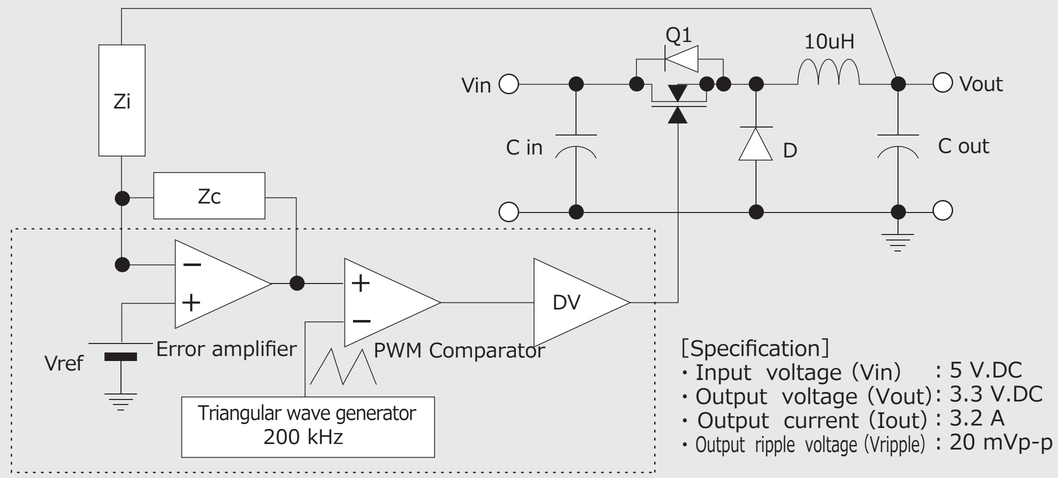
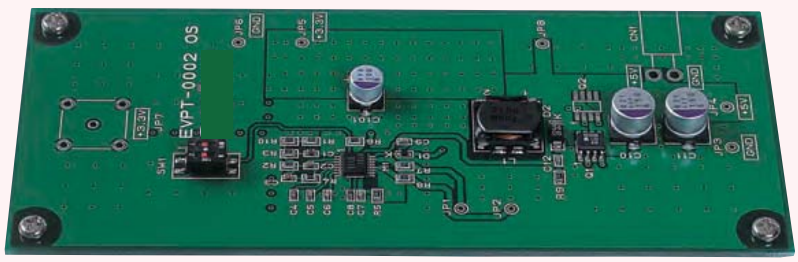


Fig.6-9 Step-down DC-DC converter design example

OS-CON



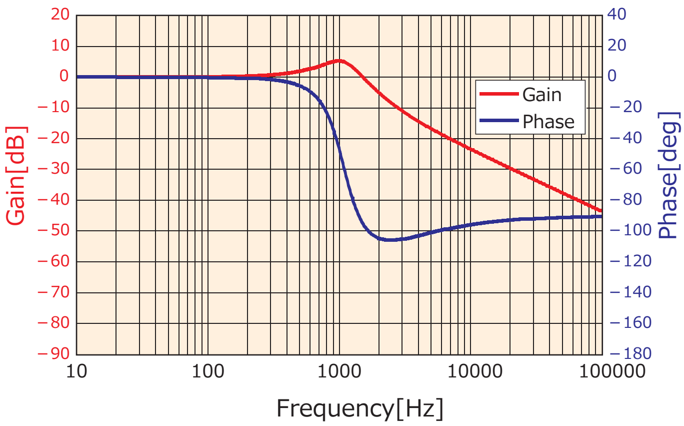
Aluminum electrolytic capacitor

photo.6-1 Evaluated circuit boards

6-6.4 Examples of design with aluminum electrolytic capacitor

Then the aluminum electrolytic capacitors are used, the frequency characteristics of the output LC filter are as shown in Fig.6-10, and there is a sufficient phase margin to such an extent that there is no need to make phase compensation. Therefore, the phase compensating circuit in Fig.6-11 is sufficient.

Fig. 6-10 Frequency characteristics of the LC filter with the AL-E



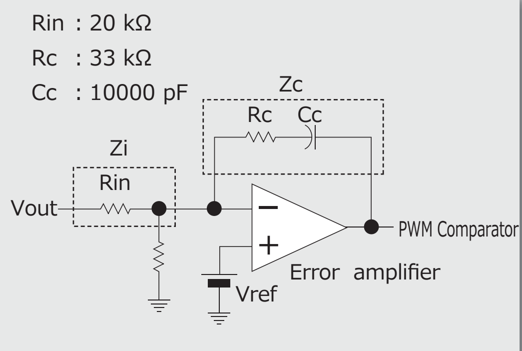


Fig. 6-11 Phase compensating circuit with the AL-E

With the phase compensation network is Fig. 6-11 (properly speaking, phase compensation is not made), the total frequency characteristics are as shown in Fig. 6-12, and there is a sufficient phase margin.

Fig. 6-12 Total frequency characteristics with the AL-E

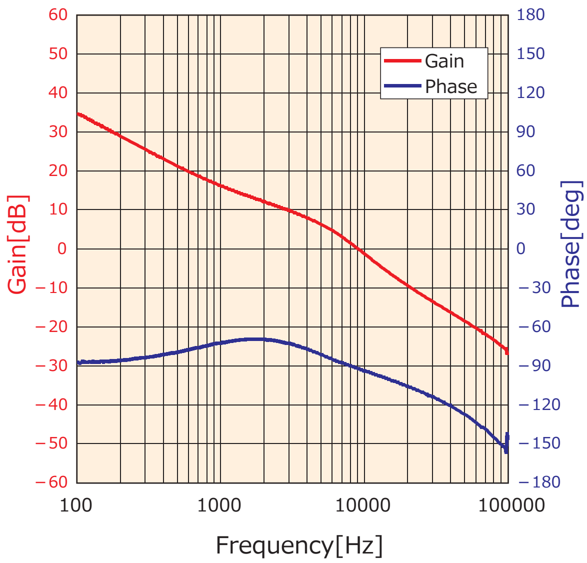
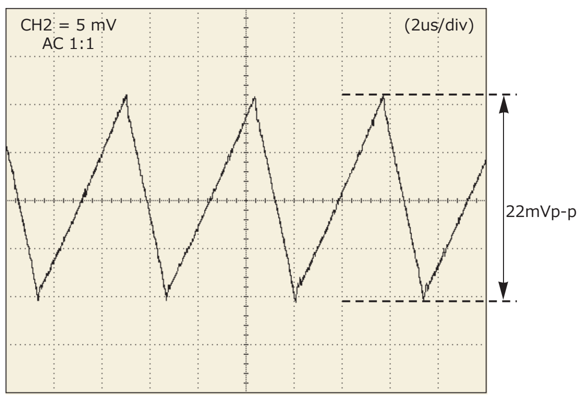


Fig. 6-13 Output ripple voltage waveform with the AL-E



6-6.5 Examples of design

When the aluminum electrolytic capacitors used in power supply circuits are replaced with the OS-CON without changing the phase compensation network, the output voltage oscillates. (Fig.6-14) As a reason, we can say that the phase margin is lost because the phase compensation network is not changed despite the fact that the frequency characteristics of the output LC filter change as shown in Fig.6-10, where the aluminum electrolytic capacitors are used, to Fig.6-15, where they are replaced with the low ESR OS-CON.

Fig. 6-14 Oscillating output voltage waveform

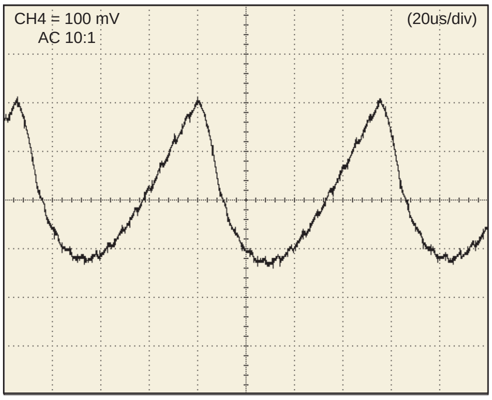
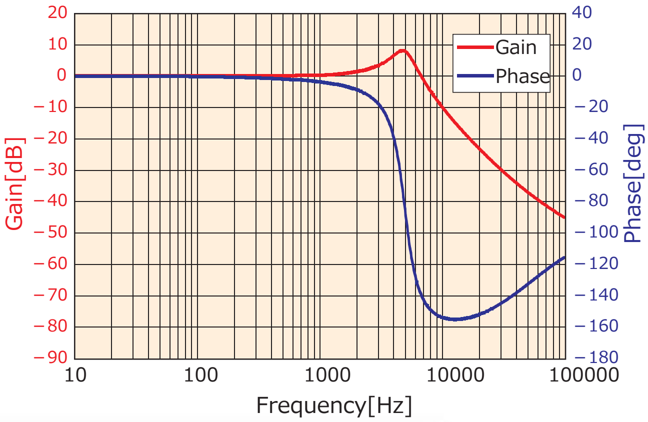
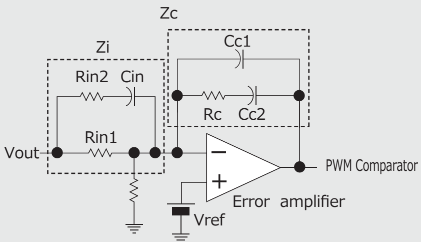


Fig. 6-15 Frequency characteristics of the LC filter with the OS-CON





Rin1 : 20 kΩ
Rin2 : 680 kΩ
Cin : 4700 pF
Rc : 3.3 kΩ
Cc1 : 330 pF
Cc2 : 33000 pF

Fig. 6-16 Phase compensating circuit with the OS-CON

When the LC filter has little phase margin as shown in Fig.6-15, appropriate phase compensation can be made by using such a phase compensation network as shown in Fig.6-16. This is to cancel the deepened phase lag by forming phase leads at Zi and Zc in Fig.6-16.

Fig. 6-17 Total frequency characteristics with the OS-CON

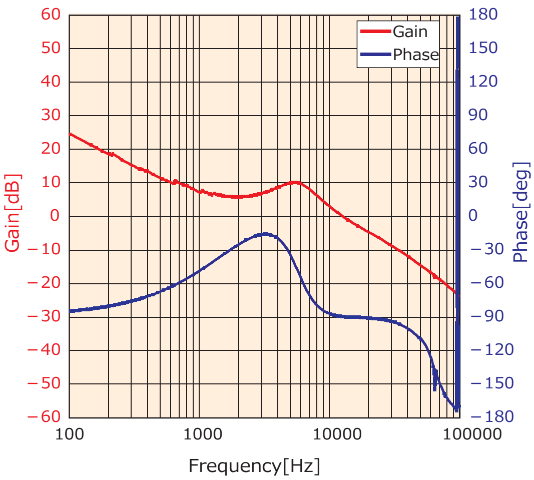
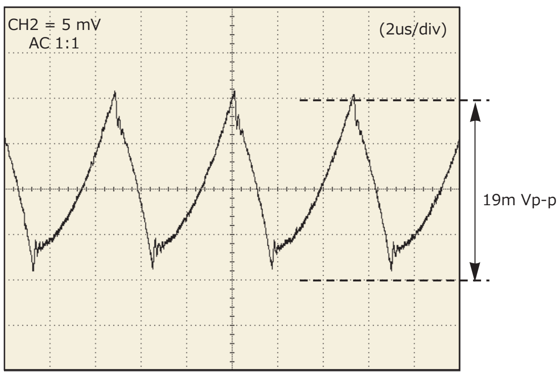


Fig. 6-18 Output ripple voltage waveform with the OS-CON



Because of this, the total frequency characteristics are as shown in Fig.6-17; the phase margin is sufficient; and the output ripple voltage waveform (Fig.6-18) is almost the same as is the case with the aluminum electrolytic capacitors.

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