Panasonic

Conductive Polymer Aluminum Solid Capacitors

OS-CON™

TECHNICAL NOTE

2015-01

About this note

- The performance, characteristics, and features of the products described in this note are based on the products working alone under prescribed conditions. Data listed here is not intended as a guarantee of performance when working as part of any other product or device. In order to detect problems and situations that cannot be predicted beforehand by evaluation of supplied data, please always perform necessary performance evaluations with these devices as part of the product that they will be used in.
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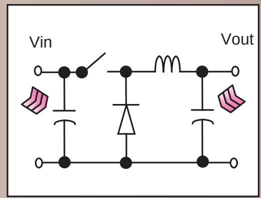
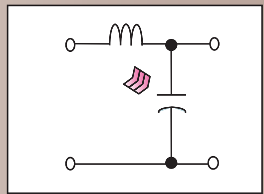
Area of Application of OS-CON

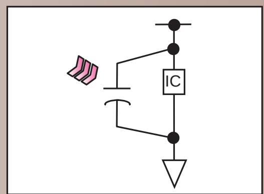
- Smoothing Capacitor in Power Supply Circuit



- Capacitor in Filter Circuit



- Backup Capacitor
- Bypass Capacitor



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.

1. Explanation of the rush current suppression methods

When the OS-CON is used in the following circuit as figure 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.

1-1. DC-DC converter input circuits

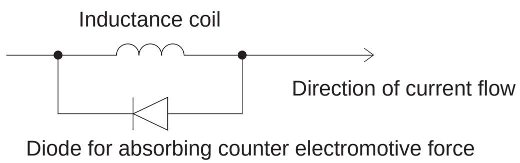
(a) DC-DC converter circuits are usually a PCB block shape and use a low ESR capacitor in the input section for high performance and miniaturization.
(b) Consideration must be given to the rush current that flows from the equipment when the DC-DC converter is adjusted and inspected.

※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 Figure 1)
※A rush current suppression measures must be taken for DC-DC converter adjustment and inspection equipment.(Refer to P. 13)

1-2. Circuits driven by chargeable batteries

(a) 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.

※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 Figure 1.)



※A protection circuit like that is shown left 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.

1-3. A rush current without protection resistor

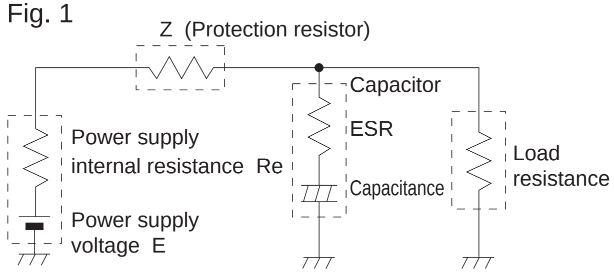
When there is no protection resistor Z as shown in Figure 1 and the power supply has Re nearly = 0Ω, The OS-CON rush current is as follows.

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

Example : For 25SVPD10M
ESR=65mΩ, or less and／Supplied DC voltage=20V,

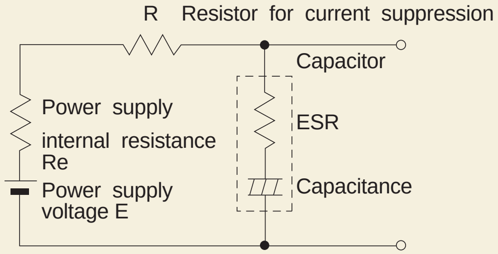
$$\frac{20\text{V}}{\text{less than } 0.065\Omega} = 300\text{A or more}$$

Fig. 1



2. Example of rush current suppression methods

2-1. Resistor method

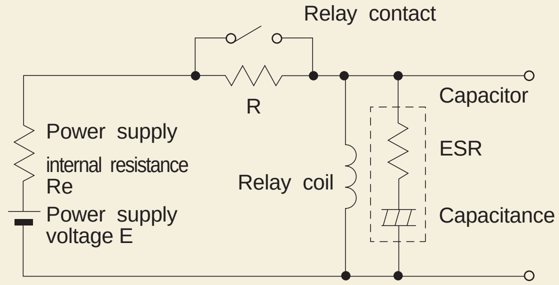


(a) Rush current is as shown below.

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

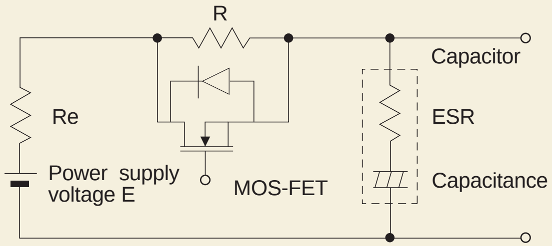
(b) Rush current is usually determined mainly by R as Re and ESR are low.
(c) Although the current is simply and clearly suppressed with this method, resister R for suppressing current causes the voltage to drop.

2-2. Resistor and relay method



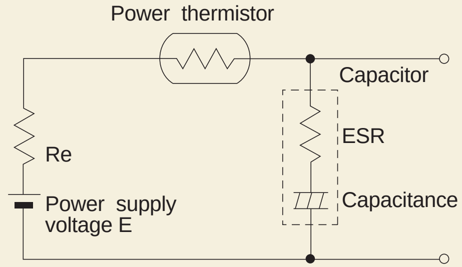
(a) A rush current is exactly the same as in the resistor method. There is almost no voltage drop caused by the current suppression resistor from the time the relay contact goes on.
(b) Note: After the capacitor has finished recharging, it may take some time or setting of voltage to turn the relay ON.

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.

2-4. Power thermistor

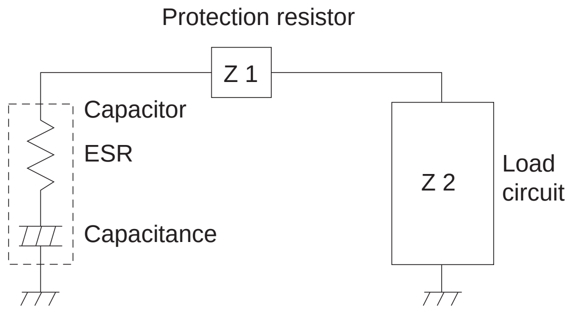


(a) Taking an example of a common power thermistor, the value is 8Ω at 25℃, but becomes 0.62Ω at 130℃.
(b) When the power thermistor is connected as shown in the above diagram, rush current is suppressed due to the large resistor value at the moment the switch is turned on. The output loss (voltage drop) 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. 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.



※The discharge equivalent circuit is as shown to the left.
※The formula for estimating discharge current is given below.

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

Example : For 25SVPD10M

- ESR=65mΩ or less
- Charging voltage=20V
- Z1, Z2=0Ω

is set, then

$$\text{Discharge current (A)} = \frac{\text{Charging voltage 20V}}{\text{ESR }0.065\Omega\text{ or less}}$$

$$= \text{300A or more}$$

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.

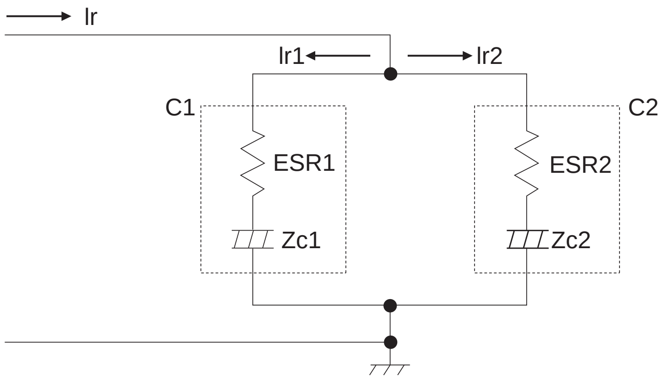
4. Precautions when connecting an OS-CON and an aluminum electrolytic capacitor in parallel

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 Figure 1.

(b) The equivalent circuit in Figure 1 can be simplified as shown in Figure 2 when it is to be used for frequencies between 100kHz and a few MHz. (Assuming the capacitor's capacitance is more than 10μF.)

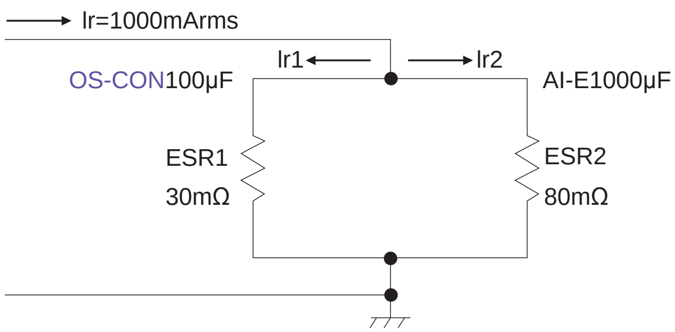
Fig.1



Ir : Total ripple current
ESR : Capacitor's equivalent series resistance
Zc : Impedance of the capacitor's capacitive components

Since impedance becomes exceedingly low when the capacity is more than 10mF. And frequencies higher than 100kHz, each Zc in Figure 1 can be omitted changing the actual ripple current value to that shown in Figure 2.

Fig.2



(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.

Formula for calculating the ripple current value

$$Ir1 = Ir \times \frac{ESR2}{ESR1 + ESR2} = 1000mA \times \frac{80m\Omega}{30m\Omega + 80m\Omega} \fallingdotseq 727mArms$$

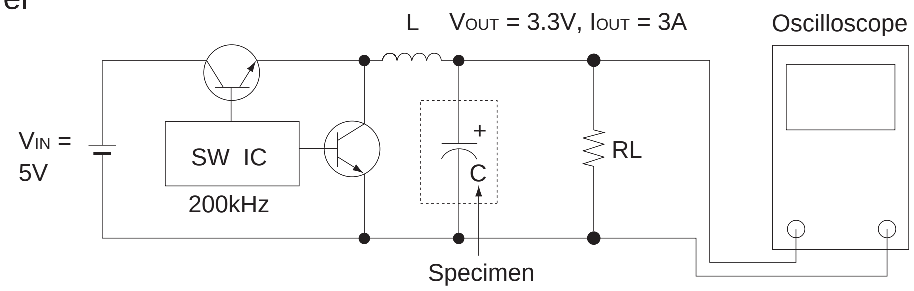
1. Voltage reduction capability of OS-CON

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.

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･100uF/6.3V (6SVP100M･φ6.3mm×L6.0mm) 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. Refer to table 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･100uF/6.3V was used. Refer to table 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. Refer to table 2.

(b) Experiment result

Table1 On-board area ratios of capacitors at each temperature (when the ripple voltage is on the same level)

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

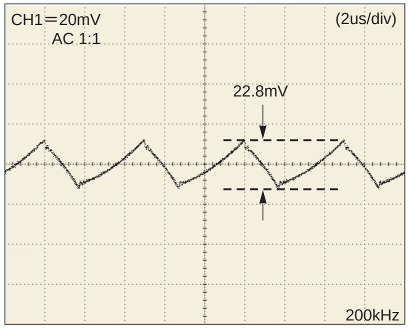
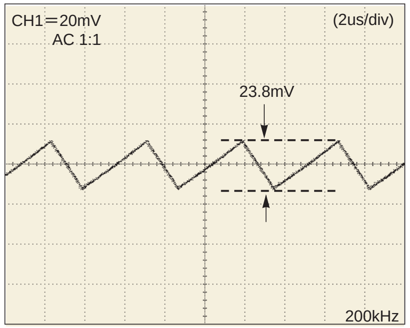
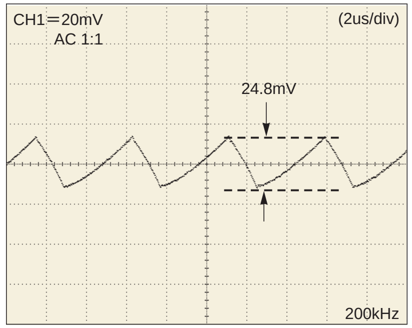
Table2 Rates of change in ESR on the basis of 25℃(※)

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

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

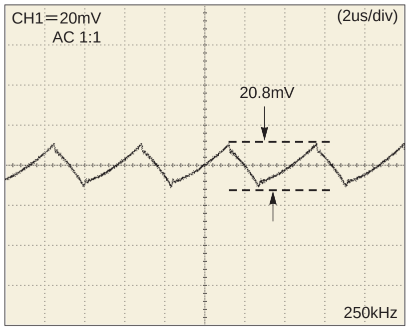
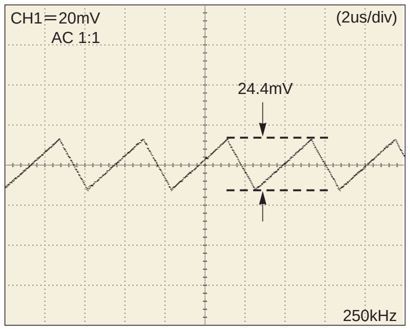
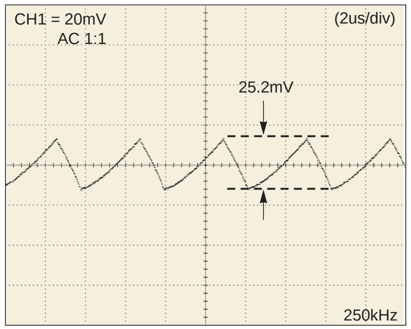
From the above results, it can be seen that OS-CON excels in temperature characteristics.

Table3 Measurement comparison at 25℃

Ambient temperature	25℃		
Capacitor type	OS-CON	Aluminum Electrolytic capacitor	Tantalum capacitor
capacitance/voltage	100μF/6.3V	680μF/6.3V	100μF/10V
Size（※1）(mm)	6.6 X 6.6	10.5 X 10.5	7.5 X 4.5
Quantity			
On-board area ratio	1	7.15	1.46
Oscillation frequency	200kHz		
ripple voltage	22.8mV	23.8mV	24.8mV
Fig	Fig1 	Fig2 	Fig3 

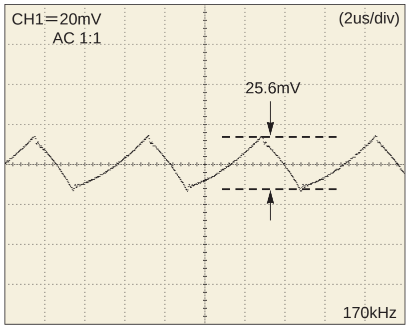
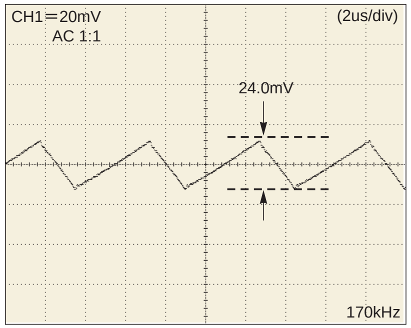
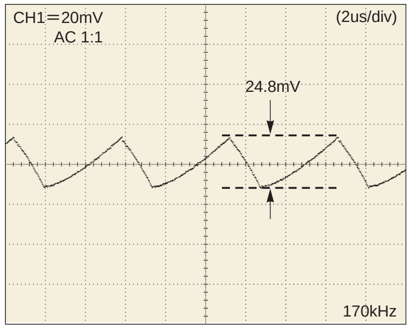
※1 The base plate dimensions were taken as the maximum dimensions except for Ta.

Table4 Measurement comparison at -20℃

Ambient temperature	-20℃		
Capacitor type	OS-CON	Aluminum Electrolytic capacitor	Tantalum capacitor
capacitance/voltage	100μF/6.3V	680μF/6.3V	100μF/10V
Size(※1)(mm)	6.6 X 6.6	10.5 X 10.5	7.5 X 4.5
Quantity			
On-board area ratio	1	16.7	1.46
Oscillation frequency	250kHz		
ripple voltage	20.8mV	24.4mV	25.2mV
Fig	Fig4 	Fig5 	Fig6 

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

Table5 Measurement comparison at 70℃

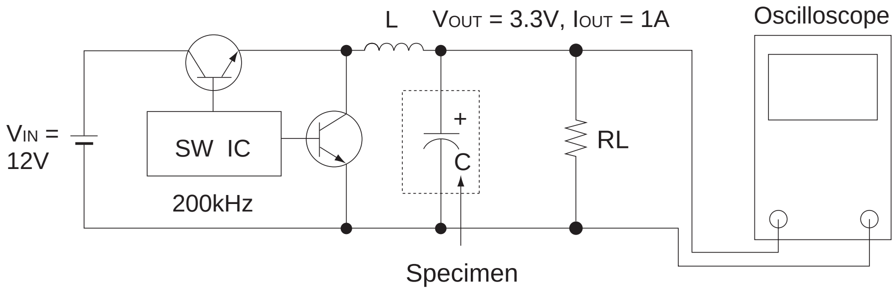
Ambient temperature	70℃		
Capacitor type	OS-CON	Aluminum Electrolytic capacitor	Tantalum capacitor
capacitance/voltage	100μF/6.3V	680μF/6.3V	100μF/10V
Size(※1)(mm)	6.6 X 6.6	10.5 X 10.5	7.5 X 4.5
Quantity			
On-board area ratio	1	4.77	1.46
Oscillation frequency	170kHz		
ripple voltage	25.6mV	24.0mV	24.8mV
Fig	Fig7 	Fig8 	Fig9 

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

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℃×1000h, rated voltage applied) of the capacitors.
The ripple voltage measurement was done at the ambient temperatures of 25℃, 0℃, and -20℃.



OS-CON 56µF/10V(10SVPD56M φ6.3mm×L6mm) and low-impedance aluminum electrolytic capacitor 330µF /10V (φ10mm×L10mm) were used for this experiment. Measured ESR value of the OS-CON was 38mΩ, while that of the aluminum electrolytic capacitor was 180mΩ. To match the equivalent ripple voltage one OS-CON brings, four pieces of the aluminum electrolytic capacitor were used.

$$\text{Output ripple voltage(outline)} = \frac{\text{Ripple current through coil}}{\text{ESR of capacitor}}$$

(1) Specifications of test samples

	OS-CON	Aluminum electrolytic capacitor
capacitance/voltage	56µF/10V	330µF/10V
ESR	45mΩ	300mΩ
Category temperature range	−55℃～+125℃	−40℃～+125℃
Endurance	125℃×2,000h	125℃×2,000h
Size(mm)	 φ6.3×L6	 φ10×L10

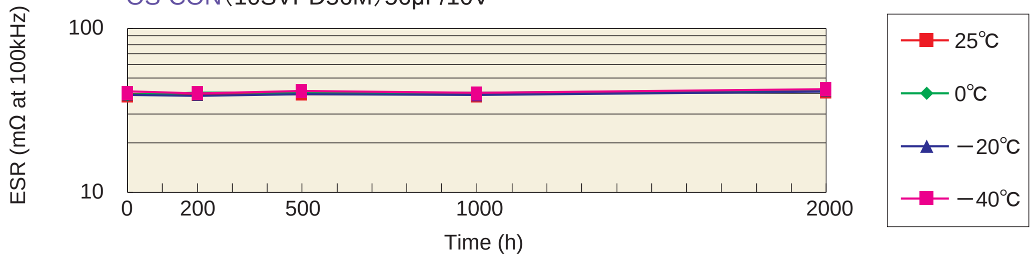
(2) ESR change of test samples

	OS-CON		Aluminum electrolytic capacitor	
Ambient temperature in measuring	Initial value	Value after 125℃× 10V applied×1,000h	Initial value	Value after 125℃× 10V applied×1,000h
25℃	38mΩ	40mΩ	180mΩ	231mΩ
0℃	39mΩ	41mΩ	369mΩ	663mΩ
−20℃	38mΩ	40mΩ	907mΩ	2,212mΩ

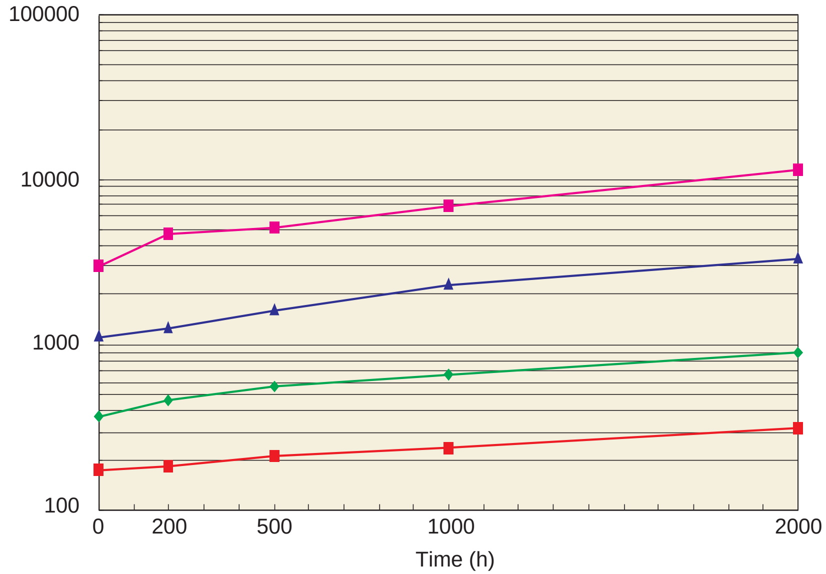
(3) Endurance（125℃×10V applied）

〔ESR〕

OS-CON（10SVPD56M）56μF/10V

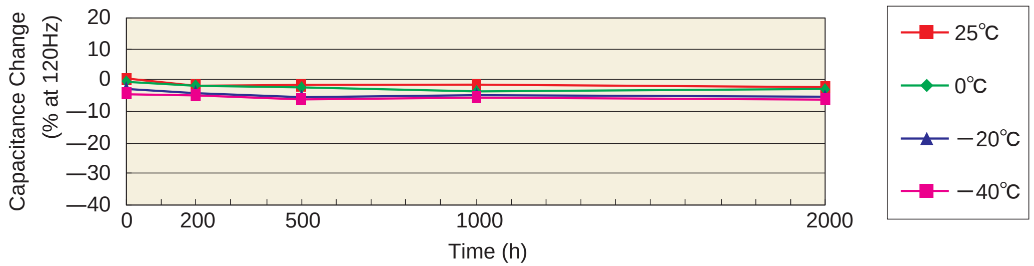


Aluminum electrolytic capacitor 330μF/10V

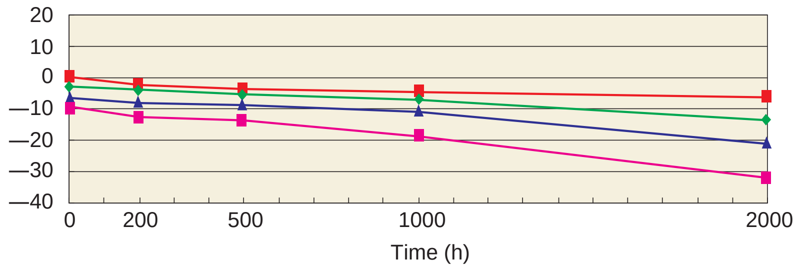


〔Capacitance〕

OS-CON（10SVPD56M）56μF/10V



Aluminum electrolytic capacitor 330μF/10V

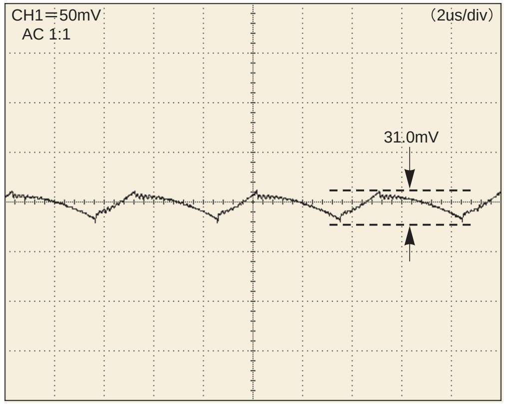


(b) Experiment result

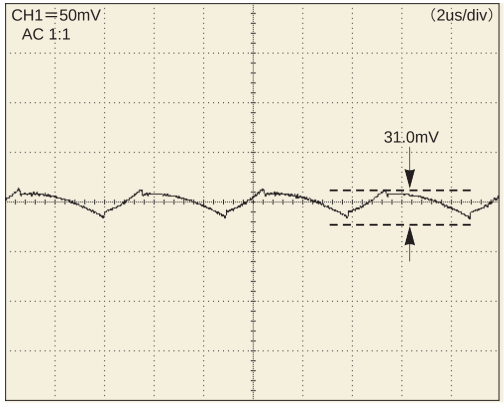
(1) Comparison of ripple voltage waveform at 25℃

OS-CON（10SVPD56M）
56μF/10V×1pc

Initial

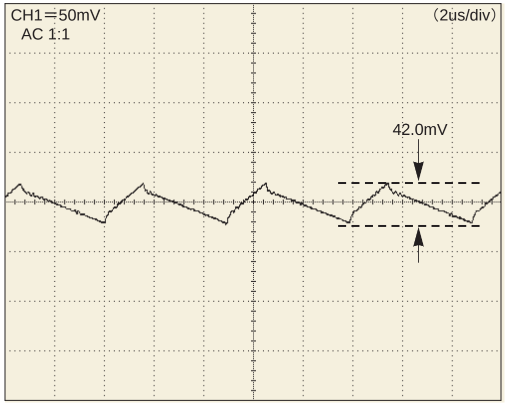


After endurance test (125℃×10V applied×1000h)

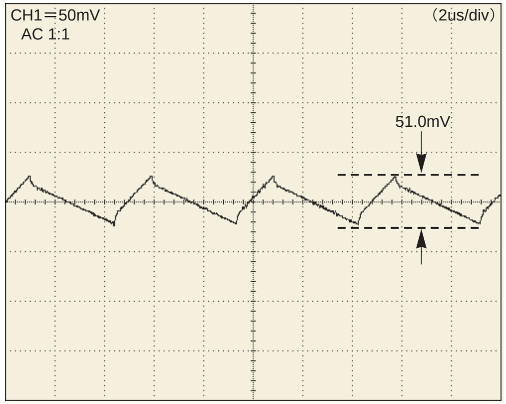


Aluminum electrolytic capacitor
330μF/10V×4pc

Initial



After endurance test (125℃×10V applied×1000h)



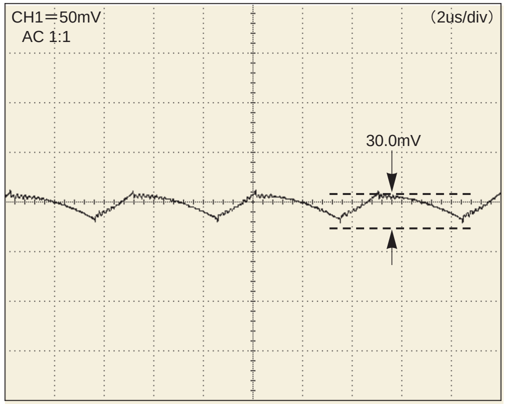
Result

	Initial	After endurance test
OS-CON	31mVp-p	31mVp-p
Aluminum electrolytic capacitor	42mVp-p	51mVp-p

(2) Comparison of ripple voltage waveform at 0℃

OS-CON（10SVPD56M）
56μF/10V×1pc

Initial



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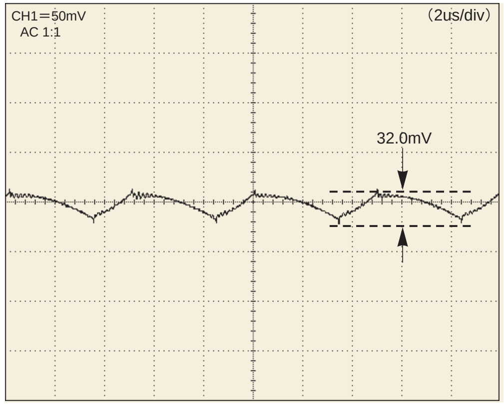
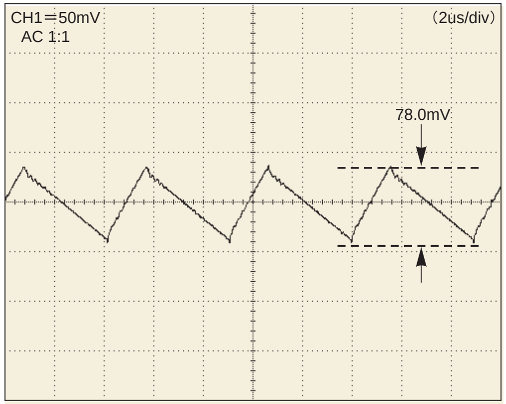
After endurance test (125℃×10V applied×1000h)



Aluminum electrolytic capacitor
330μF/10V×4pc

Initial



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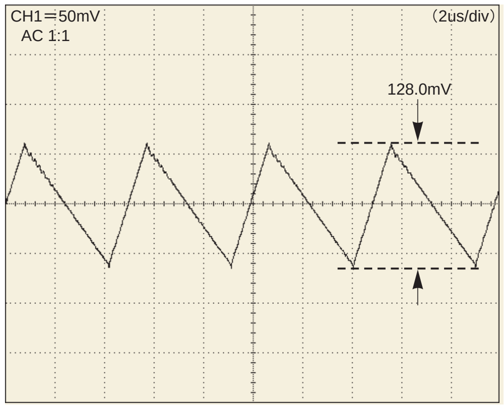
After endurance test (125℃×10V applied×1000h)



Result

	Initial	After endurance test
OS-CON	30mVp-p	32mVp-p
Aluminum electrolytic capacitor	78mVp-p	128mVp-p

2. OS-CON 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.

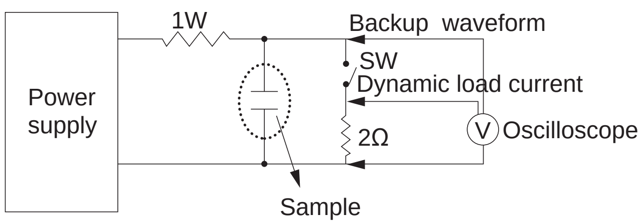
Capacitors with low ESR and large capacitance are necessary for high-speed load current transients.

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.

2-1. Test condition

Test circuit

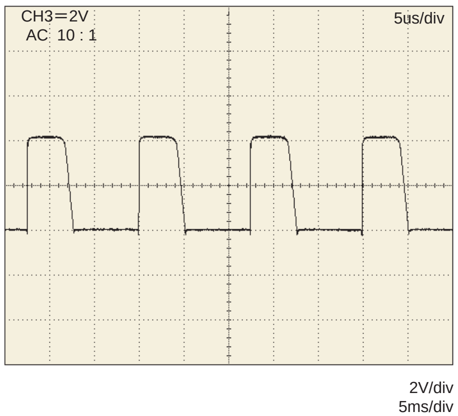


Load condition

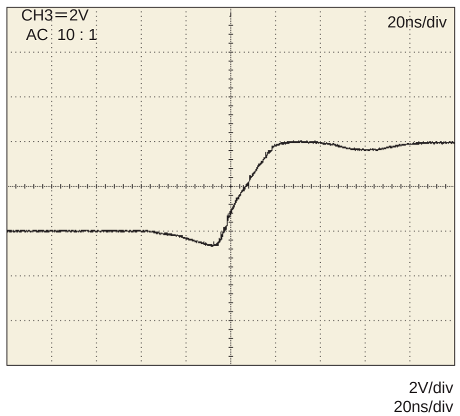
Item	Condition
Load width	5ms
Cycle	12.5ms
Rising time	20ns
Dynamic load current	2A
Voltage	4V
Power supply impedance	1Ω

(a) Switching wave form

Whole wave form



Rising wave form



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

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

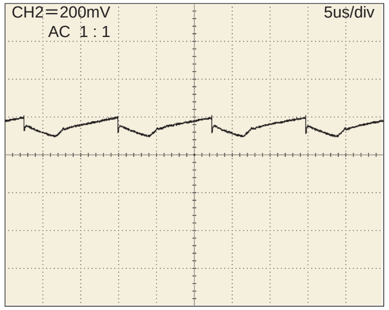
Δ V : AC Volt tolerance (V) C : Capacitance (F)
Δ I : Dynamic load current (A) ESR : ESR (Ω)
Δ t : Load width (s) T : Cycle (s)

2-2. Result

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

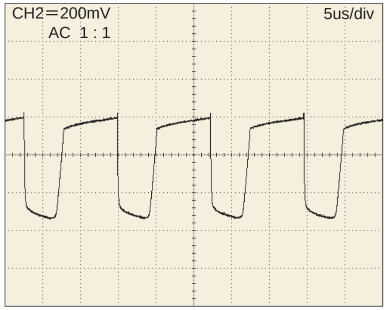
Compared with same capacitance, OS-CON voltage change of supply line is 104mV, but low-impedance Aluminum electrolytic capacitor indicates 548mV (5.3times of OS-CON), and low ESR Tantalum electrolytic capacitor indicates 212mV (2times of OS-CON).

OS-CON
10SVP100M, ESR : 21mΩ



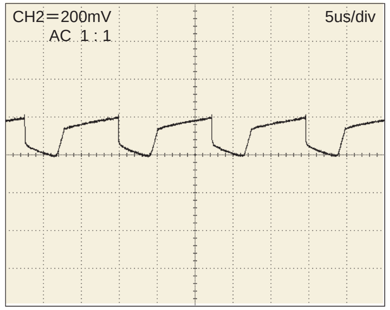
ΔV=104mV
200mV/div
5ms/div

Low Z Aluminum capacitor
10V100μF, ESR : 245mΩ



ΔV=548mV
200mV/div
5ms/div

Low ESR Tantalum capacitor
10V100μF, ESR : 85mΩ

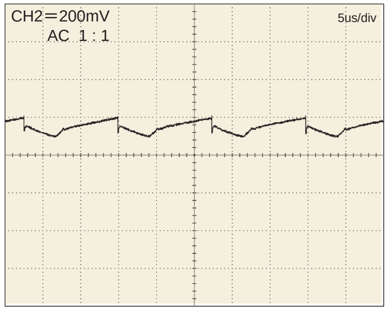


ΔV=212mV
200mV/div
5ms/div

(b) Examination of same level variable load

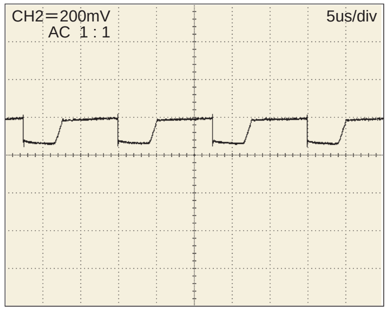
To obtain similar level of voltage change to 10SP100M, Low Z Aluminum electrolytic capacitor needs 1,500μF or more. Low ESR Tantalum electrolytic capacitor needs 220μF X 2pcs or more.

OS-CON
10SVP100M



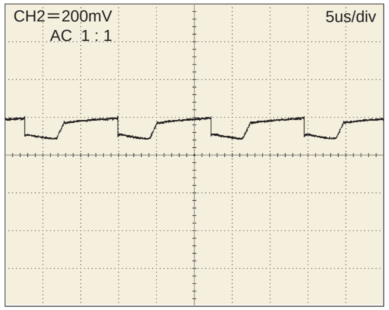
ΔV=104mV
200mV/div
5ms/div

Low Z Aluminum capacitor
10V1,500μF



ΔV=128mV
200mV/div
5ms/div

Low ESR Tantalum capacitor
10V220μF×2



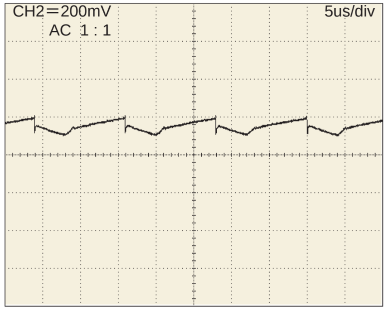
ΔV=116mV
200mV/div
5ms/div

(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

10SVP100M

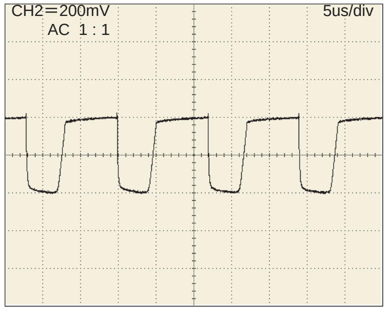


ΔV=104mV

200mV/div
5ms/div

Low Z Aluminum capacitor

10V1,500μF

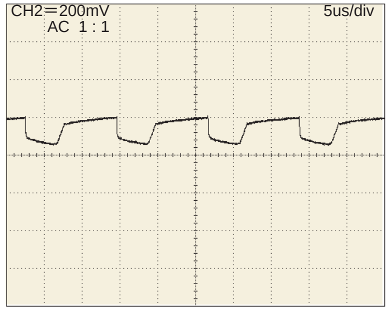


ΔV=404mV

200mV/div
5ms/div

Low ESR Tantalum capacitor

10V220μF X 2



ΔV=144mV

200mV/div
5ms/div

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. No differences were seen at initial recordings. But a difference appeared at −20℃ after an endurance test on the respective capacitors.

After Endurance Test (105℃×16V×2,000h)

OS-CON (SVP series)

20V／22μF Size φ6.3×L6.0mm

Initial ESR	42mΩ (25℃)
	42mΩ (−20℃)
ESR after endurance	45mΩ (25℃)
	45mΩ (−20℃)

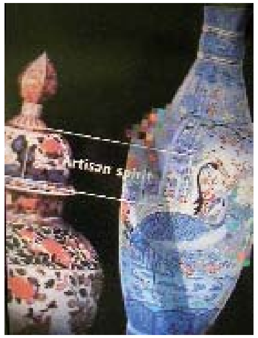


image1 25℃

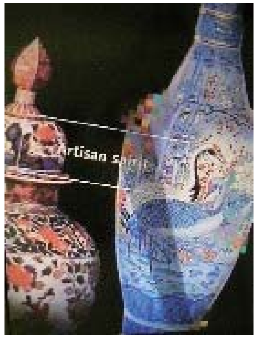
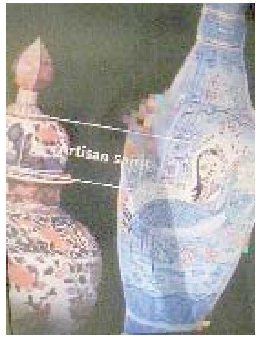


image3 −20℃

→


gamma adjusted(3.0)

Low Z aluminum electrolytic capacitor

16V／100μF Size φ6.3×L6.0mm

Initial ESR	303mΩ (25℃)
	1,080mΩ (−20℃)
ESR after endurance	418mΩ (25℃)
	1,640mΩ (−20℃)

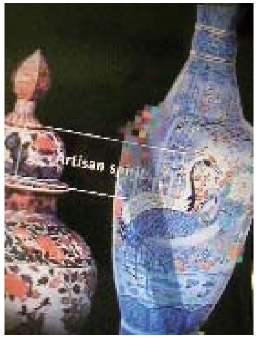


image2 25℃

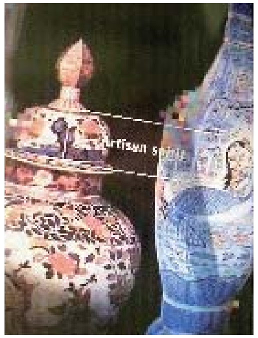


image4 −20℃

→


gamma adjusted(3.0)

(b) Summary

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

(2)With low Z electrolytic capacitors : The capacitor's deteriorated ESR (1,640mΩ) 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.

4. OS-CON 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

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 Figure 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.

4-2. Equivalent circuit for more accurate simulation

We made the equivalent circuit as shown in Figure 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.

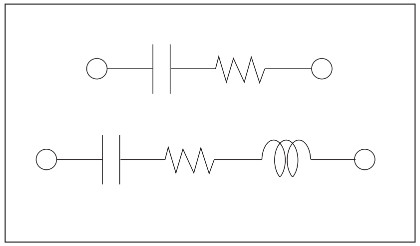


Fig.1 Current equivalent circuit

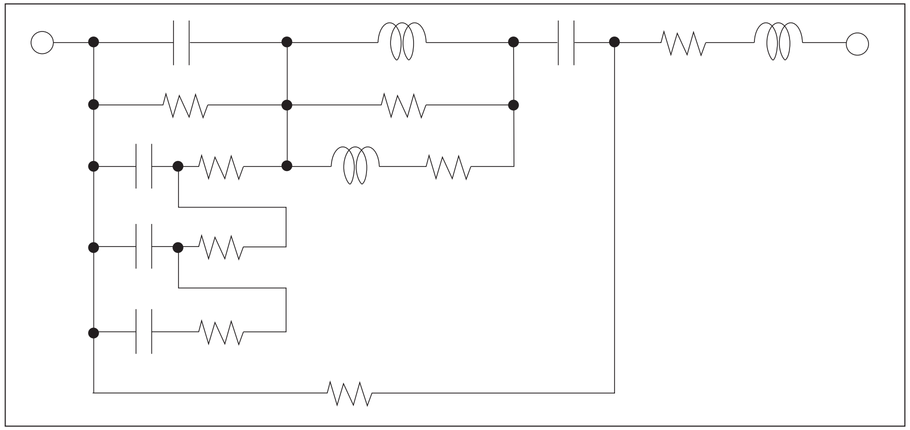
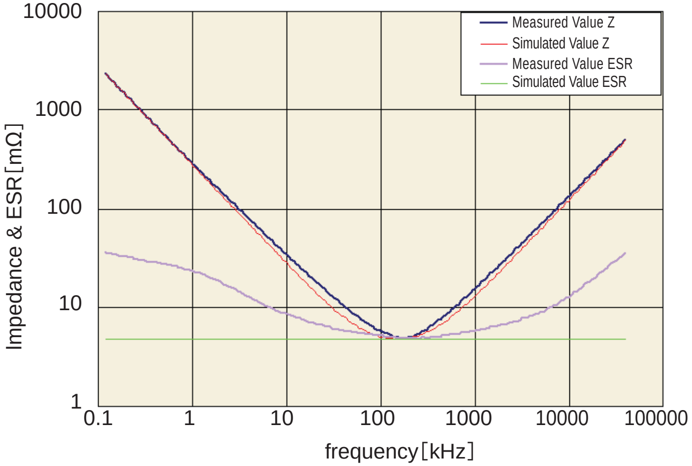


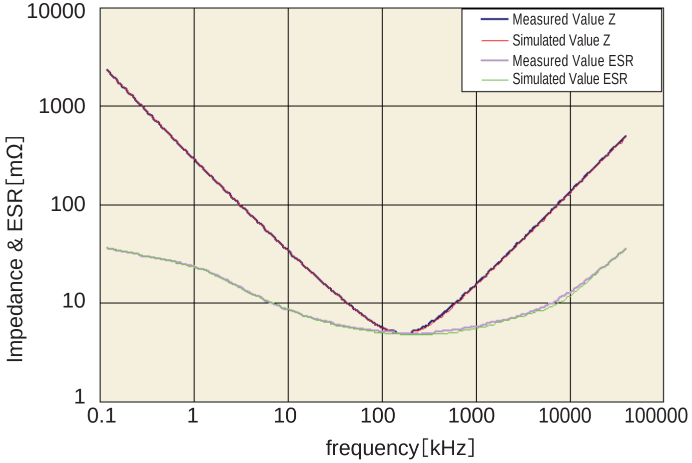
Fig.2 Equivalent circuit for more accurate simulation

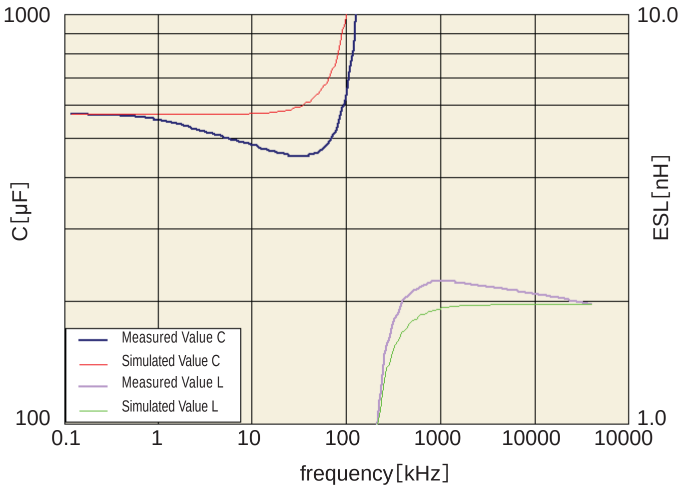
●Comparison of frequency characteristics of measurement and simulation

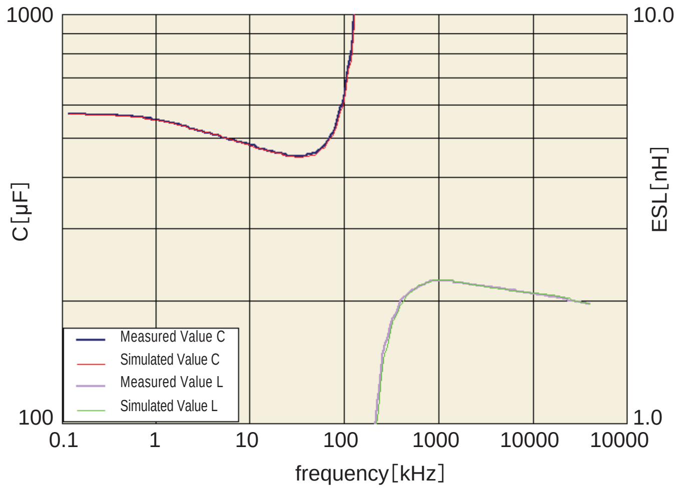
〔Current equivalent circuit〕



〔Equivalent circuit for more accurate simulation〕







Model：2SEPC560MW（2.5V-560μF）

4-3. Frequency characteristics of Capacitance

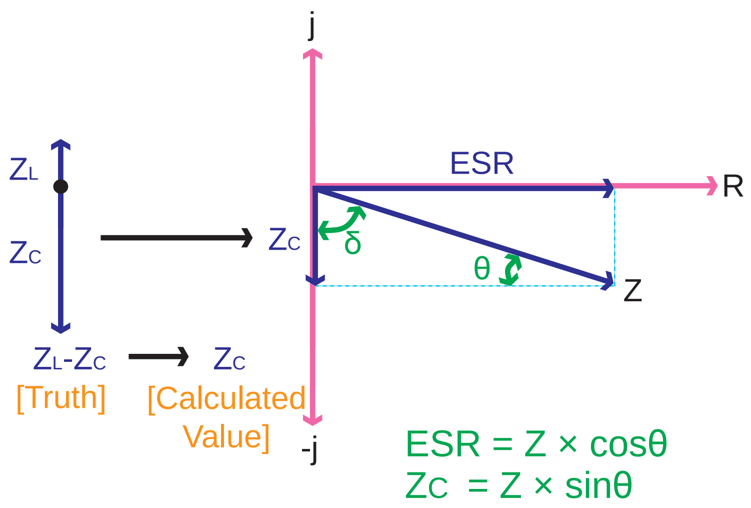
The frequency characteristics of capacitance cannot show a normal value around the resonance point when a capacitor is measured.

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.

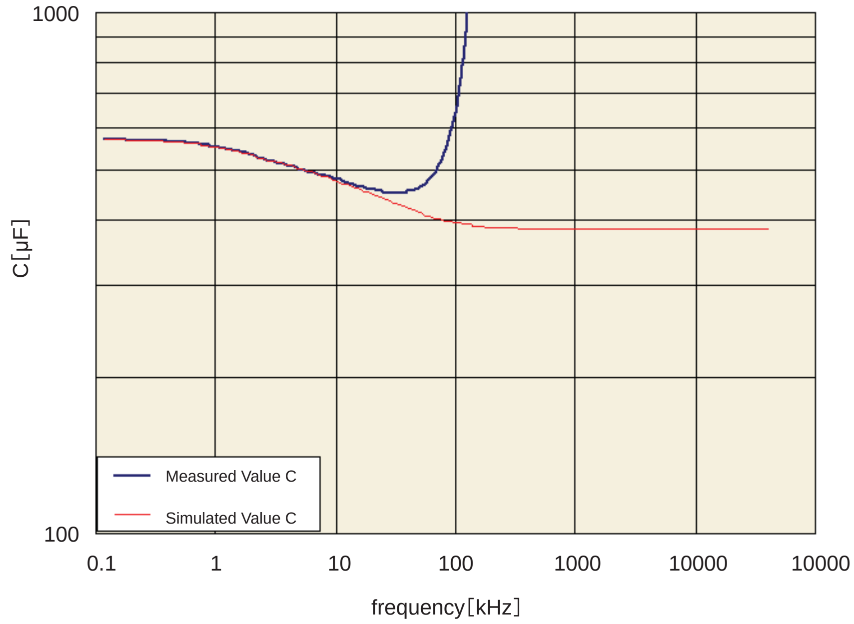
This phase lag is decided by the difference between impedance Zc of capacitance and impedance ZL of inductance. It becomes "Zc＞＞ZL" when the frequency is lower, and inductance hardly influences it. It comes to receive the influence of ZL as the frequency rises. The phase lag decreases around the resonance 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.2). 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.

Impedance element



Model：2SEPC560MW（2.5V-560μF）



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.

Fig.1 LC Filter

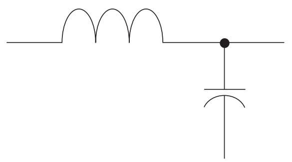
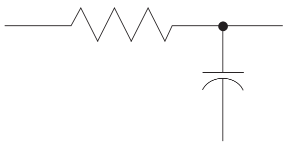


Fig.2 RC Filter



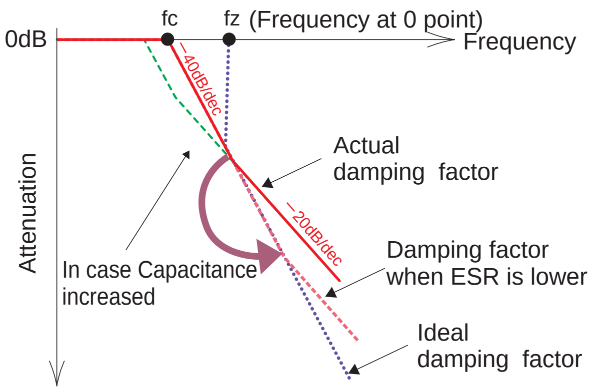
(a) The damping effect of the filter gets closer to an ideal damping rate as capacitor has lower ESR.

(b) Capacitance and ESR have 0 point frequency (fz), when the frequency is higher than 0 point frequency, +20dB/dec cancel the damping effect.

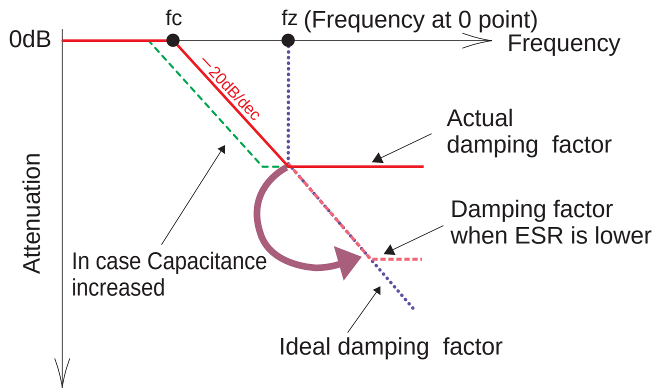
(c) LC filter : -40dB/dec is to be -20dB/dec
RC filter : -20dB/dec is to be 0 (non-damping effect)

(d) Even 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.3 Actual damping factor



(a) LC Filter



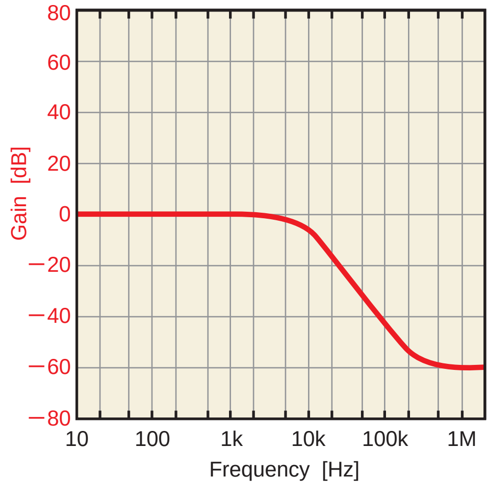
(b) RC Filter

Compare the actual damping factor of the following OS-CON with an aluminum electrolyte capacitor on the next page

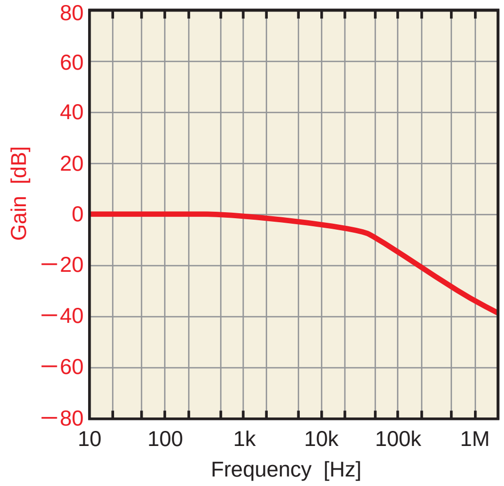
OS-CON (20SEP33M)	Aluminum electrolytic capacitor
20V/33μF, ESR=37mΩ(The actual measurement)	10V/33μF, ESR=1410mΩ(The actual measurement)

5-1. LC Filter (L=10μH)

OS-CON

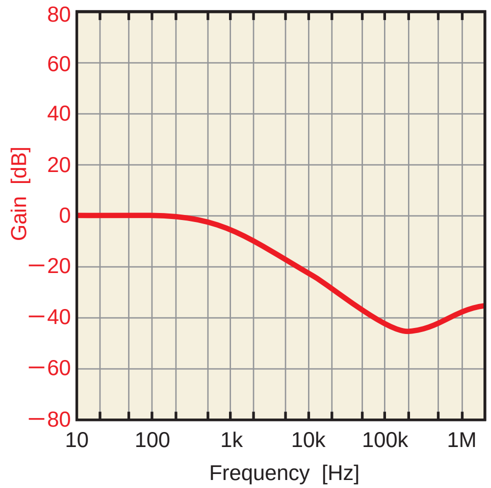


Aluminum electrolytic capacitor

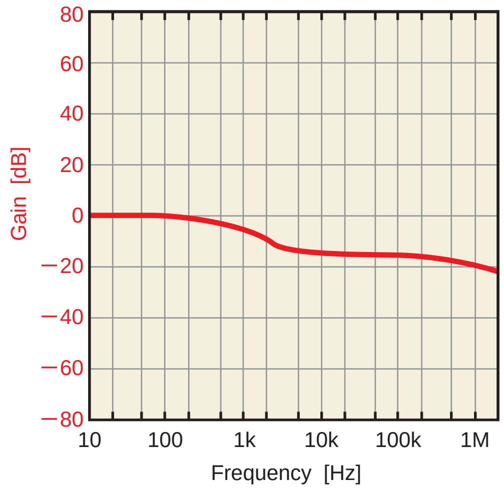


5-2. RC Filter (R=5.6)

OS-CON



Aluminum electrolytic capacitor



OS-CON shows a damping effect in higher frequency regions comparing with an aluminum electrolytic capacitor.

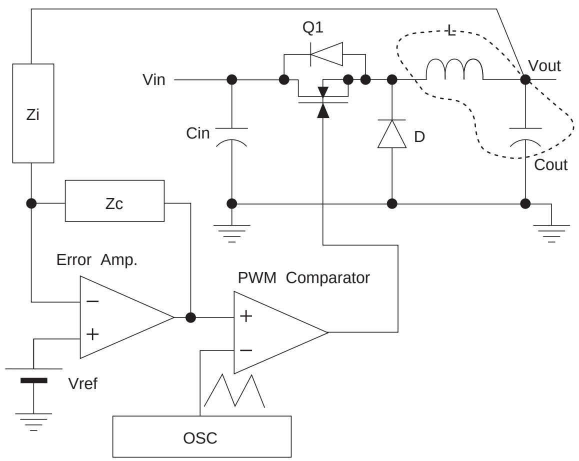
These measurements were made at room temperature. The difference in damping effect will be larger when the temperature is under 0℃, because ESR of an aluminum electrolytic capacitor will extremely increase. Oppositely OS-CON has little increase that does not affect the damping effect of the filter.

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.

Fig.1 Control block of switching power supply



6-1. Abnormal oscillation of output voltage

The switching power supply usually has the negative feed-back circuit to stabilize output voltage.

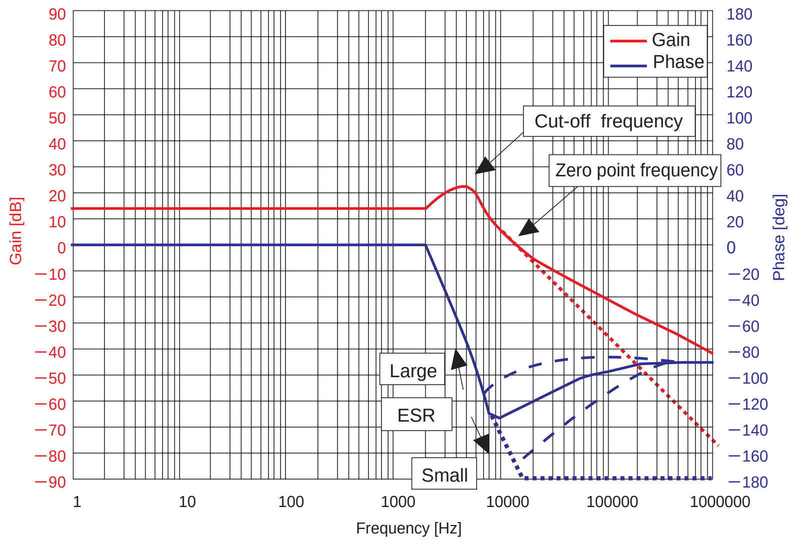
The difference between output voltage and standard voltage Vref are amplified with the error amplifier and convert to the digital signal with the PWM comparator and flip on and flip off switch Q1.

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.

The frequency characteristics of the output LC filter is expressed with the Bode diagram like Figure 2.

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.

Fig.2 Frequency characteristic of LC filter



The damping rate of the LC filter is -40dB/dec and the cut-off frequency becomes $\frac{1}{2p\sqrt{LC}}$, and become Gain and Phase like the dotted line of Figure 2.

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. Because, after the zero point frequency $\frac{1}{2p\ Cout\ ESR}$, 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.

6-2. 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.

Figure 3 : 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.3 Phase compensation network of Voltage Control Mode

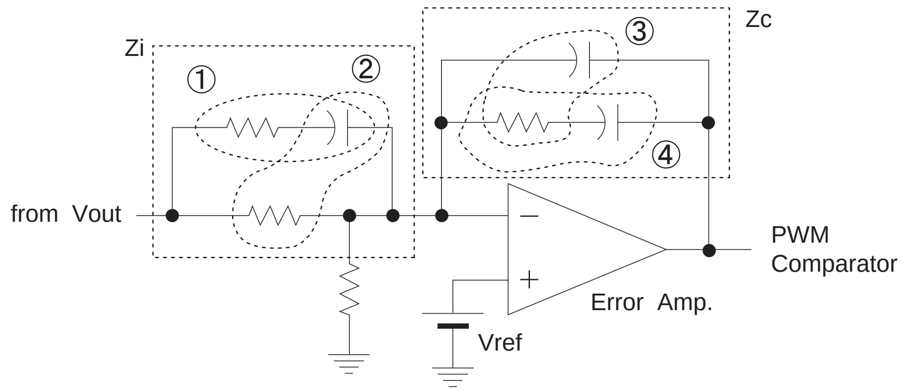
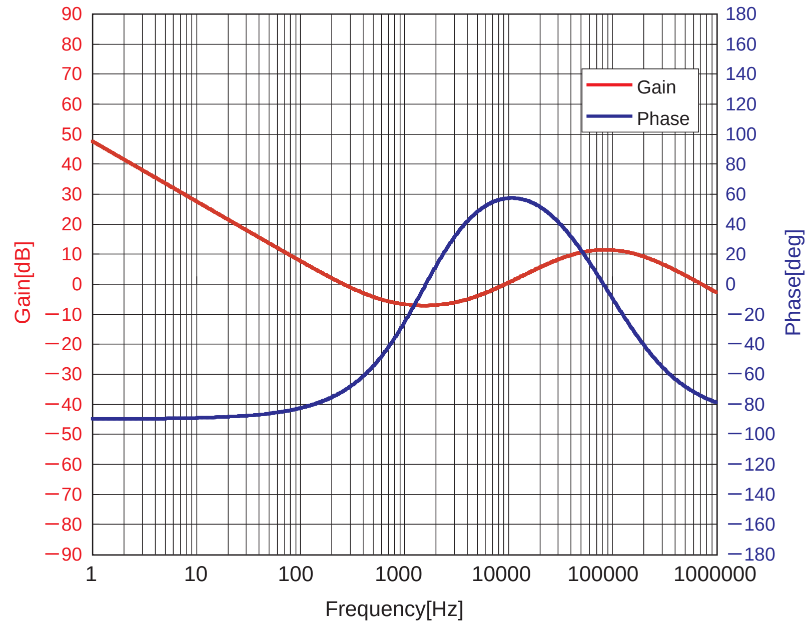


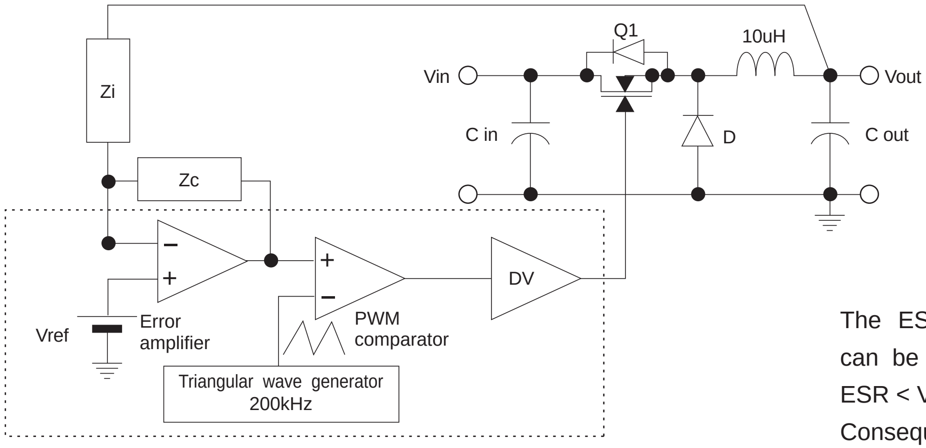
Figure 4 : Example. As the Phase of the output LC filter of Figure 2 becomes a lowest point at around 10kHz, it has about 30 degrees of Phase lead around that frequency. Because of this, it can secure the Phase margin of 30 degrees even if the Phase delay of LC filter becomes 180 degree nearly, the oscillation of output voltage can inhibited.

Fig.4 Frequency characteristic of Phase Compensation Network



6-3. Concrete design examples of prevention oscillation

Fig.5 Step-down DC-DC converter design example



[Specification]

- Input voltage (Vin) : 5V
- Output voltage (Vout) : 3.3V
- Output current (Iout) : 3.2A
- Output ripple voltage (Vripple) : 20mVp-p

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.

(a) OS-CON

6SVP100M 1-parallel φ6.3×L6mm ESR = 32mΩ ※ESR is an actual measurement.

(b) Aluminum electrolytic capacitor

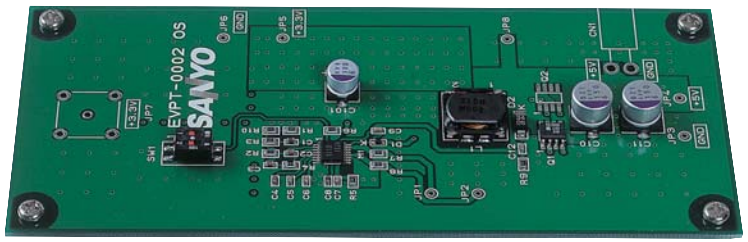
6V/680uF 3-parallel φ10×L8mm ESR = 128mΩ/p. Total ESR = 43mΩ

Photograph 1: Measuring evaluation board using the above capacitors

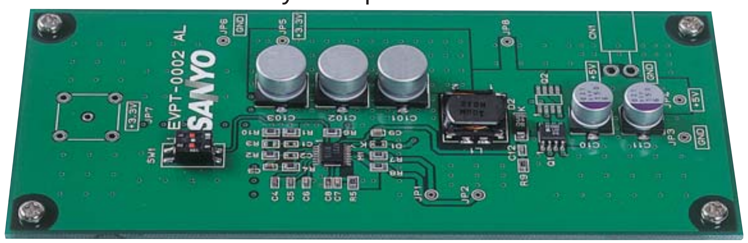
We can downsize by using the OS-CON compared with aluminum electrolytic capacitors if the most favorable phase compensating circuit is provided as follows.

Photo 1 Evaluated circuit boards

OS-CON



Aluminum electrolytic capacitor



6-4. Examples of design with aluminum electrolytic capacitors

When the aluminum electrolytic capacitors are used, the frequency characteristics of the output LC filter are as shown in Fig.6, 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.7 is sufficient.

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

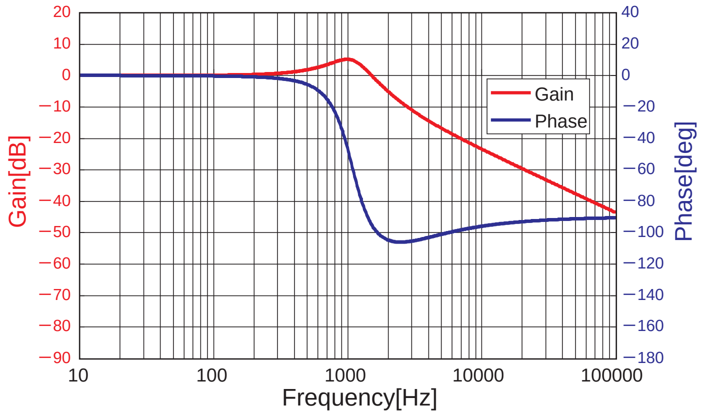
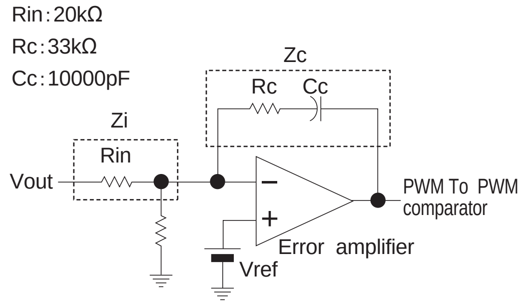


Fig.7 Phase compensating circuit with the AL-E



With the phase compensation network is Fig. 7 (properly speaking, phase compensation is not made), the total frequency characteristics are as shown in Fig. 8, and there is a sufficient phase margin.

Fig8 Total frequency characteristics with the AL-E

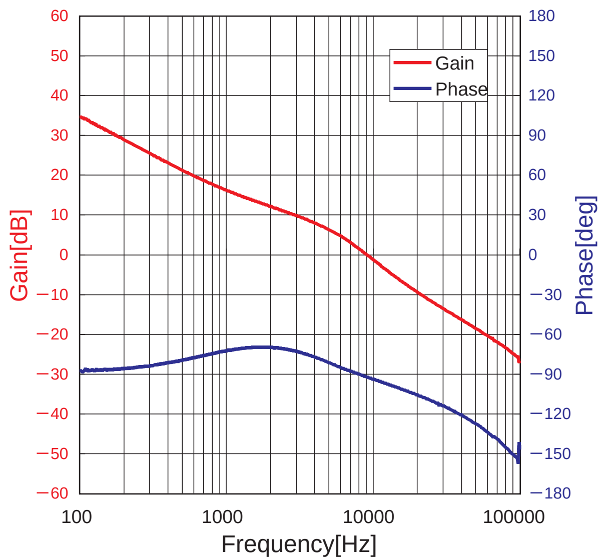
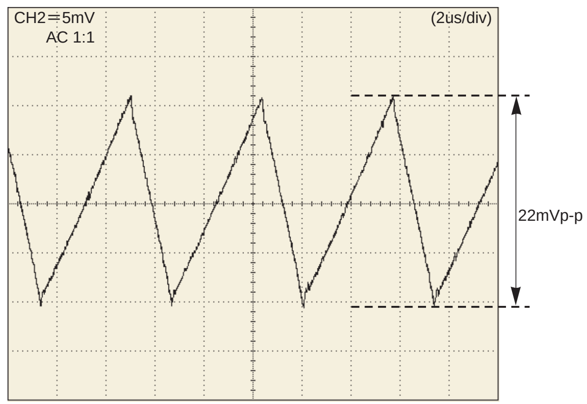


Fig.9 Output ripple voltage waveform with the AL-E



6-5. Examples of design with the OS-CON

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.10)

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, where the aluminum electrolytic capacitors are used, to Fig.11, where they are replaced with the low ESR OS-CON.

Fig.10 Oscillating output voltage waveform

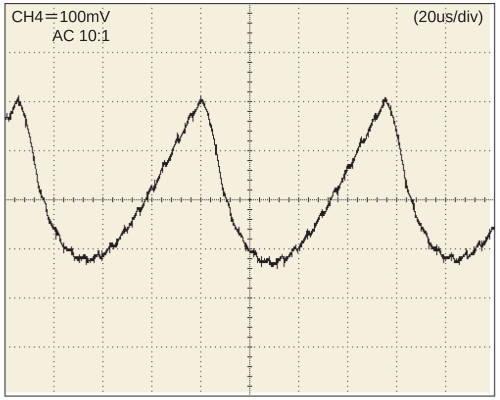


Fig.11 Frequency characteristics of the LC filter with the OS-CON

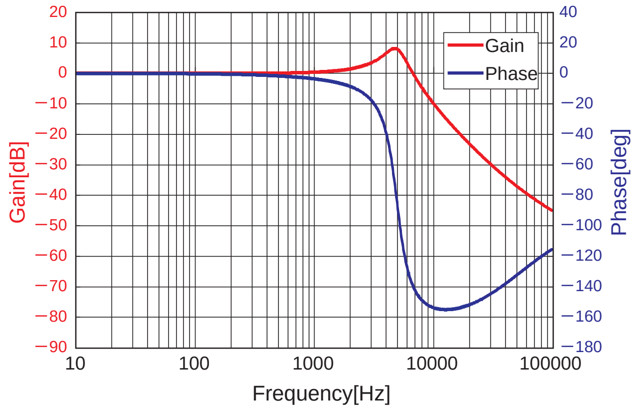
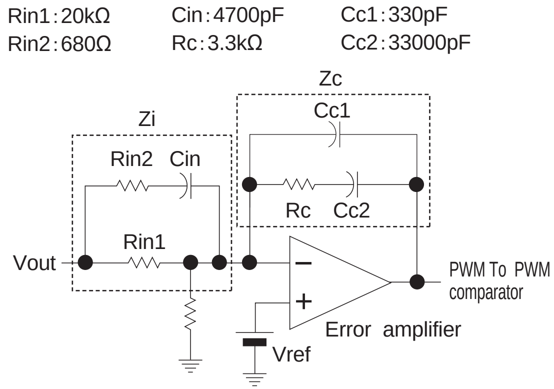


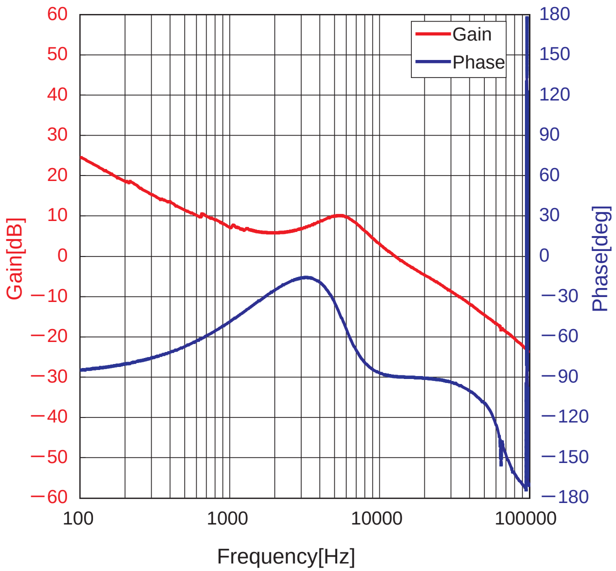
Fig.12 Phase compensating circuit with the OS-CON



When the LC filter has little phase margin as shown in Fig.11, appropriate phase compensation can be made by using such a phase compensation network as shown in Fig.12.

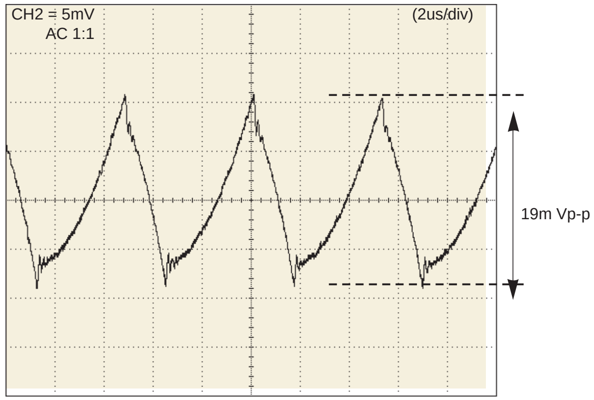
This is to cancel the deepened phase lag by forming phase leads at Zi and Zc in Fig.12.

Fig.13 Total frequency characteristics with the OS-CON



Because of this, the total frequency characteristics are as shown in Fig.13; the phase margin is sufficient; and the output ripple voltage waveform (Fig.14) is almost the same as is the case with the aluminum electrolytic capacitors.

Fig.14 Output ripple voltage waveform with the OS-CON



OS-CON

Capacitors Selection Sheet

Conductive Polymer Aluminum Solid Capacitors

Company	
Dept.	
Name	
TEL	
FAX	
E-mail	

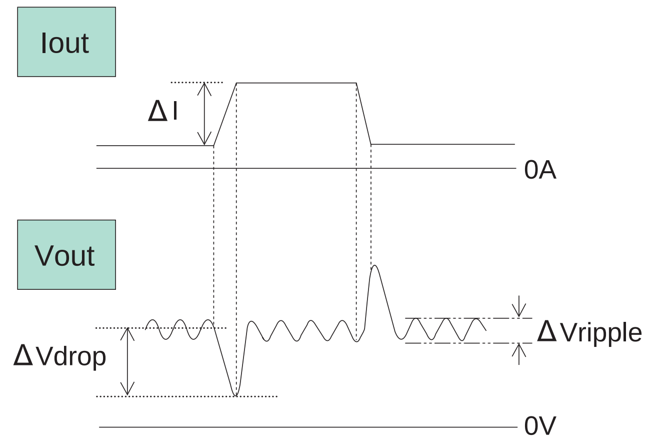
Application	Power Supply / Filter / By-pass Capacitor / Coupling Circuits / Others ( )		
Equipment	PC / PC Peripheral Unit / Audio / Communication / Automobile / Other ( )		
Height limit	mm	Mount type	Radial SMD

Indispensable item

Item	Symbol	Value	Unit
Switching Frequency	fosc		kHz
Input Voltage	Vin		V
Output Voltage	Vout		V
Output Current	Iout		A
Ripple Voltage	ΔVripple		mVp-p
Ambient Temperature	Ta		℃
Primary Inductance	L1		μH
Inductance	L		μH
Winding ratio	n1 : n2	:	

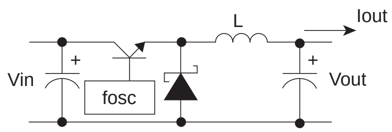
Option

Item	Symbol	Value	Unit
Current Change	ΔI		A
Voltage Drop	ΔVdrop		mV
Control IC			

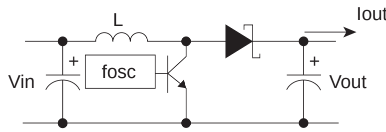


◆Please enclose the use circuit in a circle.

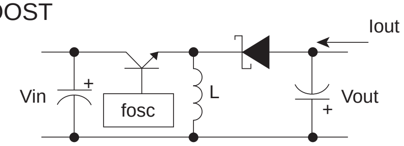
①BUCK
Vin > Vout



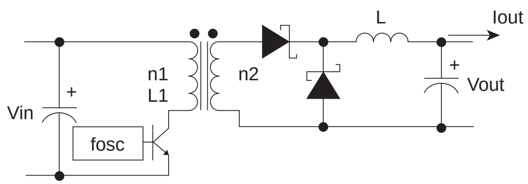
②BOOST
Vin < Vout



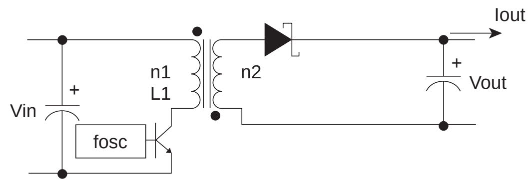
③BUCK-BOOST
0 > Vout



④FORWARD



⑤FLYBACK



The design support tool is available at the following URL on the Internet.
http://industrial.panasonic.com/