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PZ-cap

Conductive Polymer Aluminum Capacitors

Hybrid Type

July 2021
Rubycon Corporation

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- What is Conductive Polymer Aluminum Capacitors?
- What is “Hybrid Type”?
- Characteristics
- Feature of Rubycon Hybrid Type
- Series Chart
- Applications
- Technical Support
  - Design Optimization
  - Thermal Design by FEM Analysis
  - Impedance Analysis by LTSPICE
- Development Roadmap

What is Conductive Polymer Al-Capacitor?

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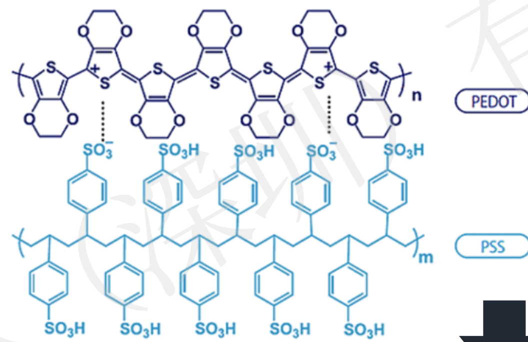
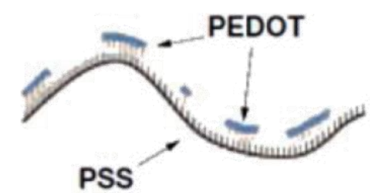
"Conductive Polymer" Electrolyte instead of Liquid Electrolyte.

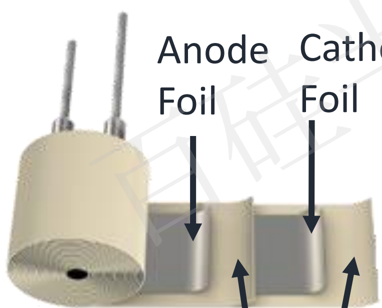
Conductive Polymer Capacitor
（100% Solid Type）

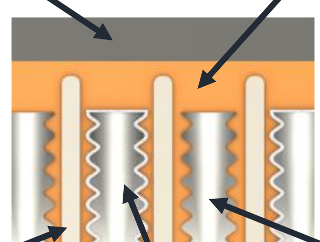
Polythiophene based Conductive Polymer (PEDOT/PSS) is dispersed into capacitor element.

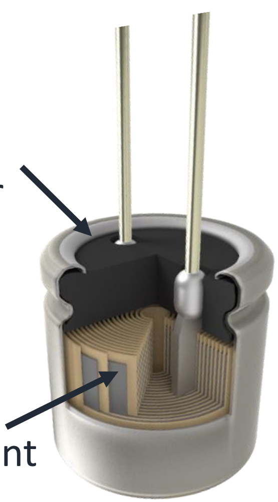
Basic Structure is same as conventional Al E-Cap.











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Category of Electrolytes

"Conductive Polymer" has very high conductivity (1=100 S/cm) and realize super low ESR Capacitor.

Conductivity [S/cm]

Electrolyte Category	Decomposition Temperature	Capacitor Category
Conductive Polymer ・Polythiophene based ・Polypyrrole based	Over 300℃	Conductive Polymer Aluminum Capacitor **PZ-Cap**
Organic Semiconductor ・TCNQ based	200～240℃	Organic Semiconductor Solid Aluminum Capacitor Example) OS-CON
Inorganic Electrolyte ・Manganese dioxide based	Over 500℃	Solid Electrolytic Capacitor Example) Tantalum Capacitor
Liquid Electrolyte ・EG based ・GBL based		Aluminum Electrolytic Capacitor (Liquid Type)

Characteristics of Conductive Polymer Capacitor (100% Solid Type)

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"Conductive Polymer Capacitor" offers much lower ESR and higher Ripple current than conventional Al E-CAP.

	Rated Voltage 63V, Size 10X12.5			
Series	**PZA**	**ZLJ**	**ZLH**	**ZL**
Electrolyte	**Conductive Polymer**	**Liquid Electrolyte**		
Impedance/ESR (Ω@100kHz)	**0.029**	**0.11**	**0.15**	**0.15**
Ripple Current (mArms@100kHz)	**2600**	**990**	**725**	**685**

← Lower ESR / Higher Ripple Current

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Positive and Negative Comparison

	Positive	Negative
Aluminum Electrolytic Capacitor (Liquid Type)	・Higher Withstanding Voltage ・Open Failure Mode ・Low Leakage Current ・Higher Capacitance ・Low Cost	・Higher ESR ・Non-Stable Temperature Characteristics ・Characteristics change over time by Dry-Up mechanism
Conductive Polymer Capacitor (100% Solid Type)	・Lower ESR ・Stable temperature characteristics ・Stable Lifetime characteristics (Small characteristics change over time) ・Higher Temperature	・Lower Withstanding Voltage ・Higher Leakage Current ・Lower Capacitance ・Expensive

Mixture of Positive feature

=> “ Hybrid Type”

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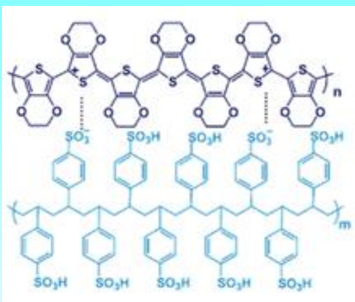
Rubycon Hybrid Type Technology

What is Hybrid Type？

Added “Functional Liquid” (Rubycon Technology) in Conductive Polymer Element

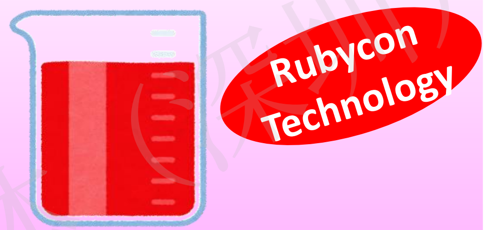
Conductive Polymer



- Lower ESR
- Higher Ripple
- Stable Temperature Characteristics

X

Functional Liquid



- Stable reforming ability to oxide film
- Inhibition of higher leakage current
- Inhibition of Polymer degradation

Hybrid Type

- Higher Voltage
- Open Failure Mode
- Higher Capacitance
- Longer Lifetime

Combination of Conductive Polymer and Functional Liquid realizes higher performance and higher reliability.

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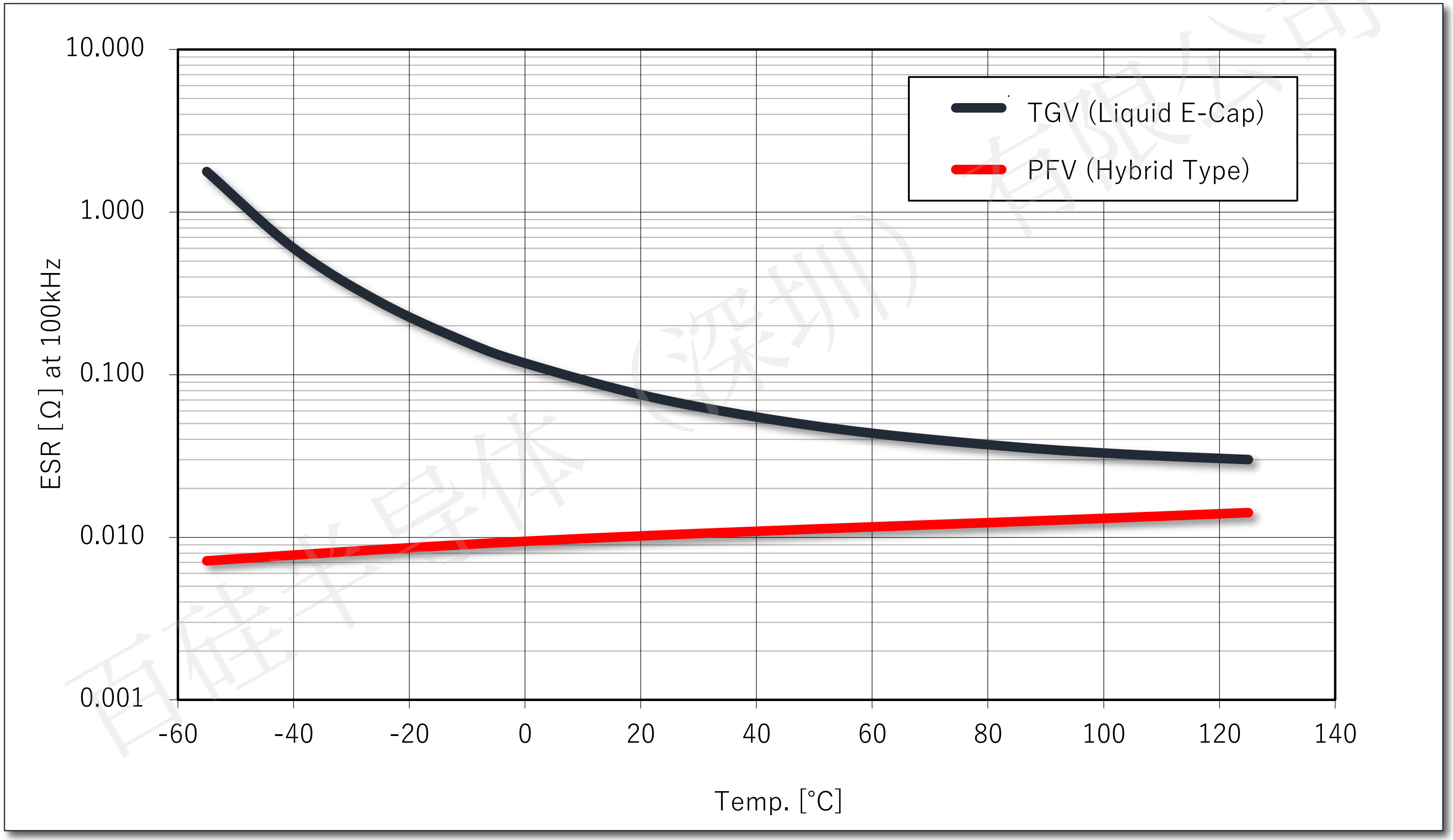
Comparison of Al E-Caps

	Conductive Polymer Capacitor (Hybrid Type）	Conductive Polymer Capacitor (100% Solid Type)	Al Electrolytic Capacitor (Liquid Type）
	35 PJV 330 M 10X10.5	35 PCV 56 M 10X12	35 TGV 220 M 10X10.5
Category Temperature	-55℃～+125℃	-55℃～+125℃	-40℃～+125℃
Size (ΦDXL）	10X10.5	10X12	10X10.5
Rated Voltage	35V	35V	35V
Capacitance	330µF	56µF	220µF
Leakage Current (WV 2分）	115.5µA (0.01CV)	392µA (0.2CV)	77.0µA (0.01CV)
Rated Ripple Current (100kHz)	2800mA	2000mA	550mA
ESR(100kHz・20℃)	20mΩ	31mΩ	120mΩ
Lifetime（125℃）	4000 Hrs	3000 Hrs	3000 Hrs

- Hybrid Type (PJV series)offers much higher capacitance and lower leakage current than 100% solid type (PCV series).
- Hybrid Type (PJV series) offers higher capacitance(x1.5), much lower ESR (1/6) and much higher ripple current (x5).

Temperature Characteristics (Hybrid vs Liquid E-Cap)

ESR vs Temperature (25V 330uF ϕ10×10.5L)



Hybrid Type has very stable ESR characteristics from low to high temperature.

Rubycon Hybrid Type PZ-CAP Merit (1)

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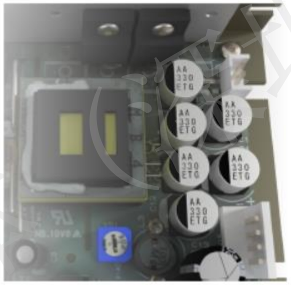
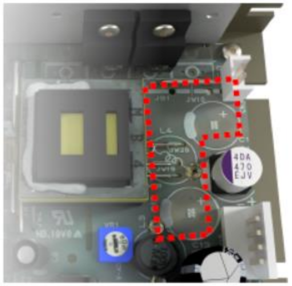
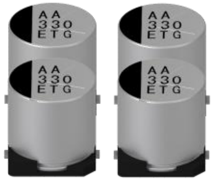
Replacement from Al E-Cap(Liquid Type)

Quantity Reduction and Cost Saving

	Al E-Cap (Liquid Type) **25TGV330M10X10.5**	**PZ Cap** **25PFV330M10X10.5**
ESR	  20mΩ/6pcs	  20mΩ/pc.
Ripple Current	 0.55A/pc. → 2.2A/6pcs	 2.0A/pc.

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Rubycon Hybrid Type PZ-CAP Merit (2)

Replacement from Al E-Cap(Liquid Type)

Space and Cost Saving

	Al E-Cap (Liquid Type) **25 HRX 5100 M 18X25**		**PZ Cap** **25 PZH 330 M 10X9**
Volume (cm^3)	$6.36cm^3$	> (-90%)	$0.71cm^3$
ESR (100kHz, 20℃)	32mΩ	> (Lower ESR)	20mΩ
リプル電流 (125℃, 100kHz)	3620mA	=	3600mA
寿命 (125℃)	3000hrs		4000hrs

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Rubycon Hybrid Type (PZ-CAP)

Rubycon Hybrid Type ： Combination of Conductive Polymer and Functional Liquid
Conductive Polymer contributes to superior Electric characteristics and Functional Liquid to higher reliability.

	Rubycon	Other Suppliers
Endurance Characteristics change, Ripple current	Conductive Polymer	Conductive Polymer & Liquid Electrolyte
ESR Temperature/Frequency Characteristics	Conductive Polymer	Conductive Polymer & Liquid Electrolyte
Healing of Oxide Film	**Functional Liquid**	**Liquid Electrolyte**
Failure Mode	Open （Deterioration of Conductive Polymer）	Open （Deterioration of Conductive Polymer） （Dry-up of Liquid Electrolyte)

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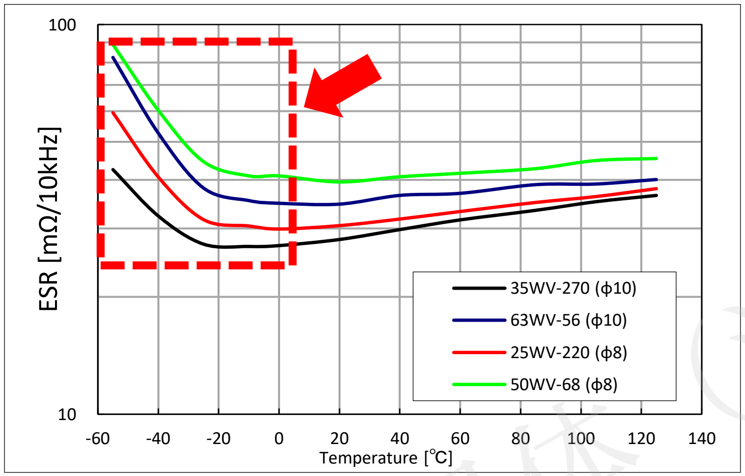
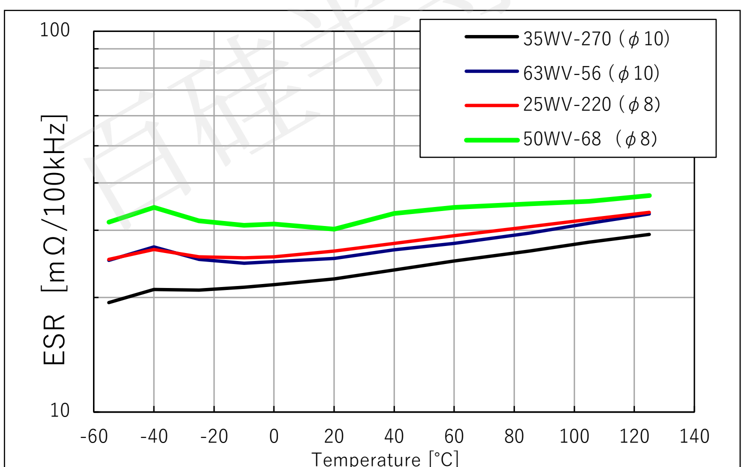
Comparison （ESR vs Temperature)

Other Suppliers vs Rubycon Hybrid Type (PZ-CAP)

Other Suppliers



Much Higher ESR at lower temp@10kHz



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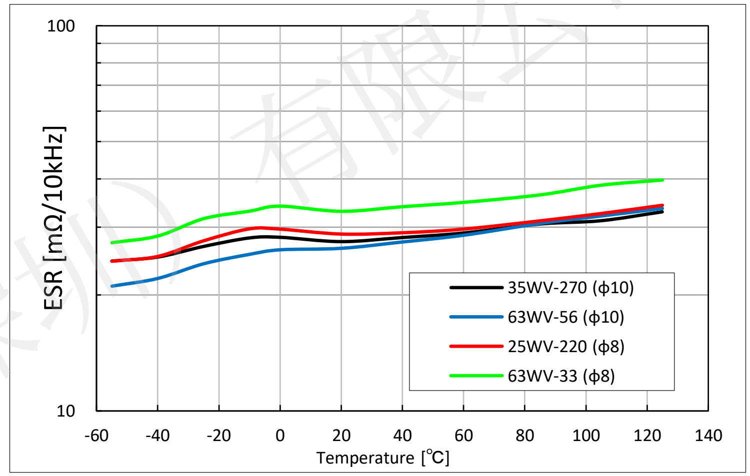

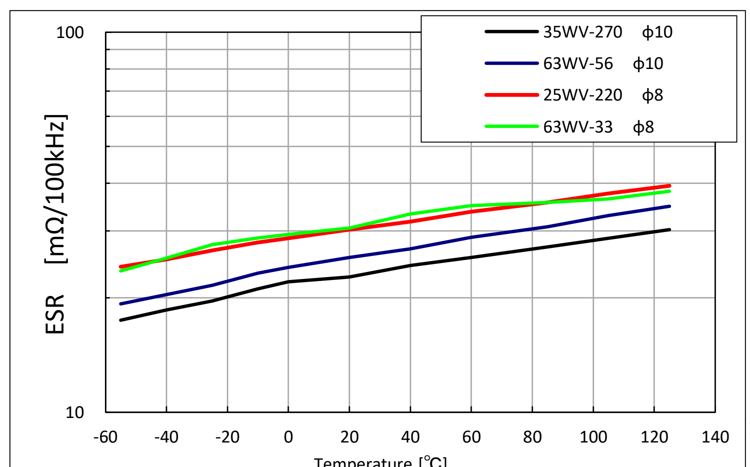

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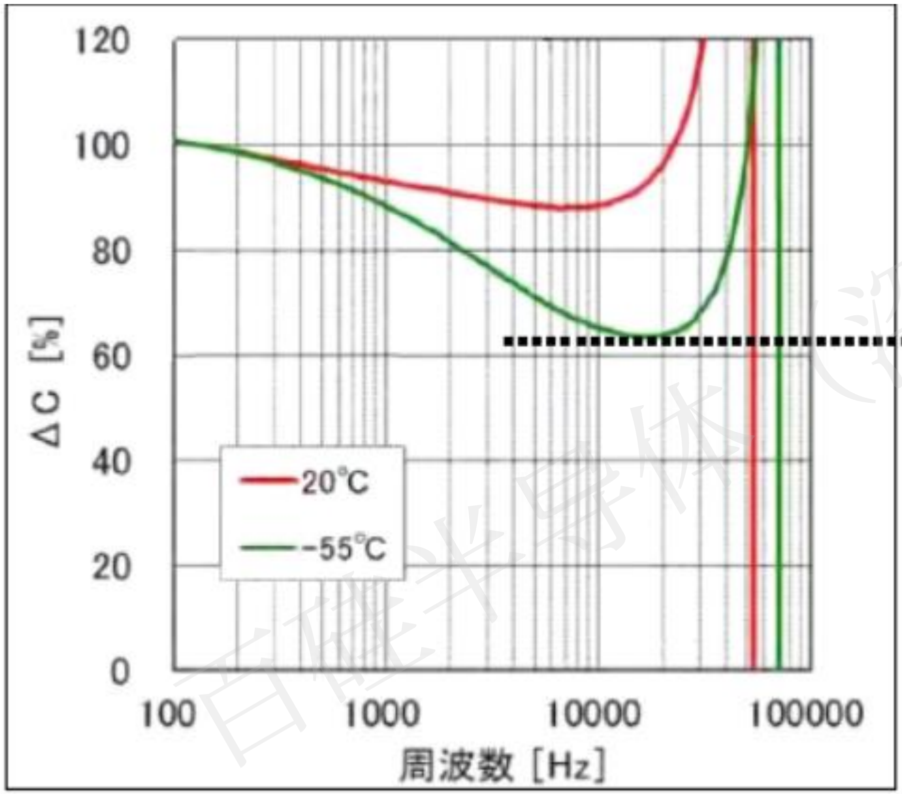
Comparison （Capacitance vs Frequency/Temperature）

Other Suppliers vs Rubycon Hybrid(PZ-CAP)

Other Suppliers



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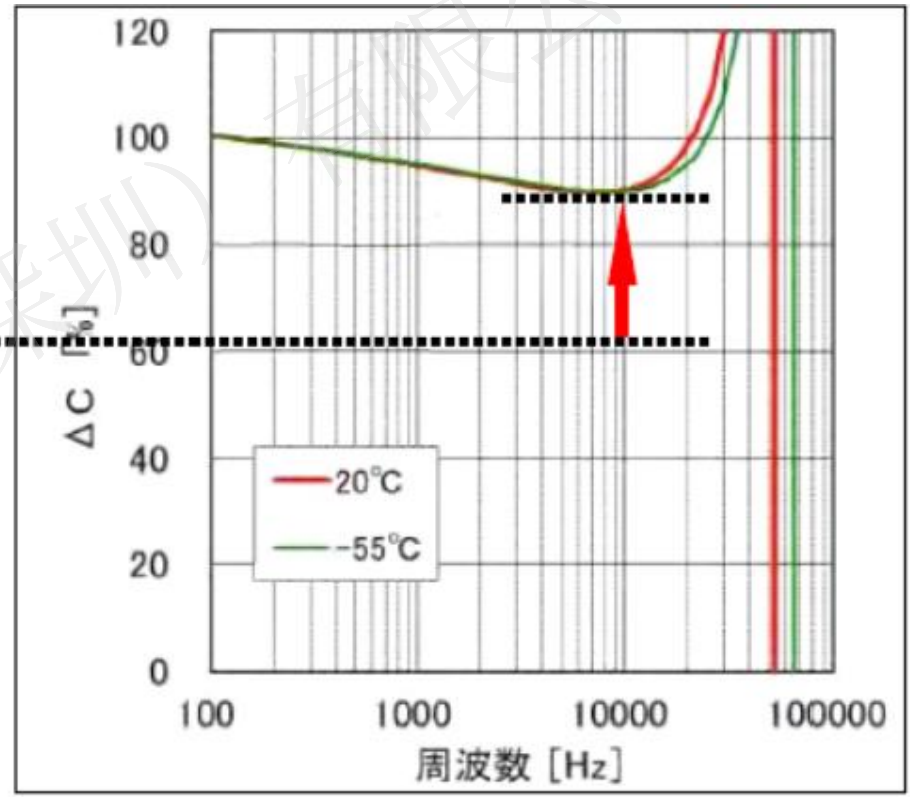

Rubycon PZ-CAP offers much smaller decrease of capacitance at lower temperature.

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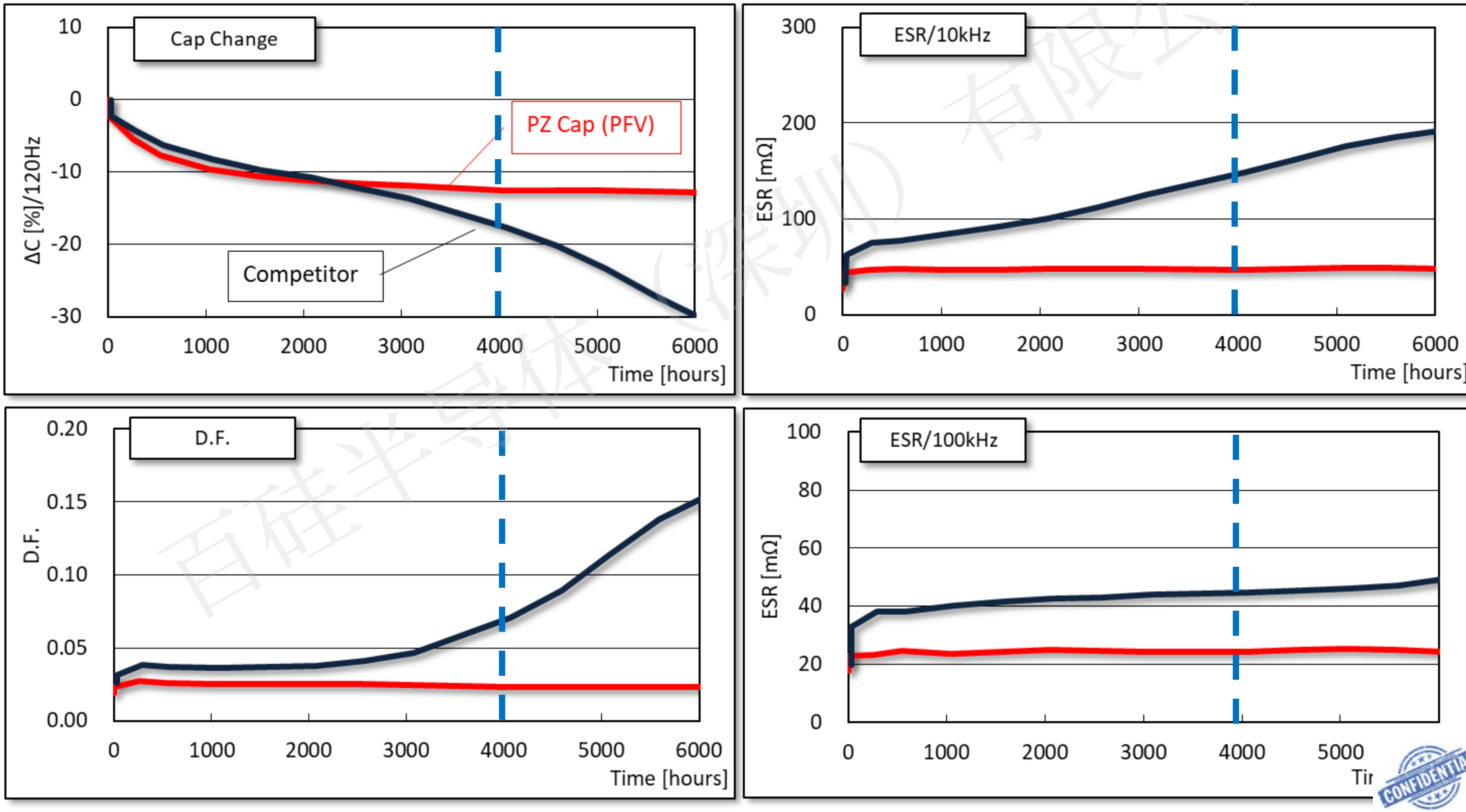
Comparison (Life Characteristics)

Rubycon PZ-CAP offers very stable characteristics over lifetime.

125℃DC Load Life Test

Sampe : PFV series, 35V 68uF ϕ6.3×8L



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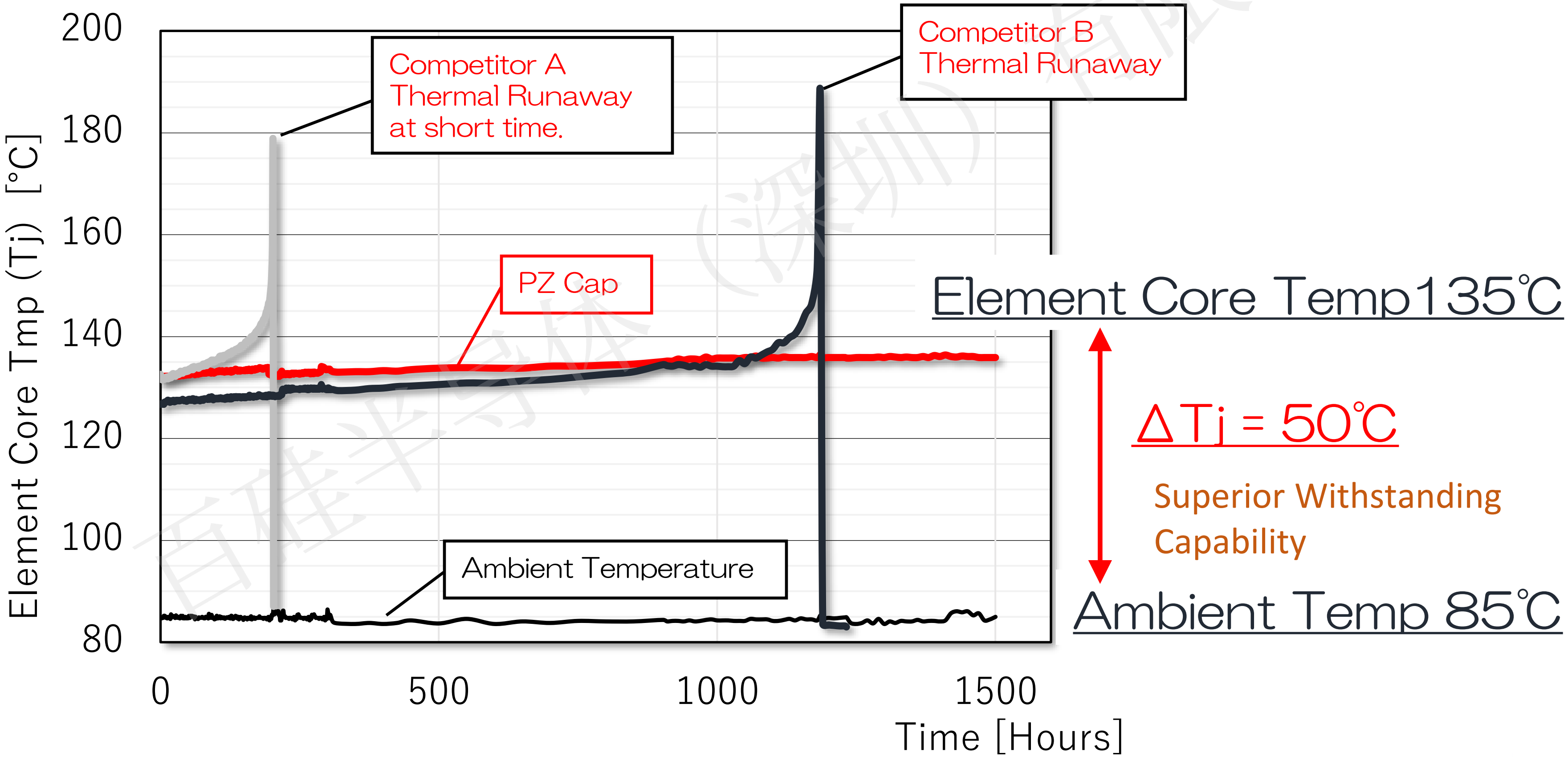
Comparison (vs High Ripple Current)

PZ-CAP shows high withstanding capability against high ripple and high internal temperature rise.

Test Condition：
Ripple Current 8Arms/100kHz at 85℃

Sample：50V 120μF　ϕ10×10.5L



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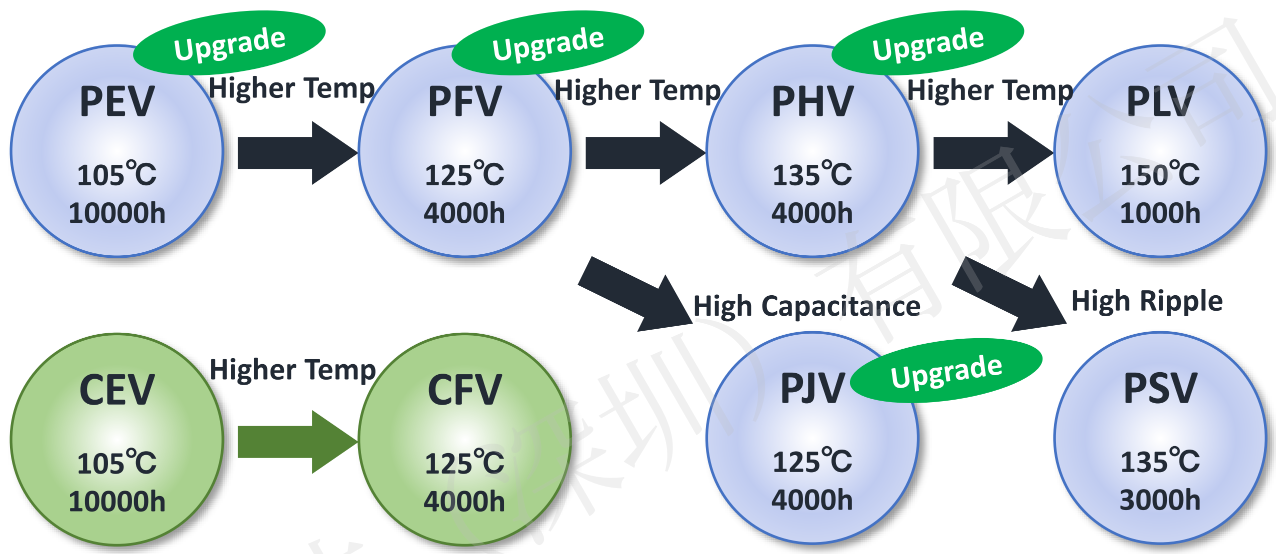
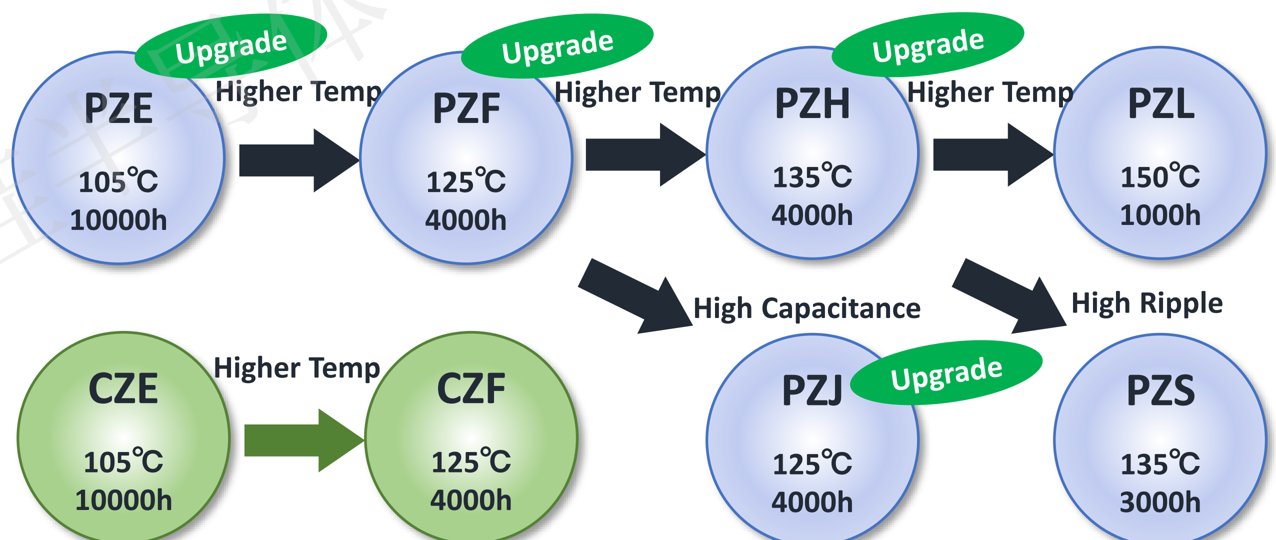
PZ-CAP Series Chart

PZ-cap

SMD Type



Radial Type



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Added Higher Capacitance

Schedule of Added Values
Sample: Available
SOP: September, 2021

(SMD Type) Upgrade

PEV series

(Radial Type) Upgrade

PZE series

Specification

-Category Temperature Range : −55 ～+105°C

-Endurance : 10,000hours at 105deg.C

-Biased Humidity : 2,000hours at 85℃85%RH

PEV

105℃

10000h

Volt [Vdc]	Cap [µF]	Size DxL PEV	Size DxL PZE	ESR [mΩ]	Ripple [mA]
25	56	6.3 x 6.1	—	50	1,300
	100	6.3 x 8	—	30	2,000
	220	8 x 10.5	8 x 9	27	2,300
	330	10 x 10.5	10 x 9	20	2,500
	820	-	10 x 20	10	3,700
35	47	6.3 x 6.1	—	60	1,300
	68	6.3 x 8	—	35	2,000
	150	8 x 10.5	8 x 9	27	2,300
	270	10 x 10.5	10 x 9	20	2,500
	680	-	10 x 20	10	3,700

Volt [Vdc]	Cap [µF]	Size DxL PEV	Size DxL PZE	ESR [mΩ]	Ripple [mA]
50	22	6.3 x 6.1	—	80	1,100
	33	6.3 x 8	—	40	1,600
	68	8 x 10.5	8 x 9	30	1,800
	100	10 x 10.5	10 x 9	28	2,000
	270	-	10 x 20	12	3,100
63	10	6.3 x 6.1	—	120	1,000
	22	6.3 x 8	—	80	1,500
	33	8 x 10.5	8 x 9	40	1,700
	56	10 x 10.5	10 x 9	30	1,800
	150	-	10 x 20	14	2,700
80	22	8 x 10.5	8 x 9	45	1,600
	39	10 x 10.5	10 x 9	35	1,700

ESR[mΩ,100kHz@20℃], Ripple[mA/100kHz, 105℃]

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Added Higher Capacitance

Schedule of Added Values
Sample: Available
SOP: September, 2021

(SMD Type) Upgrade

PFV series

(Radial Type) Upgrade

PZF series

Specification

-Category Temperature Range : −55 ～+125°C

-Endurance : 4,000hours at 125deg.C

-Biased Humidity : 2,000hours at 85℃85%RH

PEV 105℃ 10,000h → PFV 125℃ 4,000h

Volt [Vdc]	Cap [µF]	Size DxL PFV	Size DxL PZF	ESR [mΩ]	Ripple [mA]
25	56	6.3 x 6.1	—	50	900
	100	6.3 x 8	—	30	1,400
	220	8 x 10.5	8 x 9	27	1,600
	330	10 x 10.5	10 x 9	20	2,000
	470	10 x 12.5	10 x 11	14	2,600
	560	10 x 16.5	10 x 15	11	2,900
	820	-	10 x 20	10	3,000
35	47	6.3 x 6.1	—	60	900
	68	6.3 x 8	—	35	1,400
	150	8 x 10.5	8 x 9	27	1,600
	270	10 x 10.5	10 x 9	20	2,000
	330	10 x 12.5	10 x 11	14	2,600
	470	10 x 16.5	10 x 15	11	2,900
	680	-	10 x 20	10	3,000

Volt [Vdc]	Cap [µF]	Size DxL PFV	Size DxL PZF	ESR [mΩ]	Ripple [mA]
50	22	6.3 x 6.1	—	80	750
	33	6.3 x 8	—	40	1,100
	68	8 x 10.5	8 x 9	30	1,250
	100	10 x 10.5	10 x 9	28	1,600
	150	10 x 12.5	10 x 11	18	2,000
	180	10 x 16.5	10 x 15	13	2,600
	270	-	10 x 20	12	2,500
63	10	6.3 x 6.1	—	120	700
	22	6.3 x 8	—	80	900
	33	8 x 10.5	8 x 9	40	1,100
	56	10 x 10.5	10 x 9	30	1,400
	68	10 x 12.5	10 x 11	19	1,800
	100	10 x 16.5	10 x 15	15	2,500
	150	-	10 x 20	14	2,200
80	22	8 x 10.5	8 x 9	45	1,100
	39	10 x 10.5	10 x 9	35	1,200

ESR[mΩ,100kHz@20℃], Ripple[mA/100kHz, 125℃]

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Added Higher Capacitance

Schedule of Added Values
Sample: Available
SOP: September, 2021

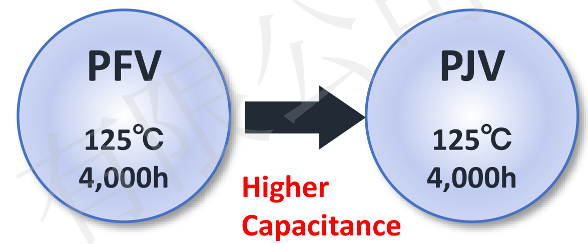
(SMD Type) Upgrade

PJV series

(Radial Type) Upgrade

PZJ series

Specification
- Category Temperature Range : －55 ～＋125°C
- Endurance : 4,000hours at 125deg.C
- Biased Humidity : 2,000hours at 85℃85%RH



Volt [Vdc]	Cap [μF]	Size DxL PJV	Size DxL PZJ	ESR [mΩ] 20℃	Ripple [mA]
25	68	6.3 x 6.1	—	50	1,080
	150	6.3 x 8	—	30	1,680
	270	8 x 10.5	8 x 9	25	1,920
	470	10 x 10.5	10 x 9	20	2,800
	560	10 x 12.5	10 x 11	14	3,200
	820	10 x 16.5	10 x 15	11	4,000
35	56	6.3 x 6.1	—	50	1,080
	100	6.3 x 8	—	30	1,680
	180	8 x 10.5	8 x 9	25	1,920
	330	10 x 10.5	10 x 9	20	2,800
	390	10 x 12.5	10 x 11	14	3,200
	560	10 x 16.5	10 x 15	11	4,000

Volt [Vdc]	Cap [μF]	Size DxL PJV	Size DxL PZJ	ESR [mΩ] 20℃	Ripple [mA]
50	82	8 x 10.5	8 x 9	30	1,700
	150	10 x 10.5	10 x 9	28	2,200
	180	10 x 12.5	10 x 11	18	2,800
	220	10 x 16.5	10 x 15	13	3,700
63	47	8 x 10.5	8 x 9	40	1,500
	82	10 x 10.5	10 x 9	30	1,900
	100	10 x 12.5	10 x 11	19	2,500
	150	10 x 16.5	10 x 15	15	3,500

ESR[mΩ,100kHz@20℃]
Ripple [mA/100kHz, 125℃]

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(SMD Type) Upgrade
PHV series

(Radial Type) Upgrade
PZH series

Added Higher Capacitance

Schedule of Added Values
Sample: Available
SOP: September, 2021

PFV 125℃ 4,000h → PHV 135℃ 4,000h

High Temp
High Ripple

Specification

- -Category Temperature Range : −55 ～＋135°C
- -Endurance : 4,000hours at 135/125deg.C ※1
- -Biased Humidity : 2,000hours at 85℃85%RH
- - Over Temperature Proof : 300hours at 150deg.C ※2

x1.6~1.8 Higher Ripple vs PFV series

Volt [Vdc]	Cap [μF]	Size DxL PHV	Size DxL PZH	ESR [mΩ] 20℃	Ripple [mA] 135℃	Ripple [mA] 125℃
25	56	6.3 x 6.1	—	50	900	1,400
	100	6.3 x 8	—	30	1,400	2,200
	220	8 x 10.5	8 x 9	22	1,600	2,900
	330	10 x 10.5	10 x 9	20	2,000	3,600
	470	10 x 12.5	10 x 11	14	2,300	4,100
	820	-	10 x 20	10	3,000	5,400
35	47	6.3 x 6.1	—	50	900	1,400
	68	6.3 x 8	—	30	1,400	2,200
	150	8 x 10.5	8 x 9	22	1,600	2,900
	270	10 x 10.5	10 x 9	20	2,000	3,600
	330	10 x 12.5	10 x 11	14	2,300	4,100
	680	-	10 x 20	10	3,000	5,400

Volt [Vdc]	Cap [μF]	Size DxL PHV	Size DxL PZH	ESR [mΩ] 20℃	Ripple [mA] 135℃	Ripple [mA] 125℃
50	68	8 x 10.5	8 x 9	30	1,250	2,300
	100	10 x 10.5	10 x 9	28	1,600	2,900
	150	10 x 12.5	10 x 11	18	2,000	3,500
	270	-	10 x 20	12	2,500	4,500
63	33	8 x 10.5	8 x 9	40	1,100	2,100
	56	10 x 10.5	10 x 9	30	1,400	2,600
	68	10 x 12.5	10 x 11	19	1,800	3,200
	150	-	10 x 20	14	2,200	4,000

ESR[mΩ,100kHz@20℃]
Ripple[mA/100kHz, 135℃], Ripple[mA/100kHz, 125℃]

※1 Endurance : ϕ6.3 2,000 hours
※2 Over Temperature Proof : ϕ6.3 150hours

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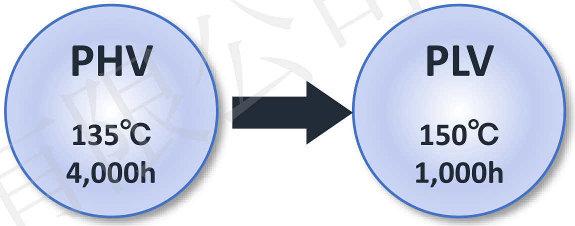
PLV series

For Extreme High Temperature Environment!

Specification
-Category Temperature Range : −55 ～+150°C
-Endurance : 1,000hours at 150deg.C
-Biased Humidity : 2,000hours at 85℃85%RH



Volt [Vdc]	Cap [μF]	Size DxL	ESR[mΩ] 20℃, 100kHz	ESR[mΩ] -40℃, 10kHz	Ripple [mArms/150℃, 100kHz]
25	150	8x10.5	25	38	1,400
	270	10x10.5	20	30	1,800
35	100	8x10.5	25	38	1,400
	150	10x10.5	20	30	1,800
50	68	8x10.5	35	53	1,000
	100	10x10.5	28	42	1,300
63	33	8x10.5	40	60	900
	56	10x10.5	30	45	1,100

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PSV series

- <u>Superior Ripple Current Performance</u>
- <u>Specified ESR after Endurance Test</u>

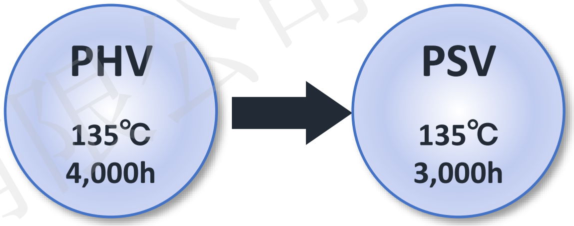
Specification

-Category Temperature Range : －55 ～＋135°C

-Endurance : 3,000hours at 135deg.C

-Biased Humidity : 2,000hours at 85℃85%RH

- Over Temperature Proof : 300hours at 150deg.C



Volt [Vdc]	Cap [μF]	Size DxL	Ripple [mArms/135℃, 100kHz]	ESR[mΩ]							
				Initial Value				After Endurance Test			
				20℃		-40℃		20℃		-40℃	
				10kHz	100kHz	10kHz	100kHz	10kHz	100kHz	10kHz	100kHz
25	220	8x10.5	2,400	26	17	21	14	33	22	27	18
	330	10x10.5	3,000	24	16	20	13	30	20	26	17
35	150	8x10.5	2,400	26	17	21	14	33	22	27	18
	270	10x10.5	3,000	24	16	20	13	30	20	26	17
50	68	8x10.5	1,870	36	24	30	20	45	30	39	26
	100	10x10.5	2,400	33	22	27	18	42	28	36	24
63	33	8x10.5	1,650	45	30	36	24	60	40	48	32
	56	10x10.5	2,100	42	28	34	23	55	37	45	30

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PSV series

Series Comparison 35V, 270μF, 10 x 10.5

		PSV Series	PHV Series
Category Temperature		-55℃～+135℃ (Over Temperature Proof 150℃)	
Rated Ripple Current (100kHz)		**3,000 mA**	2,000 mA
Initial ESR	20℃・100kHz	**16 mΩ**	20 mΩ
	-40℃・100kHz	**13 mΩ**	N/A
ESR after Endurance Test	20℃・100kHz	**20 mΩ**	40 mΩ
	-40℃・100kHz	**17 mΩ**	N/A

① PSV series realized Highest Ripple Current in the market.

(x1.5 higher vs PHV series)

≫ Best for Inverter Circuit in various applications for which Ripple Current is Key factor

This PSV series contributes to cost reduction by offering smaller size and reduction of quantity.

Applications) Power Circuit (DC Link; DC-DC Converter Input) ＝ Key Factor : High Ripple Current

Electric Power Steering, Braking System, Cooling Pump, Motor Drive, E-Compressor, Cordless Stick Vacuum etc

② PSV series realized Lowest ESR in the market.

(ESR after Endurance Test is same level as initial ESR of PHV series.)

≫ Best for various high rereliablity circuit requiring stable ESR characteristics (Feasible to replace MLCC)

Applications) High Reliability Control Circuit (Power Supply Output, Gate Drive Circuit) ＝ Key Factor: Stable ESR

Various Automotive ECU (for PCU, ADAS etc), Various High Reliable Power Supply (for Base Station etc)

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（SMD Type）

CEV series

（Radial Type）

CZE series

Specification

-Category Temperature Range : −55 ～+105°C

-Endurance : 10,000hours at 105deg.C

-Biased Humidity : 2,000hours at 85℃85%RH

CEV (CZE)

105℃ 10,000h

Volt [Vdc]	Cap [µF]	Size [mm] DxL		ESR [mΩ] 20℃, 100kHz	Rated Ripple Current [mArms/105℃, 100kHz]
		CEV	CZE		
25	220	8 x 10.5	8 x 9	27	2,300
	330	10 x 10.5	10 x 9	20	2,500
35	150	8 x 10.5	8 x 9	27	2,300
	270	10 x 10.5	10 x 9	20	2,500
50	68	8 x 10.5	8 x 9	30	1,800
	100	10 x 10.5	10 x 9	28	2,000
63	33	8 x 10.5	8 x 9	40	1,700
	56	10 x 10.5	10 x 9	30	1,800

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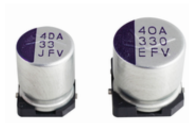
（SMD Type）

CFV series



（Radial Type）

CZF series

Specification

-Category Temperature Range : －55 ～＋125°C

-Endurance : 4,000hours at 125deg.C (Endurance 1)

3,000hours at 125deg.C (Endurance 2)

-Biased Humidity : 2,000hours at 85℃85%RH

CFV (CZF)

125℃
4000h

Volt [Vdc]	Cap [µF]	Size [mm] DxL		ESR [mΩ] 20℃, 100kHz	Rated Ripple Current [mArms/125℃, 100kHz]	
		CFV	CZF		Endurance 1	Endurance 2
25	220	8 x 10.5	8 x 9	27	1,600	1,900
	330	10 x 10.5	10 x 9	20	2,000	2,900
35	150	8 x 10.5	8 x 9	27	1,600	1,900
	270	10 x 10.5	10 x 9	20	2,000	2,900
50	68	8 x 10.5	8 x 9	30	1,250	-
	100	10 x 10.5	10 x 9	28	1,600	-
63	33	8 x 10.5	8 x 9	40	1,100	-
	56	10 x 10.5	10 x 9	30	1,400	-

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Life Expectancy Formula（PZ-CAP)

$$L = L_b \times 2^{\frac{T\max + \Delta To - Tj}{10}}$$

L　: Life expectancy under operated condition

Lb　: Specified lifetime

Tmax : Category upper temperature

ΔTo　: Temperature rise by rated ripple current applied

PSV series： ΔTo = 12K

PHV series： Δ To=5K (135°C) ，Δ To=16K (125°C)

PFV, PZF, CFV, CZF series：ΔTo = 6K

PJV, PZJ, PEV, PZE, CEV, CZE series： Δ To= 10K

※CFV,CZF: For Endurance 1

Tc　: Case surface temperature under operated condition
(In case of Tj≦40°C, Tj=40°C)

Key:

- **Arrhenius Law**
- **Core Temperature (Tj) Based Calculation (factoring in temperature rise by ripple current)**

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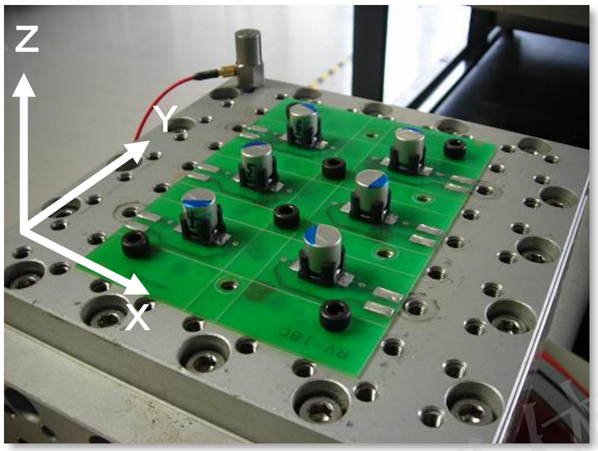
Anti-Vibration

Test Condition

【Fixture & Direction】



【Condition】

Sine wave vibration	
Frequency	10 ⇔ 2,000Hz
Cycle	15 minutes
Direction	X-Y-Z
Duration	Each 4 hours/Axis

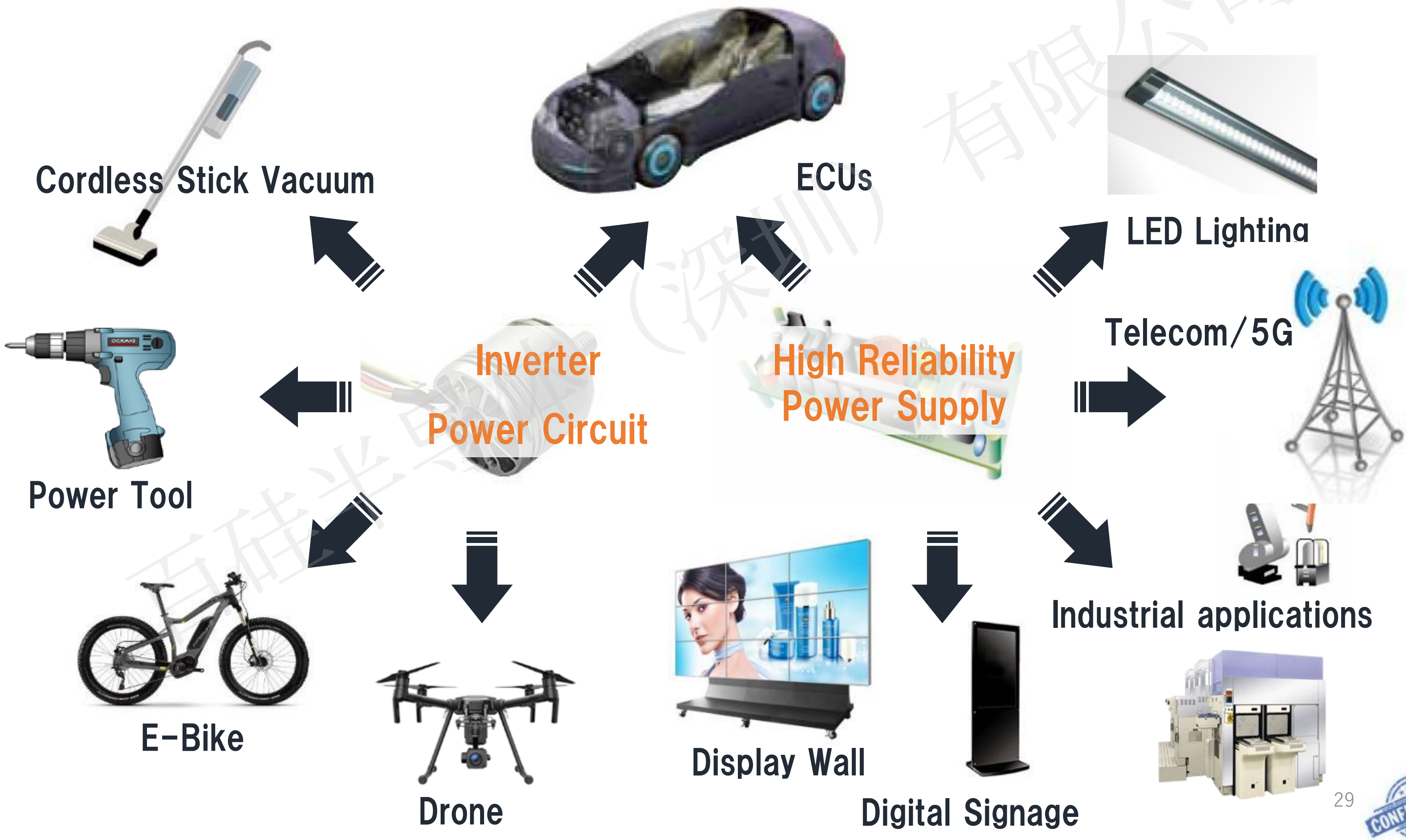
Specification

サイズ (D x L)	Standard 	Anti-Vibration 
6.3x6.1 6.3x8	**30G MAX**	**Coming soon**
8X10.5	20G MAX	**30G MAX**
10X10.5	20G MAX	**30G MAX**

Applications

PZ-cap

High Rpple, Low ESR, Stable Temperature Characteristics, and High Reliability



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Automotive Applications（1）

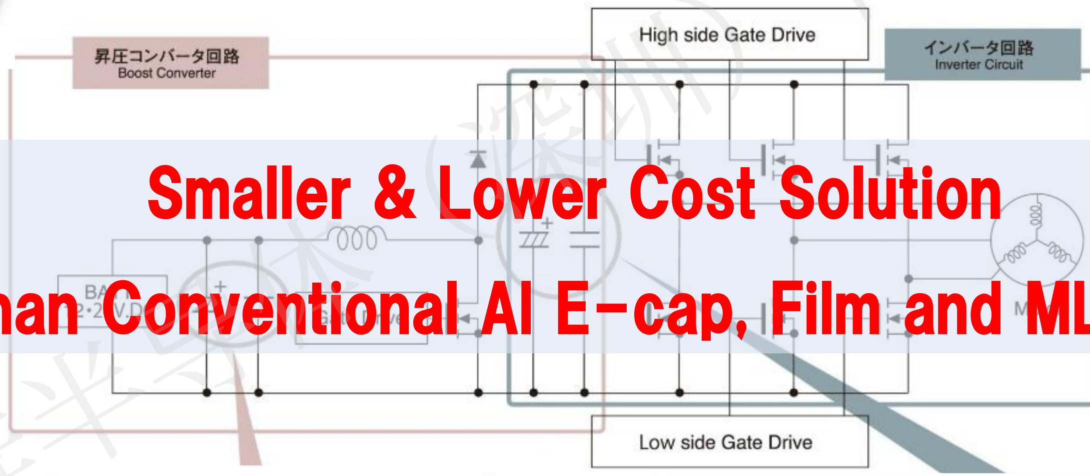
Requirement:

High Permissible Ripple Current, High temperature and Stable Temperature Characteristics

LV Inverter, DC/DC Converter Input

EPS

E-Compressor



Smaller & Lower Cost Solution

than Conventional Al E-cap, Film and MLCC

Electric Braking System

PZ-cap

PZ-cap

Electric Fuel Pump

ABS

Electric Water Pump

Cooling Fan

Electric Oil Pump

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Automotive Application（2)

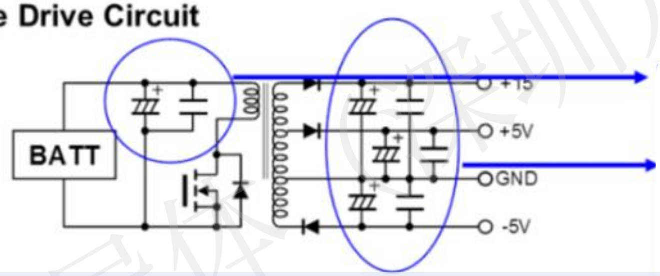
Requirement

High Temperature, Stable Temperature Characteristics and Stable ESR over lifetime

HEV System
Power Control Unit
(PCU)

Power Supply Filter Circuit, Gate Drive

Gate Drive Circuit



PZ-cap
PZ-cap

ADAS
Sensor

Smaller & Lower Cost Solution than Conventional Al E-cap and MLCC

DC-DC Converter
Stop-Start System

Battery Management System (BMS)

LED Headlamp

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Technical Consulting Support

1. Quality Required for Automotive Grade Capacitor

ZERO DEFECTS!

2. Design Process Chart and Necessary Information

Design Process | **Necessary Information**

- Application, Circuit to be used
- Development Schedule, Start of Production, Estimated Annual Usage
- Required Standard, Regulation etc. to be applied, environmental requirement etc.

Kick Off Design

step1

Fundamental Design
→ Study Withstanding Voltage, Mechanical Robustness

- Load Dump
- Jump Start
- In-Rush Current
- Switching Surge Voltage

step2

Impedance Design
→Study Capacitance, ESR, ESL

- Minimum Required Capacitance
- Required ESR by temperature, ESL

step3

Thermal Design
→Estimate Temperature Rise, Check Permissible Temperature Limit

- Heat Dissipation
- Mission Profile *

*Mission Profile: Information Specifying the operational condition (Ambient Temperature(Ta), Ripple Current (Frequency f), Estimated Time etc, including Non Operation Time, Short Time Load)

	Ta [℃]	I[Arms]	t[h]
1	T1	I1	t1
2	T2	I2	t2
・	・	・	・
n	Tn	In	tn

step4

Lifetime Design
→ Estimate Lifetime, Study Lifetime Consumption

step5

Robustness Design
→ Estimate Failure, Study the limit

- Vibration Condition, Mechanical Shock Condition
- Heat Shock, Temperature Cycle Condition
- Humidity Resistance, Mixed Environmental Condition

step6

Terminal/Packaging Design

- Terminal Spec, Packaging Requirement

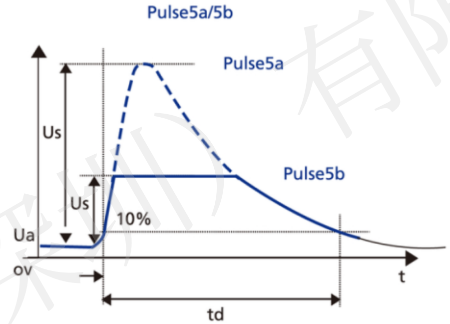
Optimize Specification

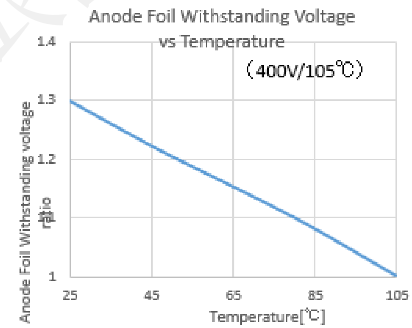
Design for a Highly Reliable, Compact and Cost Competitive product

Key Point to Select Best Capacitor（Step 1）

<Load Dump>

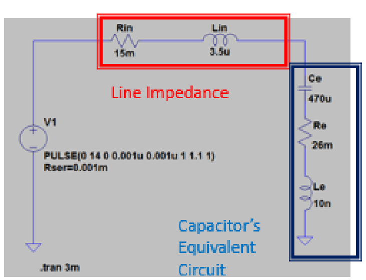
Voltage Profile below shows general Load Dump Surge Voltage. Considering the dependency of withstanding voltage of capacitor on temperature, it is very important to understand at which temperature range the transient voltage is applied. Please refer this example data on temperature dependency of anode foil withstanding voltage of Aluminum Electrolytic Capacitor on temperature.

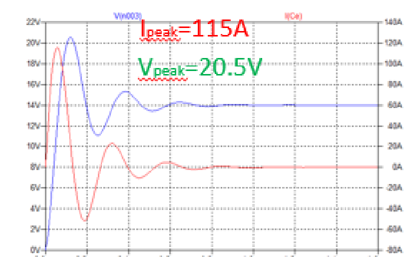




<In-Rush Current>

Robustness against Instantaneous high current depends on robustness of the electrical connection area inside capacitor. This connection point operates in a similar fashion to a single use fuse. It's important to estimate the peak in-rush current to assess if the connection area inside the capacitor can withstand it. The circuit diagram below demonstrates that it is necessary to simulate by considering line impedance since peak of in-rush current heavily depends on the impedance and residence factor.





Peak Current Value largely varies depending on Line Inductance.

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Key Point to Select Best Capacitor（Step 2）

<Capacitance>

When selecting an aluminum electrolytic capacitor for a DC Link application, the internal temperature rise due to ripple current and capacitors base life are required in order to confirm if a customers specification life can be met. The capacitance of selected capacitor is often higher than the required minimum capacitance. However, conductive polymer capacitors such as Rubycon's PZ-CAPs can offer very high ripple current with extremely small package size. This allow for designs that avoid unnecessary higher capacitance than required. Therefore, minimum required capacitance for the circuit is important information to share at the early development stage.

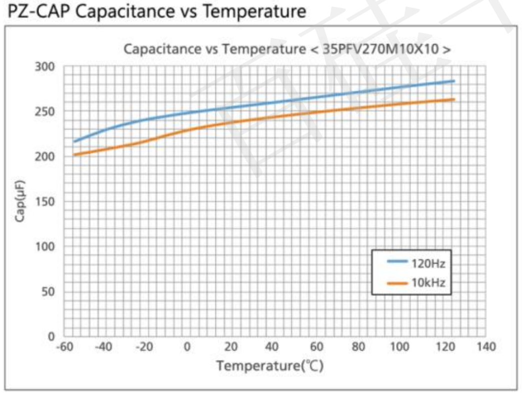
Al.Cap.

Permissible Ripple current : 60A/10kHz
Total Capacitance : 3,000μF
Total volume : 72cm^3

PZ-CAP

Permissible Ripple current : 60A/10kHz
Total Capacitance : 900μF
Total volume : 10cm^3

PZ-CAP Capacitance vs Temperature

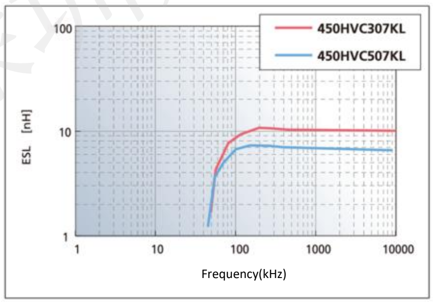


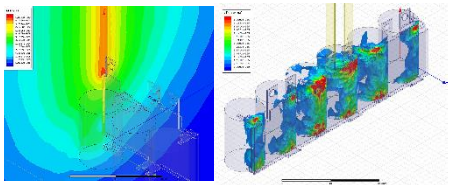
Very stable capacitance for wide temperature range even at 10kHz

<ESL>

Film Capacitor is often used as smoothing capacitor or snubber capacitor in hybrid and electric vehicles. Inductance (ESL) of this capacitor should be low to protect the switching device chopping high voltage/high current from a short circuit incident. To achieve this, Rubycon is optimizing the design based on a finite element method.

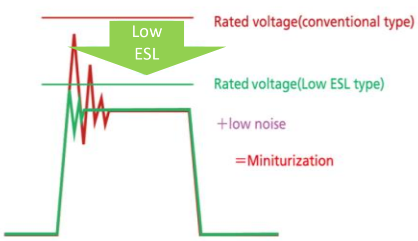
- Inhibit semiconductor breakdown by surge voltage
- Snubber less
- Inhibit capacitor's heat generation (Optimization inside electric circuit)



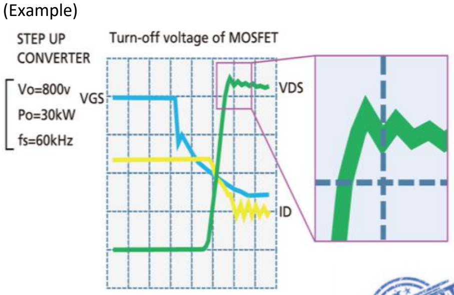


Electromagnetic Analysis
Lower than 10nH@1MHz possible depending on specification

Turn-off voltage of MOS FET



(Example)



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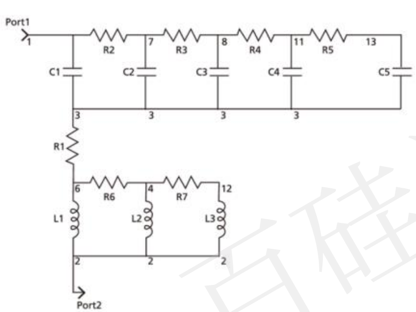
Key Point to Select Best Capacitor（Step 3）

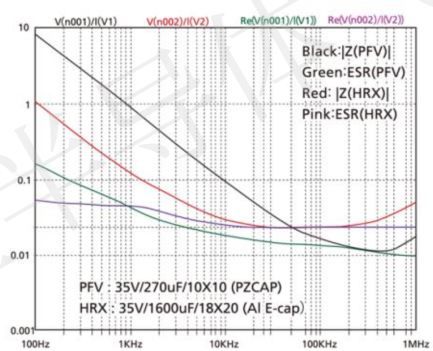
<Heat Generation Calculation>

The amount of current a capacitor can withstand is specified by maximum temperature of the capacitor element(core) or the permissible internal temperature rise. The applied ripple current has to be estimated in such case. Generally, DC Link capacitors are used in parallel connections with same type of capacitor technology. However, there are situations where a combination of capacitor technologies are used in parallel such as conventional aluminum electrolytic combined with conductive polymer type (Rubycon PZ-CAP). In this case, the calculation of the current applied on each capacitor and the losses need to be calculated via a circuit simulator. Rubycon is calculating with 15 Element Model shown below.

15 Element Model



Frequency Characteristics of 15 Element Model

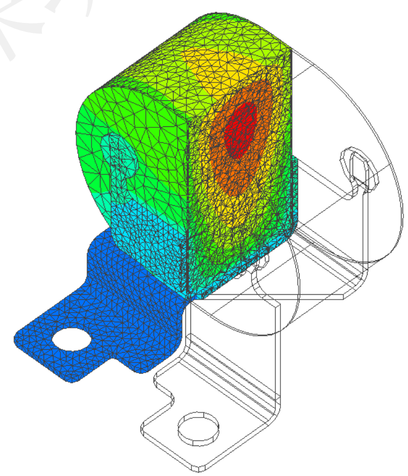


Please refer to the Spice Models of PZ-CAP on Rubycon's web site
http://www.rubycon.co.jp/tools/simulation_data_en.aspx

<Thermal Analysis and Thermal Equivalent Circuit>

The capacitors internal temperature is the most important factor to evaluate its performance (Life and maximum ripple current). It is important to correctly estimate the capacitors temperature under the true operating condition to avoid unnecessary over spec, while ensuring minimal reliability. Rubycon is doing thermal conductive analysis based on finite element method. We can offer precise thermal equivalent circuit model(TECM) by utilizing this thermal conductive analysis result and experimental test data. We offer such data for aluminum electrolytic and PZ-CAP hybrid polymer capacitors used for 12V/24V line of Automotive applications.

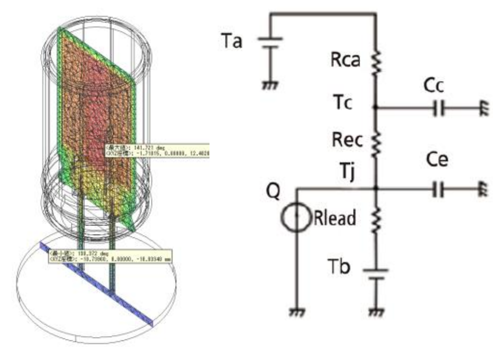
FEM Thermal Analysis Example



Temperature Distribution of Snubber Film Capacitor

Analysis example of the impact of IGBT heat generation via terminal

Thermal Equivalent Circuit Example



Tj : Element temp. Ce: Element heat capacitance Rca: Rth (Surface to amb.)
Tc: Surface temp. Cc: Al-case heat capacitance Rec: Rth (Element to surface)
Tb: PCB temp. Q : Power Loss Rlead: Rth (Element to PCB)
Ta: Ambient temp.

Aluminum Electrolytic Capacitor- Through Hole Type

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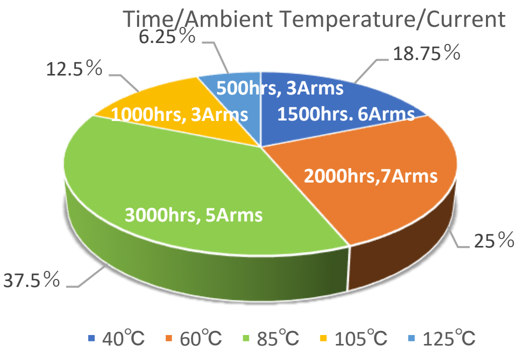
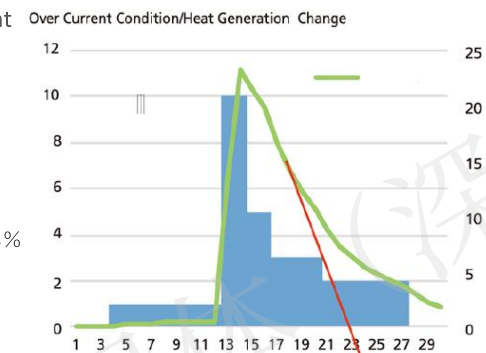
Key Point to Select Best Capacitor（Step 4）

<Life Expectancy base on Mission Profile>

Mission Profile generally consists of ambient temperature, time and ripple current under your operating condition.
It is also important to determine the operating, non operating and storage time.
Simulating the transient (peak) conditions which occur less frequently along with the typical conditions are important considerations.





Simulate Capacitor's temperature rise based on Thermal Model.
Further detailed information like capacitor's mounting condition, cooling condition (Air, Water cooling) is also necessary for more precise simulation

Amb.Temp.	Load Time	Ratio	Current	Current/pc	Temp.Rise	comsumption
40℃	1500hrs.	18.75%	6Arms	6Arms	20℃	1.5%
60℃	2000hrs.	25%	7Arms	7Arms	27.2℃	21.5%
85℃	3000hrs.	37.75%	5Arms	5Arms	13.9℃	28.9%
105℃	1000hrs.	12.75%	3Arms	3Arms	5℃	8.3%
125℃	500hrs.	6.75%	3Arms	3Arms	5℃	16.7%
	8000hrs.	100%			合計	76.9%

Lifetime Consumption Within 100%: OK

Simulate Temperature Profile → Simulate Lifetime Consumption → Optimize Capacitor Design

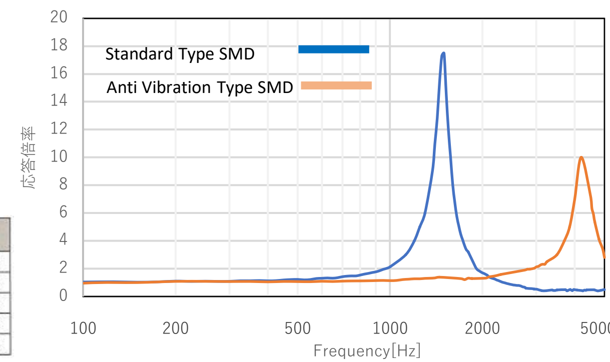
- Temperature Profile Simulation：Simulate Capacitor temperature based on Mission Profile and Thermal Model (including cooling condition)
- Life Consumption Simulation：Simulate Life Consumption based on Temperature profile
- Assessment：Determine Best Capacitor Design by communicating with customer the simulation result and the required condition like lifetime and size of capacitor.

<Anti Vibration>

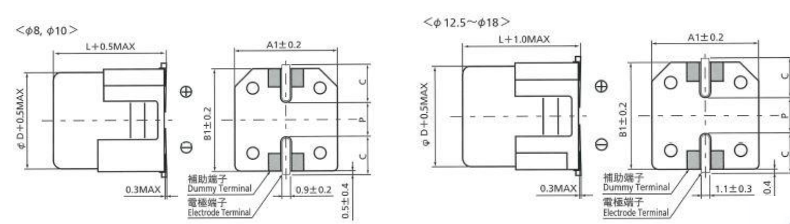
For 10x10mm size and smaller, standard surface mount capacitors (Aluminum Electrolytic Capacitor and PZ-CAP) can withstand 20G at 10Hz~500Hz. In addition, we offer an Anti Vibration Option "VB" which includes an extended base and additional soldering area to enhance vibration performance. This option can withstand 30G at 10Hz~1kHz. However, when the frequency range contains higher frequency higher frequency then what is shown below, a resonance may occur which can cause damage even if the acceleration were smaller. Rubycon can offer the analysis on such vibration phenomenon via a Laser Doppler Vibrometer.

Anti Vibration Type SMD

	A1, B1	C	P
φ8	8.3	3.1	3.1
φ10	10.3	3.4	4.5
φ12	13	4.9	4.5
φ16	17	6	6.8
φ18	19	7	6.8



Anti vibration structure shift the resonance frequency to higher range and depress the magnitude of response function. The key point is the resonance frequency exists out of usage frequency range.



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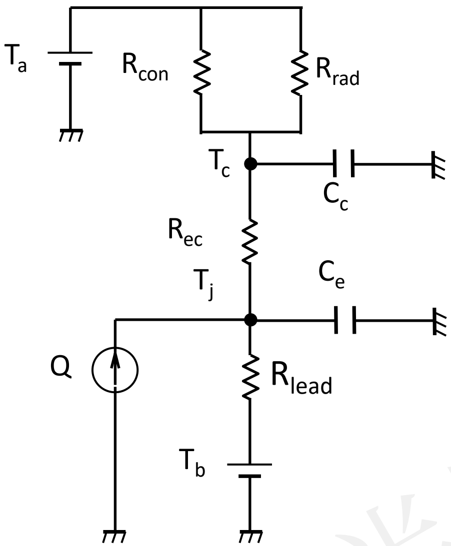
Technical Consulting Support (FEM Thermal Analysis)

Rubycon can realize significant miniaturization and cost reduction by thermal analysis and design of whole unit in addition to capacitor.

Thermal model

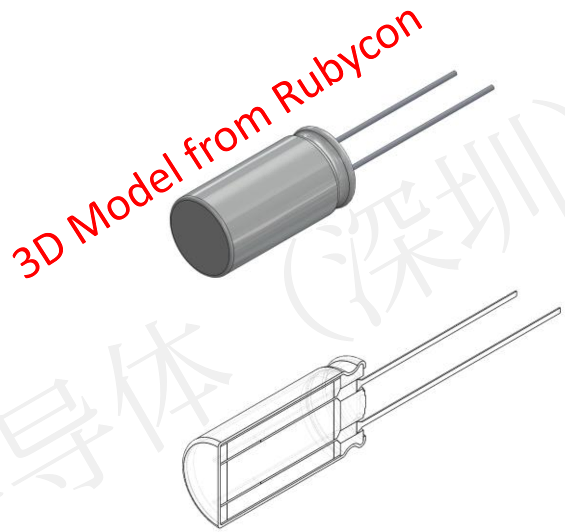


T_a: Ambient temperature
T_b: PCB temperature
T_c: Surface temperature
T_j: Element temperature

R_{con}: Thermal resistance by convection
R_{rad}: Thermal resistance by radiation
R_{ec}: Thermal resistance between element to case
R_{lead}: Thermal resistance between element to PCB

3D model for FEM

Rth_total （ϕ10X20): 78.5K/W



C_e: Element thermal capacitance
C_c: Case thermal capacitance
Q: Generating heat

3D CAD DATA

3D modeling provided by Customers

non disclosure information

non disclosure information

Rubycon FEM Analysis of Unit
=> Best Capacitor Solution

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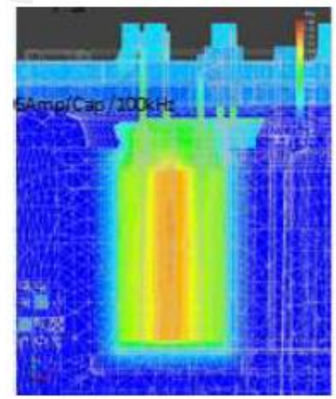
Technical Consulting Support (FEM Thermal Analysis)

non disclosure information



Rubycon can precisely estimate heat generation by simulating thermal circuit

Rth_total : 78.5K/W (Capacitor)

→ 19.6K/W (Mounted on unit)
under forced cooling condition

Heat generation ¼ !

Optimization of Thermal Design→Miniaturization & Lower Cost！

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Technical Consulting Support

(Endurance Test under Cooling Condition)

【Example】

Sample : 25 PFV 330 M 10X10.5

【Basic Specification】

Rated Ripple Current	**2.0**Arms/100kHz, 125℃
Endurance	4,000hours at 125℃

Test Condition

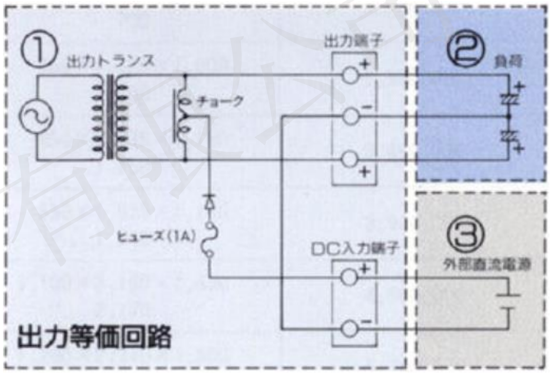
Ripple Load Test under forced cooling condition below

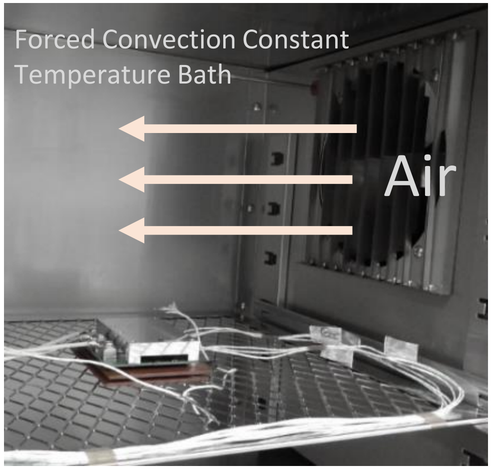
Bias Voltage [V]	14
Ambient Temperature (Ta) [℃]	105
Ripple Current[Amrs/100kHz]	**14.0**
Case Surface Temperature(Tc) [℃]	125
Element Core Temperature (Tj) [℃]	150
Case Temperature Rise(ΔTc) [K]	20
Core Temperature Rise (ΔTj) [K]	45 ※1

※1 ：PFV permissible temperature rise(at 105℃)＝29.8℃

Life Expectancy(reference)＝ 1,071hours

Test Circuit





Air Velocity：0.65 m/s

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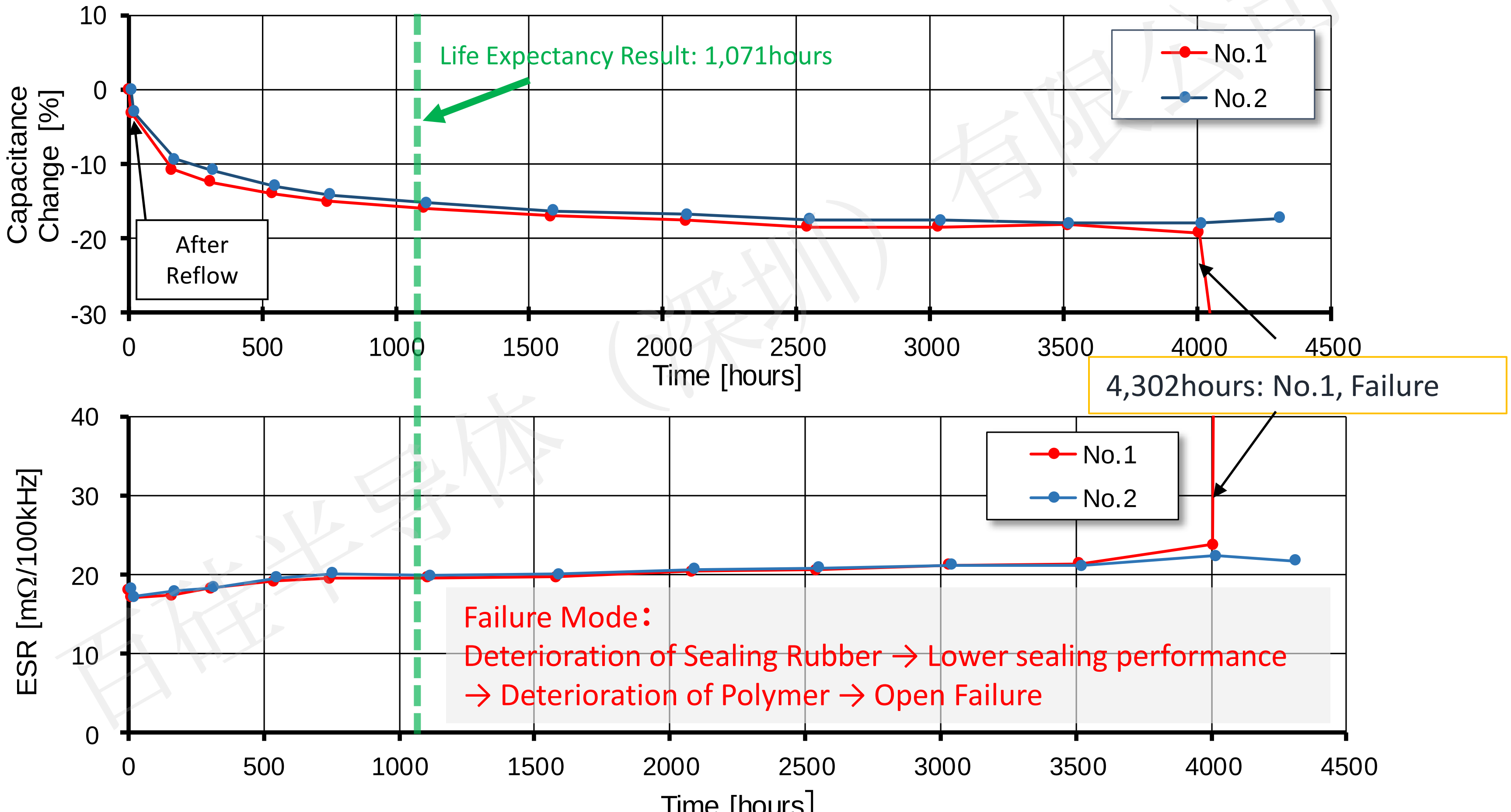
Test Result

(Endurance Test under Cooling Condition)

Test Condition: 105℃, 14.0Arms/100kHz Forced Cooling Condition ΔTj 45℃
Life Expectancy Result: 1,071hours



This test result shows much longer lifetime performance than life expectancy result under the condition exceeding 29.8deg.C which is PFV series permissible temperature rise.
We continue our study to verify correct operation with high ripple current under forced cooling condition and adequacy of our method from thermal design to life expectancy.

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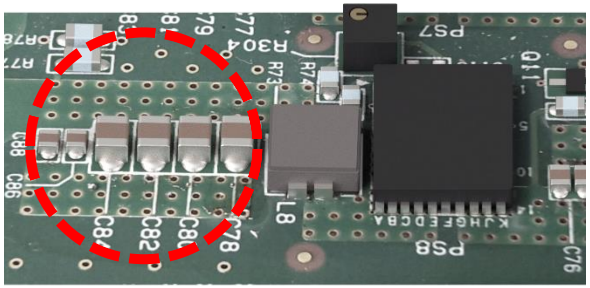
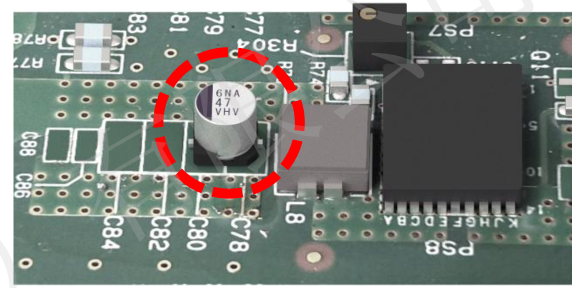
PZ-CAP Merit

Replacement from MLCC to PZ-CAP

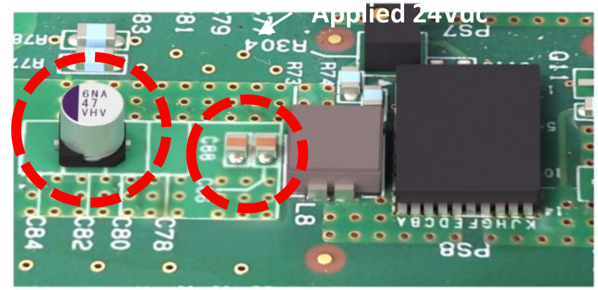




Example ① • • In case of Low frequency （lower than 400kHz）, replacement to 1pcs of PZ-CAP is feasible solution.

Impedance Analysis based on part number of MLCC, quantity, applied voltage, operating frequency
=> Best Solution with Rubycon PZ-CAP

（Impedance Analysis by LTSPICE）



Example ② • • When higher frequency characteristics are also important, replacement to 1pcs of PZ-CAP with standard MLCC is feasible solution.

Rubycon can help to replace from MLCC to PZ-CAP by Impedance Analysis.

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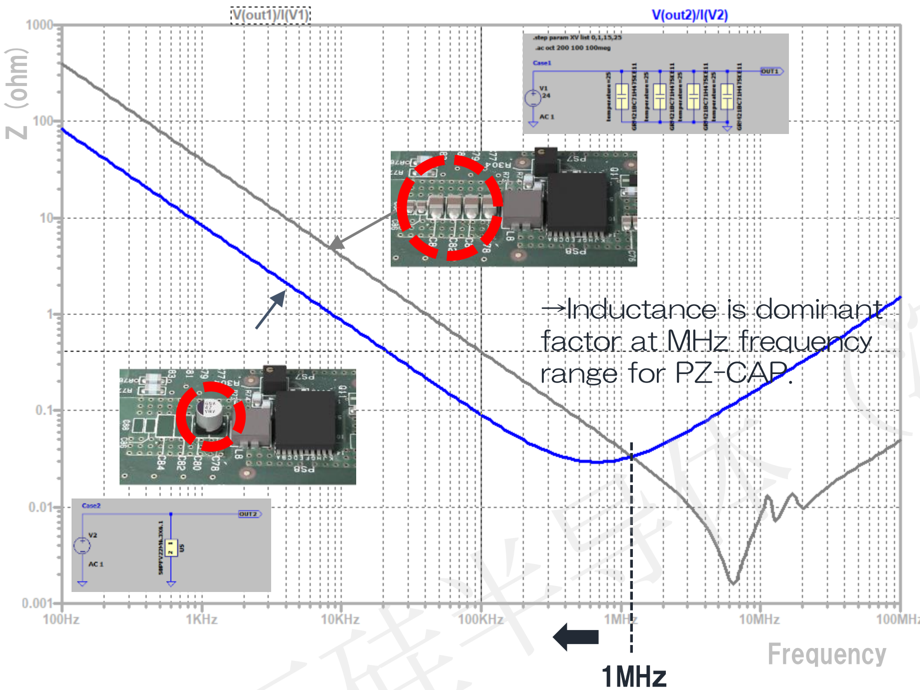
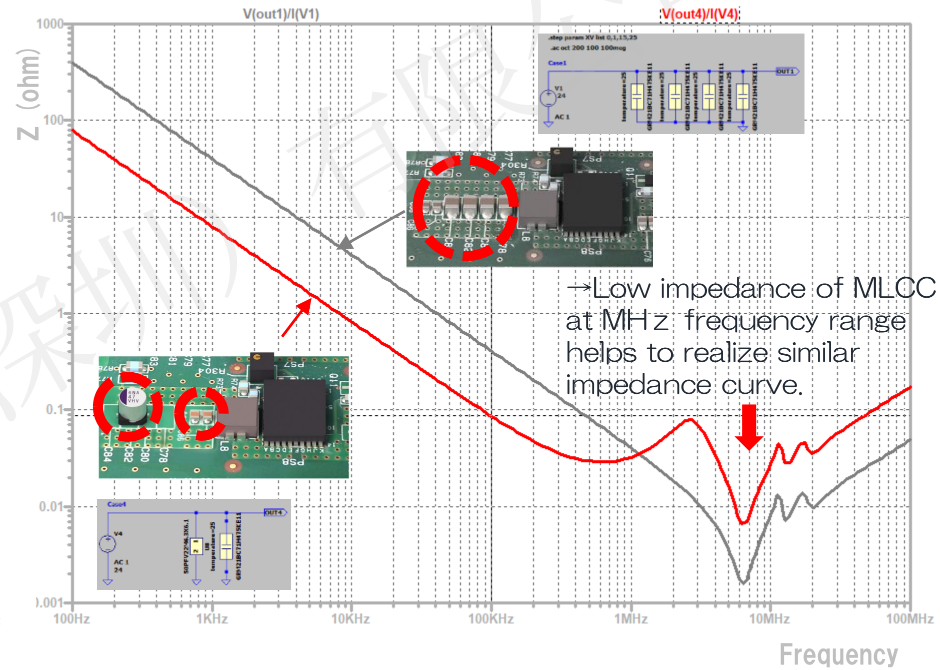
PZ-CAP Merit

Replacement from MLCC to PZ-CAP

【Simulation Result】





Conducted Emission Test Result：
Good t at LW band(150kHz～)
& AM band(400 ～ 1.5MHz)

Conducted Emission Test Result：
Good t at LW band(150kHz～),
AM band(400 ～ 1.5MHz) and
SW band(2MHz ～)

Feasible to replace and reduce MLCC by PZ-CAP！

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PZ-CAP Development Roadmap

PZ-cap

Conductive Polymer Aluminum Solid Electrolytic Capacitor

① Miniaturization & Higher Capacitance

② Higher Voltage

③ High Temperature, High Ripple and Longer Lifetime

④ Lower Cost

PFV Series
125℃
4,000h

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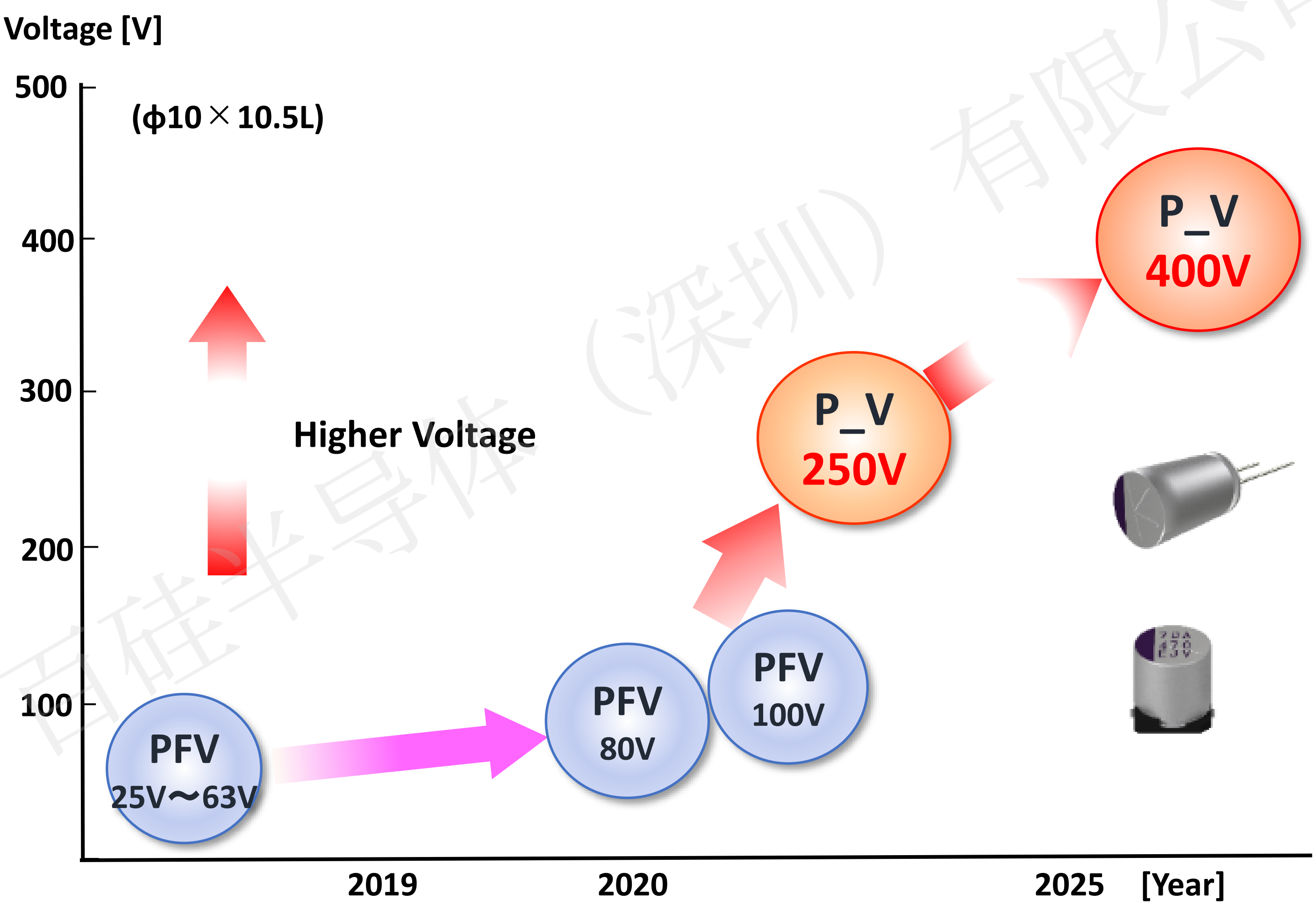
PZ-CAP Development Roadmap

Roadmap for Higher Voltage

Key：High Voltage Withstanding Material



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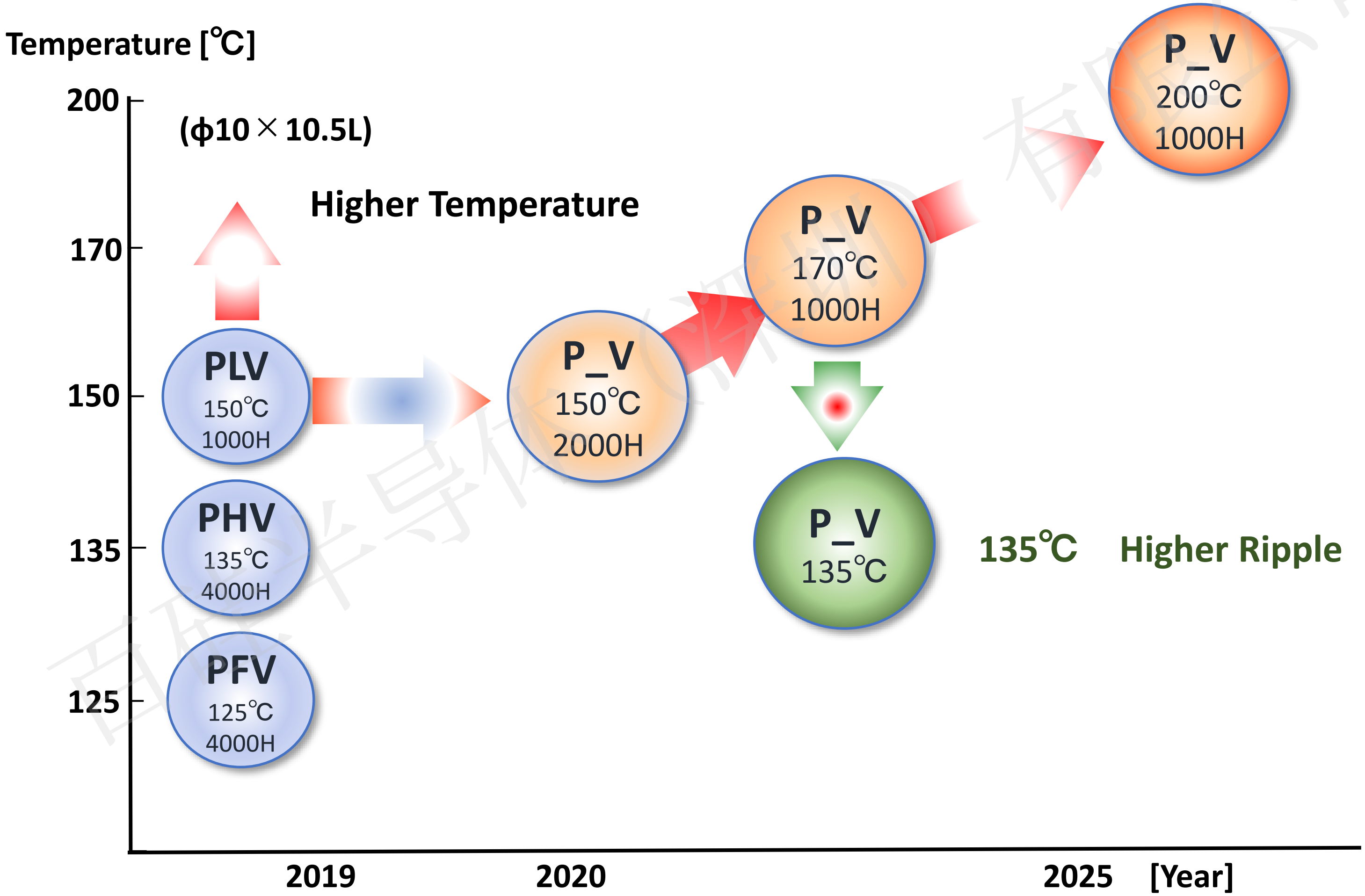
PZ-CAP Development Roadmap

PZ-cap

Roadmap for Higher Temperature
Key：High Heat Withstanding Material



TERIMA KASIH ありがとう DANKE GRAZIE

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谢谢 GRACIAS 감사 MERCI ขอขอบคุณ

THANK YOU!