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Fuel Cell Energy Processing Systems

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Class Notes: DC/DC Boost Converter Design

Fuel Cells

DC/DC Converters

Inverters

Mechatronics Laboratory

Department of Electrical Engineering

The Ohio State University

CHAPTER 5   Boost Converter Design

5.1 Introduction

The **Boost Converter** converts an input voltage to a higher output voltage. It is also named the step-up converter. Boost converters are used in fuel cell/battery powered devices, where the load side electronic circuit requires a higher operating voltage than the source can supply.

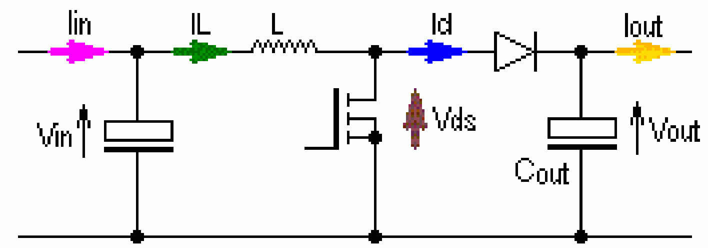


Figure 1 A topology of boost DC/DC converter

The transistor works as a switch which is turned on and off by a pulse-width-modulated control voltage. The ratio between on-time and the period t_1/T is called the *Duty Cycle*.

For theoretical analysis it will be assumed that the transistor is simplified as an ideal switch and the diode has no forward voltage drop. The diode will take into account a forward voltage drop $V_F = 0.7$V.

During the on-time of the transistor, the voltage across L is equal to V_{in} and the current I_L increases linearly. When the transistor is turned off, the current I_L flows through the diode and charges the output capacitor. The function of the boost converter can also be described in terms of energy balance: During the on-phase of the transistor, energy is loaded into the inductor. This energy is then transferred to the output capacitor during the blocking phase of the transistor.

The output voltage is always larger than the input voltage. Even if the transistor is not switched on and off the output capacitor charges via the diode until $V_{out} = V_{in}$. When the transistor is switched the output voltage will increase to higher levels than the input voltage.

- The Boost Converter is not short circuit proof, because there is inherently no switch-off device in the short-circuit path.

A distinction is drawn between **discontinuous** and **continuous** conducing mode depending on whether the inductor current I_L reduces to zero during the off-time or not. With the help of Faraday's Law the continuous mode and steady state conditions can be established.

$$\Delta I_L = \left(\frac{1}{L}\right) V_{in} \cdot t_1 = \left(\frac{1}{L}\right)(V_{out} - V_{in})(T - t_1)$$

From this it follows that:

$$V_{out} = V_{in} \cdot \frac{T}{(T - t_1)}$$

- For continuous mode the output voltage is dependent on the duty cycle and the input voltage, it is independent of the load.

In discontinuous mode, the inductor current I_L will go to zero during every period. At the moment when the inductor current becomes zero, i.e. t_2, the voltage V_1 jumps to the value of V_{out} because in this case $V_L = 0$. The drain-source capacitance in parallel with the diode-junction capacitance forms a resonant circuit with the inductance L. This is stimulated by the voltage jump across the diode. The voltage V_1 then oscillates and fades away.

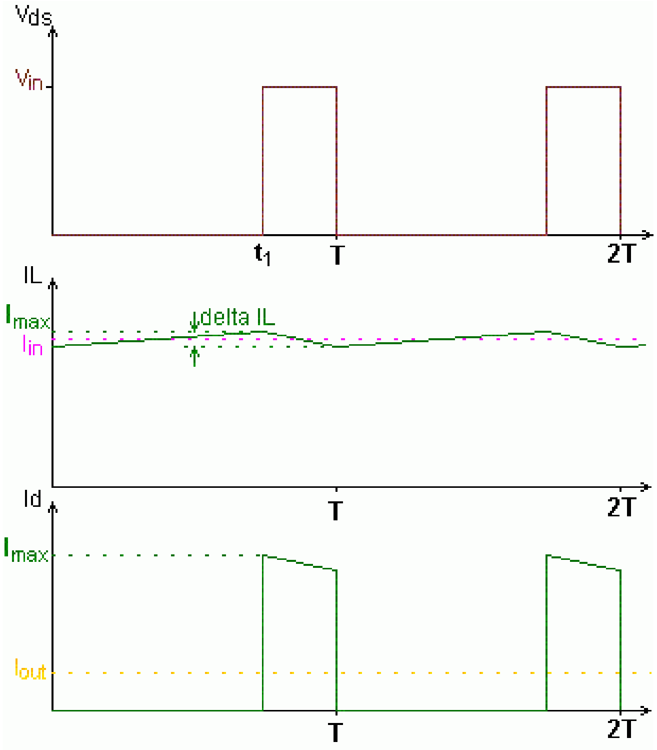


Figure 2 Continuous conducing mode (CCM)

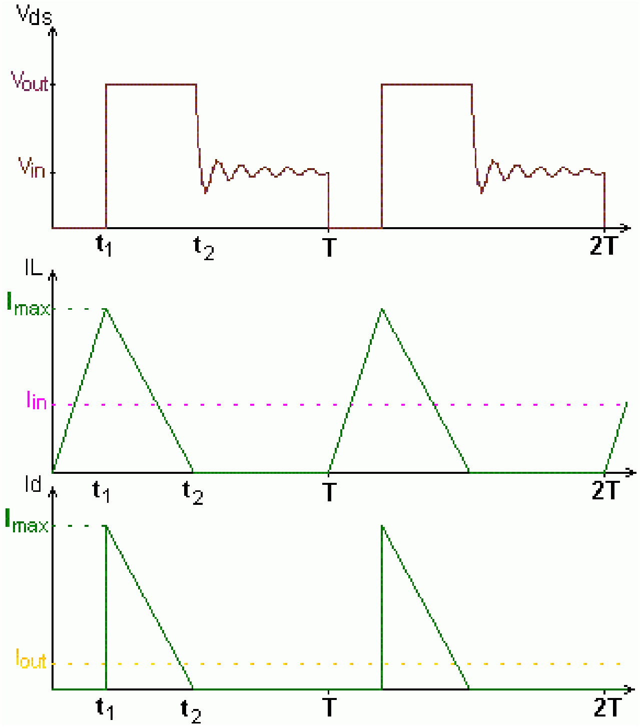


Figure 3 Discontinuous conducting mode

5.2 Power Switch Design

5.2.1 Select a power switch

BJTs (bipolar junction transistor), power MOSFETs (metal-oxide-semiconductor field effect transistors), and IGBT (insulated gate bipolar transistors) are commonly used controllable power switches (turned on/off by control signals).

BJTs and MOSFETs have characteristics that complement each other in some respects. BJTs have lower conduction losses in the ON state, especially in devices with larger blocking voltages, but have longer switching times, especially at turn-off. MOSFETs can be turned on and off much faster, but their ON state conduction losses are larger, especially in devices rated for higher blocking voltages (a few hundred volts and greater). These observations have led to attempts to combine BJTs and MOSFETs monolithically on the same silicon wafer to achieve a circuit or even perhaps a new device that combines the best qualities of both types of devices.

These attempts have led to the development of the IGBT, which is becoming the device of choice in most new applications.

In this section, design procedure will be discussed based on the difference between BJTs and MOSFETs. The methodology of using IGBT will be conceptually the same.

The criteria for choosing a power switch are the voltage and current ratings and the switching frequency. Generally, BJTs can be used for more highly rated applications than MOSFETs as shown in Figure 4.

MOSFETs have higer switching frequency than BJTs. Higher frequency in power electronic circuits leads to smaller inductors and capacitors in size and weight and therefore is desired. The related details will be given in the inductor and capacitor design sections below.

BJTs are driven by base drive current I_B. The ON state base current $I_{B(sat.)}$ can be large especially in large current applications, which is not desired. MOSFETs are driven by gate-source voltage V_{GS} and consumes little current. High base current leads to high loss, more complicated circuit, and more thermal concerns.

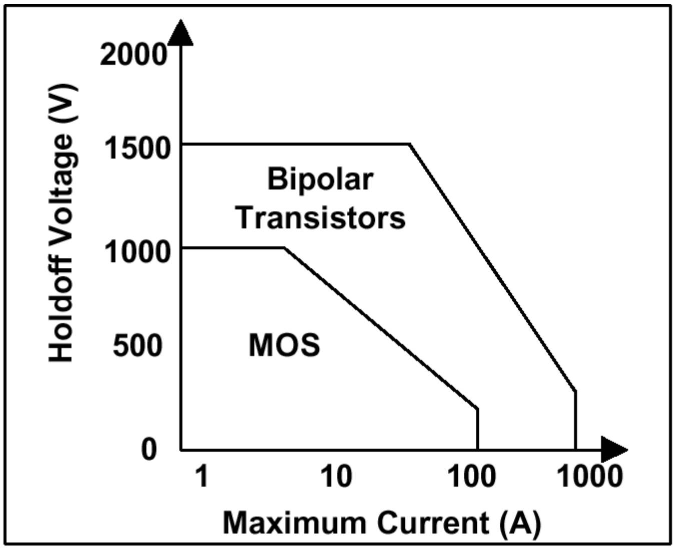


Figure 4 Votage and current ratings for BJTs and power MOSFETs

The power switch selection and design procedures will be illustrated by the following design example.

Design requirement:

A 240-watt DC/DC boost converter with V_{in}=24V and V_{out}=48V.

Design:

Based on the circuit topology shown in Figure 1, assuming large inductance and small current ripple, the peak transistor current should be close to the average inductor current (i.e., the input current):

$I_{in}=P/V_{in}=240W/24V=10A$

Based on this current capability requirement, considering some safety margin, two candidate transistors are chosen for comparison, one is BJT 2N6547

http://www.semi-tech-inc.com/categories.php

http://www.electronica.ro/catalog/semiconductors.html

the other is power MOSFET HUFA75307D3

http://www.fairchildsemi.com/collateral/powermosfets_sg.pdf

both of which satisfy the voltage and current requirement in that, for 2N6547, I_C=15A>10A and V_{CE}=400V>48V, and for HUFA75307D3, I_D=15A>10A and V_{DS}=55V>48V.

However, form Figure 5, it can be observed that the base current needs to be as high as 3.0A to saturate the collector which is undesirable. A BJT must work at saturation region (ON state) or cutoff region (OFF state) to be a power switch. A MOSFET is voltage driven and the threshold voltage for HUFA75307D3 is 4V and the maximum gate-source voltage V_{GSmax}=20V. Therefore a TTL logic +5V or MOSFET logic +15V circuit can be used to drive this MOSFET, which is easy for digital implementation.

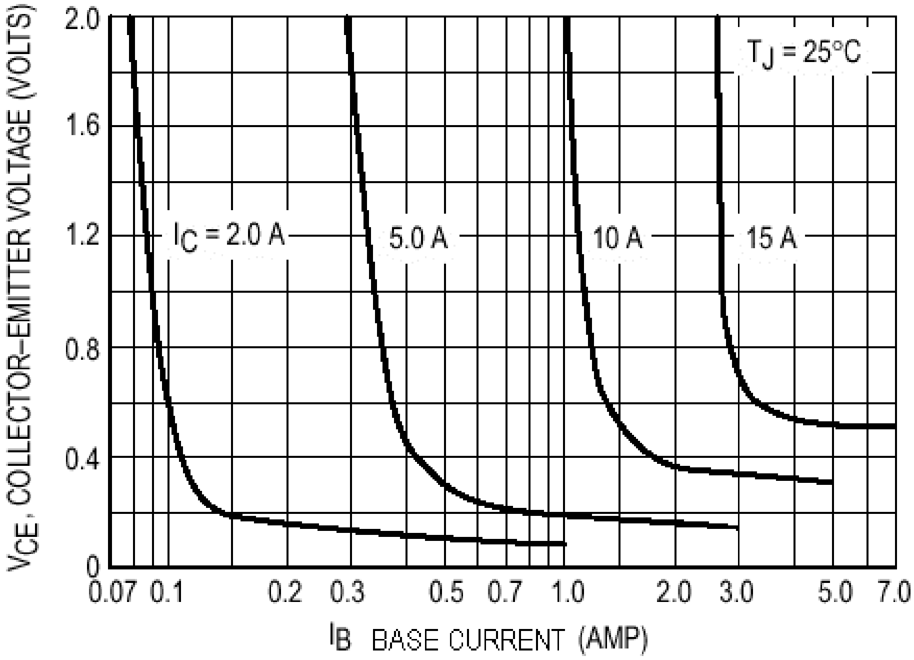


Figure 5 Collector Saturation Region of 2N6547

Transient performances of these two devices need to be compared also. The rise time and fall time of 2N6547 are t_r=1.0μs and t_f=1.5μs for inductive load, while those of HUFA75307D3 is t_r=40ns and t_f=45ns respectively. Therefore, the power MOSFET HUFA75307D3 can be used in much higher switching frequency.

Based on the above analysis, the power MOSFET HUFA75307D3 defeats the BJT 2N6547 in performance and becomes the solution. Before the circuit is implemented, the thermal issue needs to be addressed.

The switching loss can be calculated as follows

$$P_{loss}=\frac{W_{loss}}{T}=\frac{1}{T}\left(W_{loss\_ON}+W_{loss\_OFF}\right)=\frac{V_{ds}I_d}{2T}\left(t_{ON}+t_{OFF}\right)$$

$$=\frac{48\times10}{2\times\dfrac{1}{20\times10^3}}\left(60+100\right)\times10^{-9}=0.768\text{W}$$

The ON-state loss can be calculated as follows:

$$t_1=\frac{1}{f}\left(\frac{V_{out}+V_F-V_{in}}{V_{out}}\right)=\frac{1}{20\times10^3}\left(\frac{48+0.7-24}{48}\right)\sec=25.73\,\mu\text{s}$$

$$P_{ON\_loss}=\frac{W_{ON\_loss}}{T}=\frac{1}{T}\left(I_D^2 r_{DS(ON)}t_1\right)$$

$$=\frac{1}{\dfrac{1}{20\times10^3}}\left(15^2\times0.075\times25.73\times10^{-6}\right)=8.684\text{W}$$

Therefore the overall loss P_{loss}= P_{SW_loss} + P_{ON_loss} =9.452W<P_D=45W (see the datasheet), where P_D is the heat dissipation capacity of the MOSFET. From the data sheet, the maximum thermal resistance from junction-to-sink is 3.3°C/W. Therefore, the junction-to-sink temperature different is

$$\Delta T_{js}=R_{\theta js}\times P_{loss}=3.3^\circ\text{C/W}\times9.452\text{W}=31.2^\circ\text{C}$$

According to the data sheet, the maximum operating temperature is T_{jmax}=175°C. Therefore, with right heat sink, the MOSFET will be safe. Assuming 50% duty ratio, the transient thermal behavior can be calculated based on the normalized maximum transient thermal impedance in Figure 6 (the top curve):

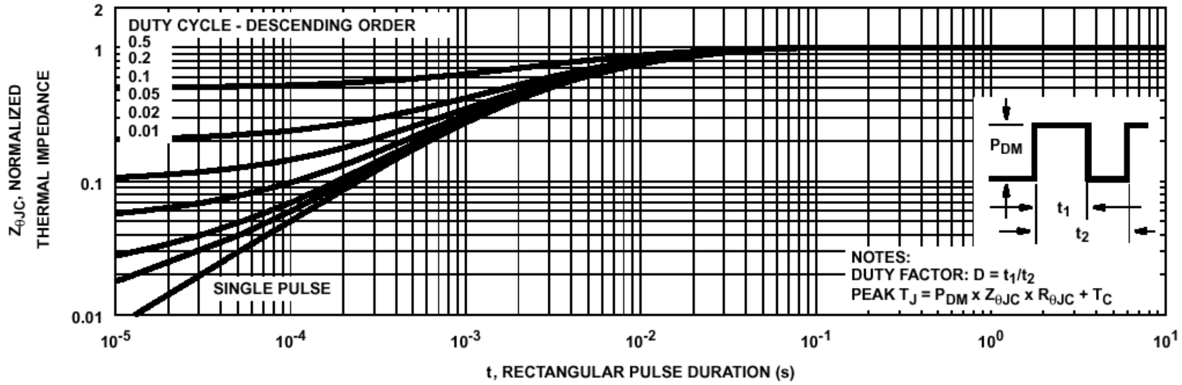


Figure 6 Normalized maximum transient thermal impedance of HUFA75307D3

$$\Delta T_{JC}(t) = P_{loss} Z_{\theta JC(50\%)}(t) R_{\theta JC}$$

$$\Delta T_{JC}(10\mu s) = P_{loss} Z_{\theta JC(50\%)}(10\mu s) R_{\theta JC} = 9.452\text{W} \times 0.5 \times 3.3^{\circ}\text{C/W} = 15.60^{\circ}\text{C}$$

$$\Delta T_{JC}(100\mu s) = P_{loss} Z_{\theta JC(50\%)}(100\mu s) R_{\theta JC} = 9.452\text{W} \times 0.53 \times 3.3^{\circ}\text{C/W} = 16.53^{\circ}\text{C}$$

$$\Delta T_{JC}(1ms) = P_{loss} Z_{\theta JC(50\%)}(1ms) R_{\theta JC} = 9.452\text{W} \times 0.63 \times 3.3^{\circ}\text{C/W} = 19.65^{\circ}\text{C}$$

$$\Delta T_{JC}(10ms) = P_{loss} Z_{\theta JC(50\%)}(10ms) R_{\theta JC} = 9.452\text{W} \times 0.85 \times 3.3^{\circ}\text{C/W} = 26.51^{\circ}\text{C}$$

$$\Delta T_{JC}(100ms) = P_{loss} Z_{\theta JC(50\%)}(100ms) R_{\theta JC} = 9.452\text{W} \times 1 \times 3.3^{\circ}\text{C/W} = 31.2^{\circ}\text{C} = \Delta T_{JC}(\infty)$$

5.3 Inductor Design and Current Ripple Calculation

Given the following operating conditions:

$V_{\text{in\_min}}$, $V_{\text{in\_max}}$, V_{out}, I_{out} and f, where f is the switching frequency.

Using these parameters, then a **proposal for *L*** can be obtained:

$$L = \left(\frac{1}{f}\right) \cdot \left(V_{\text{out}} + V_{\text{F}} - V_{\text{in\_min}}\right) \cdot \left(\frac{V_{\text{in\_min}}}{V_{\text{out}} + V_{\text{F}}}\right) \cdot \left(\frac{1}{\Delta I_{\text{L}}}\right)$$

where V_{F} = 0.7V (Diode Forward-voltage) and 15% current ripple is assumed, i.e.,

$$\Delta I_L = 0.15 I_{in} = 0.15 I_{out} \left(\frac{V_{out} + V_F}{V_{in\_\min}}\right)$$

For the calculation of the curve-shapes, i.e. the peak current I_{max}, two cases have to be distinguished, i.e. *continuous conducting mode* and *discontinuous conducting mode*:

$$\Delta I_{\text{L}} = \left(\frac{1}{f}\right) \cdot \left(V_{\text{out}} + V_{\text{F}} - V_{\text{in}}\right) \cdot \left(\frac{V_{\text{in}}}{V_{\text{out}} + V_{\text{F}}}\right) \cdot \left(\frac{1}{L}\right) \quad \text{and}$$

$$I_{\text{in}} = I_{\text{out}} \cdot \left(\frac{V_{\text{out}} + V_{\text{F}}}{V_{\text{in}}}\right)$$

From this it follows that:

a. For $\Delta I_L < 2I_{in}$ the converter is in continuous mode and it follows that:

$$t_1 = \left(\frac{1}{f}\right)\cdot\left(\frac{V_{out} + V_F - V_{in}}{V_{out}}\right)$$

$$\Delta I_L = \frac{1}{L}\cdot V_{in}\cdot t_1 \text{ and}$$

$$I_{max} = I_{in} + \frac{1}{2}\Delta I_L$$

b. For $\Delta I_L > 2I_{in}$ the converter is in discontinuous mode and it follows that:

$$t_1 = \sqrt{2I_{out}\cdot L\cdot\left(\frac{V_{out} + V_F - V_{in}}{f\cdot V_{in}^2}\right)}$$

$$t_2 = t_1\cdot\left(\frac{V_{out} + V_F}{V_{out} + V_F - V_{in}}\right) \text{ and}$$

$$I_{max} = \frac{1}{L}\cdot V_{in}\cdot t_1$$

For the above design example, the required inductance can be calculated as follows:

$$\begin{aligned} L &= \frac{1}{f}\left(V_{out} + V_F - V_{in}\right)\left(\frac{V_{out} + V_F}{V_{in}}\right)\frac{1}{\Delta I_L} \\ &= \frac{1}{20\times10^3}\times(48 + 0.7 - 24)\times\frac{48 + 0.7}{24}\times\frac{1}{0.15\times10}\text{H} \\ &= 406\mu\text{H} \end{aligned}$$

Based on the inductor manufacturer MTE Corporation catalog in

Table 1, considering the DC current capacity and some safety range, the type 18RB001 should be chosen, whose current capacity is 18A>10A and inductance is 650μH>406 μH.

The peak transistor current I_{max} can be calculated as follows assuming continuous conducting mode (CCM)

$$\begin{aligned} I_{\max} &= I_{in} + \frac{1}{2}\Delta I_L = I_{in} + \frac{1}{2}\left(\frac{1}{f}\right)(V_{out} + V_F - V_{in})\left(\frac{V_{in}}{V_{out} + V_F}\right)\frac{1}{L} \\ &= 10 + \frac{1}{2}\frac{1}{20\times10^3}(48 + 0.7 - 24)\left(\frac{24}{48 + 0.7}\right)\frac{1}{650\times10^{-6}}\text{A} \\ &= 10 + 0.468\text{A} = 10.468\text{A} \end{aligned}$$

I_{max}=10.468A<15A, therefore the current capacity of the MOSFET meets the peak requirement.

Table 1 MTE Corporation power magnetic components – DC inductors

DC AMPS	INDUC. mH	CATALOG No.
1	35.00	1RB001
1	60.00	1RB002
1	80.00	1RB003
2	10.00	2RB001
2	15.00	2RB002
2	20.00	2RB003
2	50.00	2RB004
4	5.00	4RB001
4	12.00	4RB002
4	15.00	4RB003
4	25.00	4RB004
9	2.00	9RB001
9	3.22	9RB002
9	7.50	9RB003
9	11.50	9RB004
12	1.00	12RB001
12	2.10	12RB002
12	4.00	12RB003
12	6.00	12RB004
18	**0.65**	**18RB001**
18	1.375	18RB002
18	2.75	18RB003
18	3.75	18RB004
18	6.00	18RB005
25	0.45	25RB001
25	1.00	25RB002
25	1.275	25RB003
25	1.75	25RB004
25	4.00	25RB005
32	0.85	32RB001
32	1.62	32RB002
32	2.68	32RB003
40	0.50	40RB001
40	0.75	40RB002
40	1.00	40RB003
40	2.50	40RB004
50	0.625	50RB001
50	0.97	50RB002
50	1.35	50RB003
50	2.00	50RB004
62	0.32	62RB001
62	0.61	62RB002
62	0.67	62RB003
62	1.20	62RB004
62	1.50	62RB005
80	0.31	80RB001
80	0.40	80RB002
80	0.50	80RB003
80	0.75	80RB004
80	1.25	80RB005
92	0.20	92RB001
92	0.60	92RB002
92	1.00	92RB003
110	0.25	110RB001
110	0.30	110RB002
110	0.45	110RB003
125	0.11	125RB001
125	0.22	125RB002
125	0.50	125RB003
125	0.85	125RB004
150	0.15	150RB001
150	0.22	150RB002
150	0.32	150RB003
150	0.65	150RB004
200	0.12	200RB001
200	0.21	200RB002
200	0.40	200RB003
200	0.50	200RB004
240	0.09	240RB001
240	0.25	240RB002
240	0.35	240RB003
300	0.08	300RB001
300	0.135	300RB002
300	0.32	300RB003
450	0.055	450RB001
450	0.11	450RB002
450	0.14	450RB003
450	0.25	450RB004
500	0.043	500RB001
500	0.09	500RB002
500	0.14	500RB003
500	0.19	500RB004
600	0.04	600RB001
600	0.11	600RB002
600	0.18	600RB003
700	0.044	700RB001
700	0.06	700RB002
700	0.15	700RB003
850	0.036	850RB001
850	0.065	850RB002
850	0.11	850RB003
1000	0.02	1000RB001
1000	0.042	1000RB002
1000	0.10	1000RB003

5.4 Design Tips

- The larger the chosen value of the inductor L, the smaller the current ripple ΔI_L. However this results in a physically larger and heavier inductor.
- Choose ΔI_L so that it is not too big. The suggestions proposed by us have adequately small current ripple along with physically small inductor size. With a

larger current ripple, the voltage ripple of the output voltage V_{out} becomes clearly bigger while the physical size of the inductor decreases marginally.

- The higher the chosen value of the switching frequency f, the smaller the size of the inductor. However the switching losses of the transistor also become larger as f increases.
- The smallest possible physical size for the inductor is achieved when $\Delta I_L = 2I_{in}$ at V_{in_min}. However, the switching losses at the transistors are at their highest in this state.

5.5 Capacitor Design

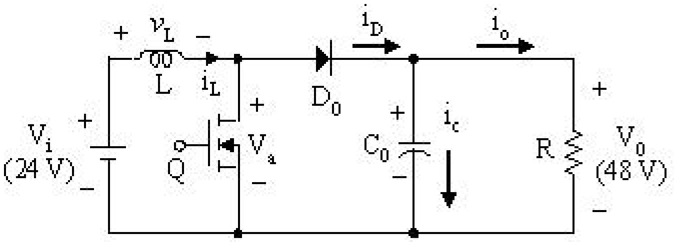


Figure 7 A conventional boost converter

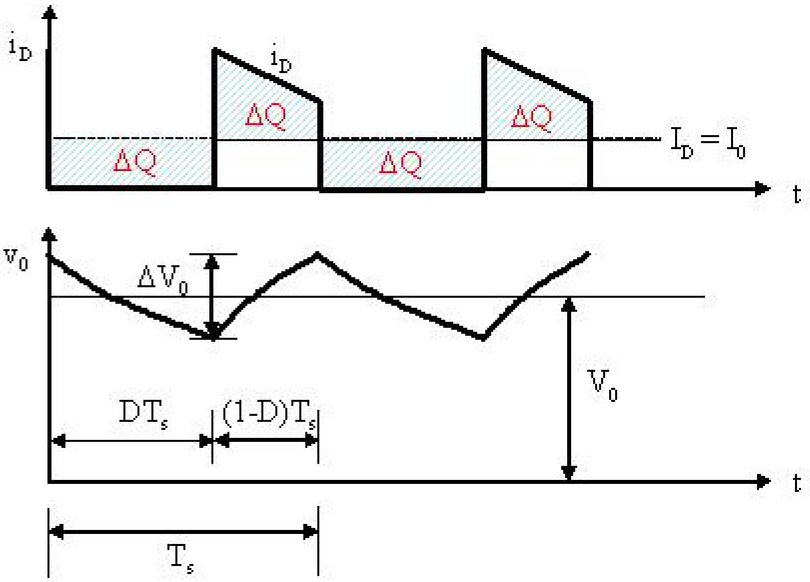


Figure 8 Output voltage ripple

Figure 1 and Figure 1 show a conventional boost converter and the output voltage ripple and diode current, respectively. Assuming that the diode current (i_D) is a square wave form, we can calculate the peak diode current ($I_{D,\ peak}$) for a duty ratio of 0.5

$$I_{D,peak} = \frac{I_0}{D} = \frac{I_0}{0.5} = 10\ A$$

where $I_0 = P/V_0 = 240/48 = 5$ A and the RMS diode current ($I_{D,\ rms}$) is

$$I_{D,rms} = I_{D,peak} \cdot \sqrt{D} = 10 \cdot \sqrt{0.5} = 7.07\ A$$

Therefore, the RMS capacitor current ($I_{c,rms}$) is given by

$$I_{c,rms} = \sqrt{I^2{}_{D,rms} - I^2{}_0} = \sqrt{7.07^2 - 5^2} = 5\ A$$

Also, the output voltage ripple can be obtained using the following equation

$$\Delta V_0 = \frac{\Delta Q}{C} = \frac{I_{c,rms} DT_s}{C}$$

Putting the values below into the above equation, the capacitance is

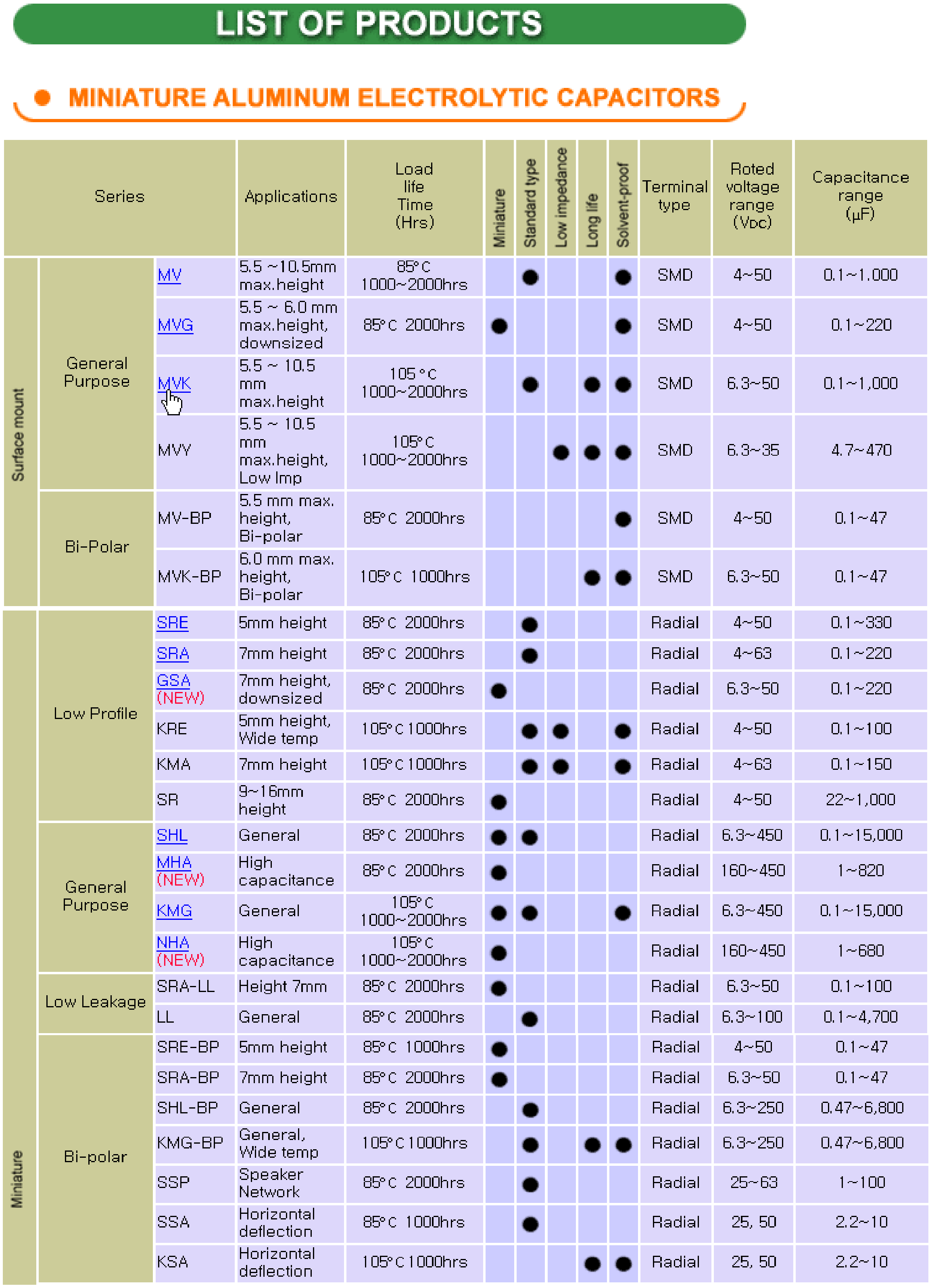
$$D = 0.5,\ T_s = 1/(20\times10^3)\ \text{sec},\ I_{c,rms} = 5\ \text{A},\ \Delta V_0 = 48\ \text{mV}.$$

$$\therefore C = \frac{\Delta Q}{\Delta V_0} = \frac{I_{c,rms} DT_s}{\Delta V_0} = \frac{5 \cdot 0.5}{48\times10^{-3}\times20\times10^3} = 2600\ \mu F$$

Therefore, the capacitor should be selected based on the rated voltage, the rated ripple current, and the capacitance calculated above. Finally, we chose the rated voltage (100 V) considering over-voltage by a parasite inductance, the rated ripple current (at least 5 A), and the capacitance (at least 2600 μF).

Next, we have to choose the supplier that manufactures the capacitors with the above specifications. In this case, we choose the Aluminum Electrolyte Capacitor manufactured by Sam Young Electronics Co., and the list of products is given below.

Table 2 List of Aluminum Electrolyte Capacitors



LIST OF PRODUCTS

● MINIATURE ALUMINUM ELECTROLYTIC CAPACITORS

Series			Applications	Load life Time (Hrs)	Miniature	Standard type	Low impedance	Long life	Solvent-proof	Terminal type	Roted voltage range (VDC)	Capacitance range (μF)
Surface mount	General Purpose	MV	5.5 ~10.5mm max.height	85°C 1000~2000hrs		●			●	SMD	4~50	0.1~1.000
		MVG	5.5 ~ 6.0 mm max.height, downsized	85°C 2000hrs	●				●	SMD	4~50	0.1~220
		MVK	5.5 ~ 10.5 mm max.height	105°C 1000~2000hrs		●		●	●	SMD	6.3~50	0.1~1,000
		MVY	5.5 ~ 10.5 mm max.height, Low Imp	105°C 1000~2000hrs			●	●	●	SMD	6.3~35	4.7~470
	Bi-Polar	MV-BP	5.5 mm max. height, Bi-polar	85°C 2000hrs					●	SMD	4~50	0.1~47
		MVK-BP	6.0 mm max. height, Bi-polar	105°C 1000hrs				●	●	SMD	6.3~50	0.1~47
Miniature	Low Profile	SRE	5mm height	85°C 2000hrs		●				Radial	4~50	0.1~330
		SRA	7mm height	85°C 2000hrs		●				Radial	4~63	0.1~220
		GSA (NEW)	7mm height, downsized	85°C 2000hrs	●					Radial	6.3~50	0.1~220
		KRE	5mm height, Wide temp	105°C 1000hrs		●	●		●	Radial	4~50	0.1~100
		KMA	7mm height	105°C 1000hrs		●	●		●	Radial	4~63	0.1~150
		SR	9~16mm height	85°C 2000hrs	●					Radial	4~50	22~1,000
	General Purpose	SHL	General	85°C 2000hrs	●	●				Radial	6.3~450	0.1~15,000
		MHA (NEW)	High capacitance	85°C 2000hrs	●					Radial	160~450	1~820
		KMG	General	105°C 1000~2000hrs	●	●			●	Radial	6.3~450	0.1~15,000
		NHA (NEW)	High capacitance	105°C 1000~2000hrs	●					Radial	160~450	1~680
	Low Leakage	SRA-LL	Height 7mm	85°C 2000hrs	●					Radial	6.3~50	0.1~100
		LL	General	85°C 2000hrs		●				Radial	6.3~100	0.1~4,700
	Bi-polar	SRE-BP	5mm height	85°C 1000hrs	●					Radial	4~50	0.1~47
		SRA-BP	7mm height	85°C 2000hrs	●					Radial	6.3~50	0.1~47
		SHL-BP	General	85°C 2000hrs		●				Radial	6.3~250	0.47~6,800
		KMG-BP	General, Wide temp	105°C 1000hrs		●		●	●	Radial	6.3~250	0.47~6,800
		SSP	Speaker Network	85°C 2000hrs		●				Radial	25~63	1~100
		SSA	Horizontal deflection	85°C 1000hrs		●				Radial	25, 50	2.2~10
		KSA	Horizontal deflection	105°C 1000hrs				●	●	Radial	25, 50	2.2~10

	Low E.S.R Low Imp	KXL	Low Imp., General	105° C 1000~2000hrs	●		●		●	Radial	6.3~50	10~10,000
		NXA	Low Imp., Long life	105° C 2000~5000hrs			●	●	●	Radial	6.3~35	4.7~15,000
		LXV	Low Imp., Long life	105° C 2000~5000hrs			●	●	●	Radial	6.3~50	18~15,000
		LXZ	Low Imp., Long life, Downsized	105° C 2000~5000hrs			●	●	●	Radial	6.3~35	33~18,000
		NXB	Ultra Low Imp., Long life,	105° C 2000~5000hrs			●	●		Radial	6.3~100	3.3~6,800
	High - Reliability	KMF	High ripple	105° C 2000hrs	●		●	●		Radial	160~450	3.3~330
		KMX	Long life, High ripple	105° C 5000hrs	●		●	●		Radial	160~450	3.3~330
		LXA	Long life	105° C 5000hrs~7000hrs				●	●	Radial	10~63	0.47~4,700
	Special Application	AHS	Audio grade, downsized	85° C 2000hrs	●					Radial	10~100	0.1~10,000
		PHL	For photo flash	5~35° C 5000 times						Radial	330	60~200

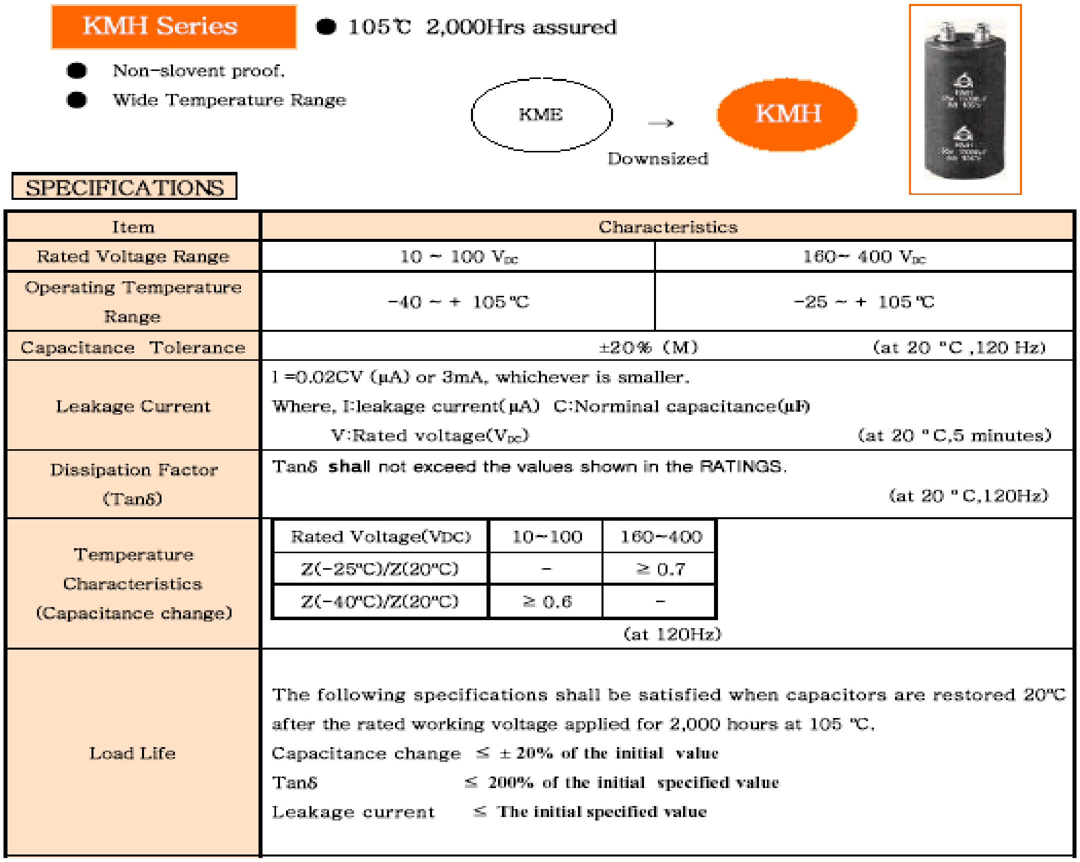
LARGE SIZED ALUMINUM ELECTROLYTIC CAPACITORS

Series			Applications	Load life Time (Hrs)	Miniature	Standard type	Low impedance	Long life	Solvent-proof	Terminal type	Roted voltage range (Vdc)	Capacitance range (μF)
PCB Terminal Type	General Purpose	SMH	General	85° C 2000hrs		●				Pin	100~500	56~82,000
		RDA	Miniature	85° C 2000hrs	●					Pin	160~450	68~2,700
		KMH	General, Wide temp	105° C 2000hrs		●		●		Pin	16~450	56~47,000
		TDA	Miniature	105° C 2000hrs	●			●		Pin	160~450	56~2,200
		SLT	20mm height	85° C 2000hrs	●					Pin	160~400	47~560
		KLT	20mm height	105° C 2000hrs	●			●		Pin	160~400	47~560
		LXG	Miniature long life	105° C 5000hrs	●			●		Pin	10~400	56~47,000
	Special Application	KLG	No spark with DC overvoltage	105° C 2000hrs	●					Pin	200, 400	47~1,500
		DL	General Audio	85° C 2000hrs		●				Pin	50~100	3,300~22,000
		AHS	Hi-Fi Audio Miniature	85° C 2000hrs	●					Pin	50~100	3.300~22,000
Screw-Bolt Terminal Type	General Purpose	SME	General	85° C 2000hrs		●				Screw	10~250	560~680,000
		KMH	General, wide temp.	105° C 2000hrs		●		●		Screw	10~400	180~680,000
	For Inverter	RWA	High ripple	85° C 2000hrs		●				Screw	350, 400	270~10,000
		RWF	High ripple, long life	85° C 5000hrs				●		Screw	350~450	2,700~15.000
	Special Application	PH	For Photo Flash	5~35° C 5,000 times						Pin/ Screw	330	165~2,000
		DH	For Welding	40° C 1,000,000 times							315, 475	100~330

In general, the price of capacitors is determined by the order of rated voltage, capacitance, maximum permissible ripple currents, maximum permissible temperature, and ESR (Equivalent Series Resistance). Therefore, designers have to choose the optimal type that can satisfy the requirements such as cost, permissible temperature, size, and ESR, etc. In this case, we selected KMH series used for General Purpose from the above catalog.

The below table shows only the information required for selection of our capacitor in full data sheets of KMH series. From “table of permissible ripple current”, we have to consider a factor by switching frequency and case diameter when we calculate the maximum permissible currents. So, we selected Φ35 of rated voltage 100 V, and we have to multiply a factor (1.3) by the permissible ripple current (from table of “rating of KMH series”) because the switching frequency is 20 kHz.

Table 3 Data sheet of KMH Series



KMH Series

● 105℃ 2,000Hrs assured

- Non-slovent proof.
- Wide Temperature Range

SPECIFICATIONS

<table>
<tr><th>Item</th><th colspan="2">Characteristics</th></tr>
<tr><td>Rated Voltage Range</td><td>10 ~ 100 V_{DC}</td><td>160~ 400 V_{DC}</td></tr>
<tr><td>Operating Temperature Range</td><td>-40 ~ + 105℃</td><td>-25 ~ + 105℃</td></tr>
<tr><td>Capacitance Tolerance</td><td colspan="2">±20% (M) (at 20 °C ,120 Hz)</td></tr>
<tr><td>Leakage Current</td><td colspan="2">I =0.02CV (μA) or 3mA, whichever is smaller.
Where, I:leakage current(μA) C:Norminal capacitance(μF)
V:Rated voltage(V_{DC}) (at 20 °C,5 minutes)</td></tr>
<tr><td>Dissipation Factor (Tanδ)</td><td colspan="2">Tanδ shall not exceed the values shown in the RATINGS.
(at 20 °C,120Hz)</td></tr>
<tr><td>Temperature Characteristics (Capacitance change)</td><td colspan="2"><table><tr><td>Rated Voltage(VDC)</td><td>10~100</td><td>160~400</td></tr><tr><td>Z(-25°C)/Z(20°C)</td><td>-</td><td>≥ 0.7</td></tr><tr><td>Z(-40°C)/Z(20°C)</td><td>≥ 0.6</td><td>-</td></tr></table>(at 120Hz)</td></tr>
<tr><td>Load Life</td><td colspan="2">The following specifications shall be satisfied when capacitors are restored 20℃ after the rated working voltage applied for 2,000 hours at 105 ℃.
Capacitance change ≤ ± 20% of the initial value
Tanδ ≤ 200% of the initial specified value
Leakage current ≤ The initial specified value</td></tr>
</table>

PERMISSIBLE RIPPLE CURRENT

Frequency Multiplying Factor

Rated Voltage (VDC)	Case Diameter (mm)	Frequency(Hz)				
		60	120	300	1K	10K~
10~50	Φ30 ~ ϕ89	0.95	1.00	1.03	1.05	1.09
63	Φ35	0.90	1.00	1.06	1.10	1.08
	Φ50 ~ ϕ89	0.95	1.00	1.03	1.05	1.09
100	Φ35	0.82	1.00	1.12	1.22	1.30
	Φ50	0.90	1.00	1.06	1.10	1.18
	Φ63.5 ~ ϕ89	0.95	1.00	1.03	1.05	1.09
160~250	Φ35	0.80	1.00	1.19	1.34	1.46
	Φ50 ~ ϕ63.5	0.81	1.00	1.14	1.26	1.36
	Φ76 ~ ϕ89	0.82	1.00	1.12	1.22	1.30
315~400	Φ35 ~ ϕ89	0.80	1.00	1.19	1.34	1.46

RATINGS OF KMH Series

VDC µF	100(2A)			160(2C)			200(2D)			250(2E)		
180												
220												
270										A5	0.8	0.15
330							A5	0.9	0.15	A5	0.9	0.15
390							A5	1.0	0.15	A5	1.0	0.15
470							A5	1.1	0.15	A5	1.1	0.15
560				A5	1.2	0.15	A5	1.2	0.15	A5	1.2	0.15
680				A5	1.3	0.15	A5	1.3	0.15	A6	1.4	0.15
820				A5	1.4	0.15	A5	1.4	0.15	A8	1.6	0.15
1,000				A5	1.6	0.15	A6	1.7	0.15	A8	1.6	0.20
1,200				A6	1.9	0.15	A6	1.9	0.15	A8	1.8	0.20
1,500				A6	2.1	0.15	A8	2.3	0.15	A10	2.1	0.20
1,800	A5	2.7	0.10	A8	2.5	0.15	A8	2.5	0.15	A12	2.5	0.20
2,200	A5	3.0	0.10	A8	2.8	0.15	A10	2.5	0.15	A12	2.5	0.20
2,700	A6	3.5	0.10	A10	3.3	0.15	A12	3.6	0.15	C10	3.5	0.20
3,300	A8	4.2	0.10	A12	3.8	0.15	C8	4.1	0.15	C12	4.2	0.20
3,900	A8	4.2	0.12	8	3.8	0.20	C10	4.9	0.15	C12	4.6	0.20
4,700	A10	5.0	0.12	C10	4.6	0.20	D10	5.3	0.20	D12	5.7	0.20
5,600	A10	5.4	0.12	C10	5.1	0.20	D10	5.8	0.20	D12	6.3	0.20
6,800	A12	5.8	0.15	C12	6.1	0.20	D12	6.9	0.20	E12	7.7	0.20
8,200	C8	6.4	0.15	D10	7.0	0.20	D12	7.6	0.20	E12	8.4	0.20
10,000	C10	7.8	0.15	D12	8.4	0.20	E12	9.3	0.20	E14	10.0	0.20
12,000	C12	9.3	0.15	E10	9.4	0.20	E12	10.2	0.20	F14	11.9	0.20
15,000	C12	10.4	0.15	E12	11.4	0.20	E12	10.2	0.20	F14	11.9	0.20
18,000	D10	10.4	0.20	E14	13.4	0.20	F14	13.1	0.25			
22,000	D12	12.5	0.20	F14	14.5	0.25						
27,000	E12	13.7	0.25	F14	16.0	0.25						
33,000	E12	15.2	0.25									
39,000	E14	16.1	0.30									
47,000	F14	19.3	0.30									
56,000	F14	21.1	0.30									

▲ Tanδ

▲ Permissible Ripple Current(Arms / 105℃, 120Hz)

▲ Case Code

Based on the above table ("Rating of KMH Series") and our requirements, even if we can choose any capacitor above 3300 μF/4.2 A in 100 V rated voltage, we selected a 3900 μF/4.2 A because we have to consider ESR.

– Capacitance: 3900 μF > 2600 μF

– Maximum permissible ripple current: $4.2\times1.3 = 5.46$Arms > 5 A

Therefore, our design is reasonable by conditions above.

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2. Hoft, R., Semiconductor Power Electronics, Van Nostrand Reinhold, 1986.

3. Design of switch mode power supplies, http://henry.fbe.fh-darmstadt.de/smps_e/smps_e.asp