EE682 – Group Project Design

Lecture #2 Inductor/Capacitor Design

Prof. Ali Keyhani

Boost DC/DC Converter Design

Inductor Design

For continuous mode ($\Delta I_L < 2I_{in}$)

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

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

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

(See Figure 2)

Inductor Design

For discontinuous mode ($\Delta I_L > 2I_{in}$)

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

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

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

(See Figure 3)

Inductor Design

Assuming 15% current ripple:

$$\Delta I_L = 0.15 I_L = 0.15 I_{in} = 1.5\text{A}$$

$$L = \frac{1}{f}\left(V_{out} + V_F - V_{in}\right)\left(\frac{V_{out} + V_F}{V_{in}}\right)\frac{1}{\Delta I_L}$$
$$= \frac{1}{20\times 10^3}\times\left(48 + 0.7 - 24\right)\times\frac{48 + 0.7}{24}\times\frac{1}{0.15\times 10}\text{H}$$
$$= 406\mu\text{H}$$

Inductor Design – MTE Co. Products

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

DC AMPS	INDUC. mH	CATALOG No.
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

DC AMPS	INDUC. mH	CATALOG No.
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

Inductor Design

Select product:

18RB001, 650μH>406μH, 18A

Peak current:

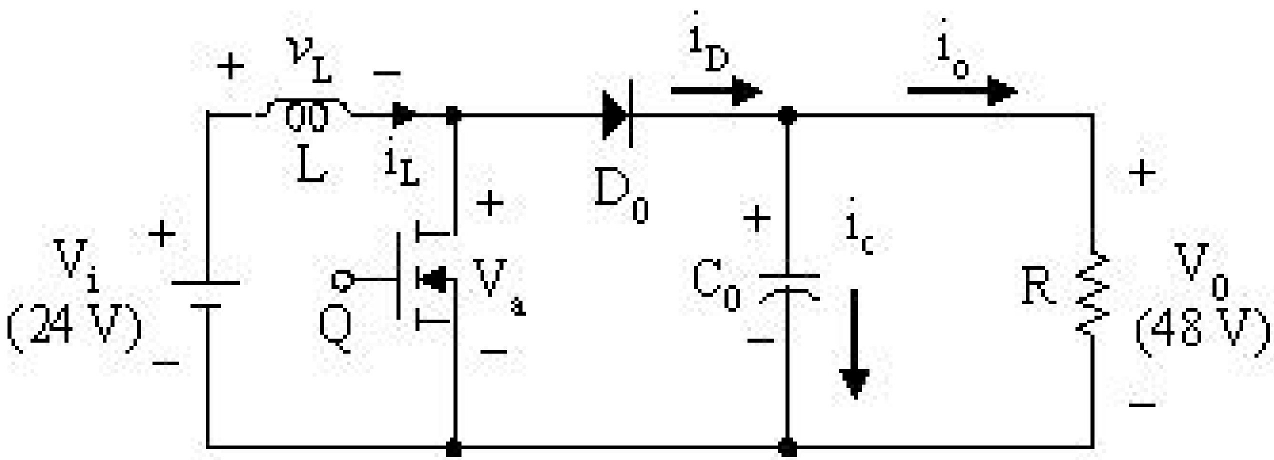
$$I_{\max} = I_{in} + \frac{1}{2}\Delta I_L = I_{in} + \frac{1}{2}\left(\frac{1}{f}\right)\left(V_{out} + V_F - V_{in}\right)\left(\frac{V_{in}}{V_{out} + V_F}\right)\frac{1}{L}$$

$$= 10 + \frac{1}{2}\frac{1}{20\times10^3}\left(48 + 0.7 - 24\right)\left(\frac{24}{48 + 0.7}\right)\frac{1}{650\times10^{-6}}\text{A}$$

$$= 10 + 0.468\text{A} = 10.468\text{A}$$

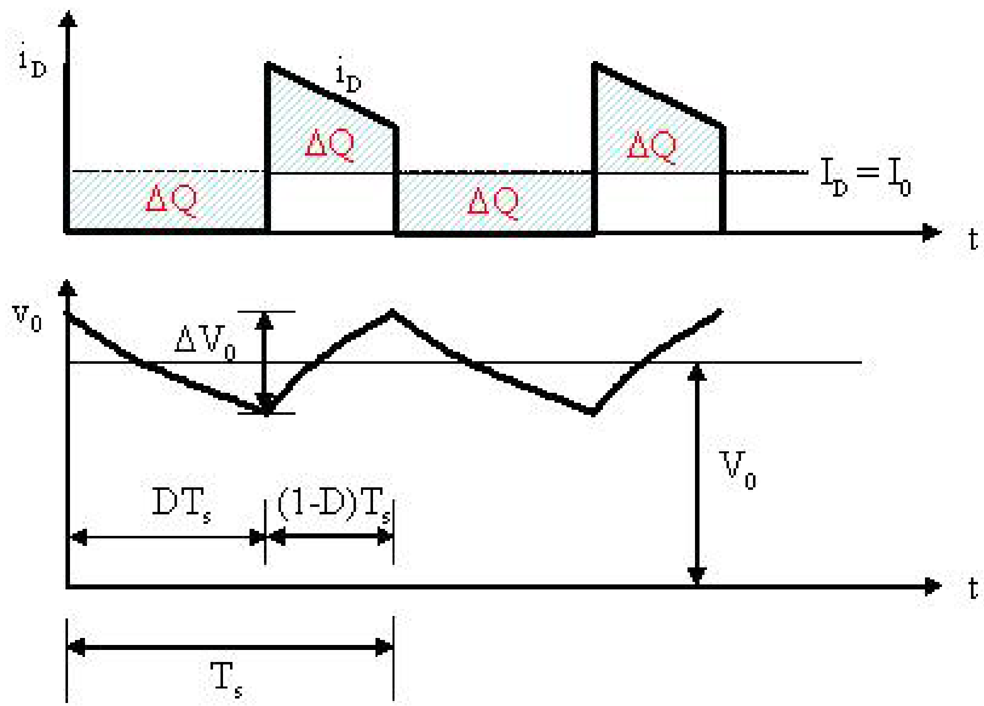
$10.468\text{A} < 15\text{A} = I_{\text{Dmax}}$

Capacitor Design



A conventional boost converter

Capacitor Design



Output voltage ripple

Capacitor Design: Capacitance Calculation

Assume the diode current (i_D) is a square wave form

- Peak diode current:

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

(Where D = 0.5, I_0 = P/V_0 = 240/48 = 5 A)

- RMS diode current:

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

- RMS capacitor current

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

Capacitor Design: Capacitance Calculation

- Output voltage ripple:

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

- Capacitance

$$\therefore C = \frac{\Delta Q}{\Delta V_0} = \frac{I_{c,rms} D T_s}{\Delta V_0} = \frac{5 \cdot 0.5}{48 \times 10^{-3} \times 20 \times 10^{3}} = 2600\ \mu F$$

Where, D = 0.5, T_s = 1/(20×10^3) sec, $I_{c,rms}$ = 5 A, ΔV_0 = 48 mV.

Capacitor Design: Supplier Selection

- Our Final Specifications:
  - Rated output voltage > 48 V
  - Rated ripple current > 5 A
  - Capacitance > 2600 μF

Capacitor Design: How to choose the type

- Considerations of designers:
  - Cost, Permissible temperature, Size, and ESR, etc

- Factors for Cost:
  - Materials
  - Rated voltage
  - Capacitance
  - Maximum permissible ripple currents
  - Maximum permissible temperature
  - ESR (Equivalent Series Resistance)

Capacitor Design: Supplier Selection

List of Aluminum Electrolyte 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)
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

(Manufactured by Sam Young Electronics Co.)

* Please refer to class note for more list

- Our selection: KMH Series for General Purpose

Capacitor Design: Supplier Selection

Data Sheet of KMH Series

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

- Our Selection:
  - Rated output voltage: 100 V (Overvoltage due to parasite inductance)
  - Mutiplying factor: 1.3 (f_s = 20 kHz)

Capacitor Design: Supplier Selection

Rating of KMH Series

VDC / μF	100(2A)			160(2C)			200(2D)			250(2E)		
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

▲ Tanδ

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

▲ Case Code

- Final Selection: 100 V/3900 μF/4.2 A
  - Output voltage: 100 V > 48 V
  - Capacitance: 3900 μF > 2600 μF (Due to the effect of ESR)
  - Maximum permissible ripple current: $4.2 \times 1.3 = 5.46$ Arms > 5 A