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4TH YEAR, B.E ECE,

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DESIGN CALCULATIONS

5 V DC–DC Buck Converter using LM2596S-5

Given Specifications:

- Input Voltage Vin = 6 V – 20 V
- Output Voltage Vout = 5 V
- Load Current Io = 3 A
- Switching Frequency fs = 150 kHz
- Output Ripple Voltage < 50 mV

1.Duty Cycle Calculation:

$$D = V_{out} / V_{in(max)}$$
$$D = 5 / 20$$
$$\mathbf{D = 0.25}$$

- **Note:**
  Duty cycle tells how long the switch inside the IC is ON. We calculate it at maximum input voltage because that is the worst operating condition.

2.Inductor Ripple Current:

$$\Delta I_L = 0.3 \times I_o$$
$$\Delta I_L = 0.3 \times 3$$
$$\mathbf{\Delta I_L = 0.9\ A}$$

- **Note:**
  Ripple current is the small up-and-down change in inductor current. We choose about 30% of load current to keep the circuit stable and efficient

3. Inductor Value Calculation:

$$L = [\ V_{out} \times (V_{in} - V_{out})\ ] / [\ V_{in} \times \Delta I_L \times f_s\ ]$$

$$\Delta IL = 0.3 \times 3$$

$$L = [\ 5 \times (20 - 5)\ ] / [\ 20 \times 0.9 \times 150000\ ] = \mathbf{L = 27.8\ \mu H}$$

- **Note:**
  Ripple current is the small up-and-down change in inductor current. We choose about 30% of load current to keep the circuit stable and efficient

$$\boxed{L = 33\ \mu H}$$

- 27.8 µH is not a standard value, so we select the next higher standard value (33 µH) to reduce ripple and improve performance

4.Actual Inductor Ripple Current:

$$\Delta I_L(\text{actual}) = \frac{Vo(Vin - Vo)}{Vin \cdot fs \cdot L}$$

$$\Delta I_L(\text{actual}) = \frac{5(20-5)}{20(150k)(0.33u)}$$

$$\boldsymbol{\Delta I_L(\text{actual}) = 0.76A}$$

- **Note:**
  After choosing the standard inductor value, we re-calculate ripple current to confirm it is within safe limits.

5.Peak Inductor Current:

$$I_{L\ (peak)} = Io + (\Delta I_L / 2)$$

$$I_{L\ (peak)} = 3 + (0.76 / 2)$$

$$\mathbf{I_{L\ (peak)} = 3.38\ A}$$

- **Note:**
  Peak current is the highest current flowing through the inductor. The inductor must handle this current without saturating

6.Output Capacitor Ripple Voltage (Capacitive):

$$\Delta V_C = \Delta I_L / (8 \times fs \times C)$$

$$\Delta V_C = 0.76 / (8 \times 150000 \times 330\mu)$$

$$\boldsymbol{\Delta V_C \approx 1.9\ mV}$$

- **Note:**
  This ripple comes from the charging and discharging of the output capacitor during switching

7.Output Capacitor ESR Ripple Voltage:

$$\Delta VESR = \Delta IL \times ESR$$

$$\Delta VESR = 0.76 \times 0.05$$

$$\mathbf{\Delta VESR = 38\ mV}$$

- **Note:**
  ESR is the small internal resistance of the capacitor. It causes most of the output voltage ripple.

8. Total Output Ripple Voltage:

$$\Delta Vout = \Delta VC + \Delta VESR$$

$$\Delta Vout = 1.9 + 38$$

$$\mathbf{\Delta Vout = 39.9\ mV}$$

- **Note:**
  Total ripple voltage is within the allowed limit of 50 mV, so the design is acceptable.

9.Diode Current Check:

$$\mathbf{ID \approx Io = 3A}$$

- **Note:**
  The diode must handle the full load current. A Schottky diode is used to reduce losses and increase efficiency

Design validation:

- The design calculations were carried out for a 5 V, 3 A buck converter using the LM2596S-5 IC.
- The inductor value was calculated based on the selected ripple current and a standard 33 μH inductor was chosen.
- Peak inductor current was calculated to ensure the inductor operates without saturation. Output ripple voltage was computed and found to be less than the specified limit of 50 mV.
- Since a fixed-output regulator was used, the output voltage is inherently regulated at 5 V.
- Thus, the calculated values confirm that the design meets all required electrical specifications.