Q1

We are asked to design a 250 W duty controlled full bridge isolating converter with $V_{in} = 100\,\text{V}$, $V_o = 24\,\text{V}$ and %1 peak-to-peak output voltage ripple. Switching frequency is $f_s = 200\,\text{kHz}$ and the duty cycle is given as $D = 0.45$.

1-a

In a full-bridge, the transformer primary sees $\pm V_{in}$ during the active intervals. Because the secondary uses a center-tapped full-wave rectifier, the output filter effectively sees two identical pulses per switching period. So we can define an equivalent duty as

$$D_{\text{eq}} = 2D$$

During the on-interval, the rectifier output (before the inductor) is basically the reflected secondary voltage:

$$V_x = \left(\frac{N_s}{N_p}\right) V_{in}$$

Then, the output stage behaves like an ideal buck:

$$V_o = D_{\text{eq}}\, V_x = (2D) \left(\frac{N_s}{N_p}\right) V_{in}$$

Solving for the turns ratio:

$$\frac{N_s}{N_p} = \frac{V_o}{(2D)V_{in}} = \frac{24}{(0.9)\cdot 100} = 0.2667$$

$$\boxed{\frac{N_s}{N_p} \approx 0.267 \text{ (per half-secondary)}}$$

(If someone defines secondary as total turns $N_{s,\text{total}} = 2N_s$, then $N_{s,\text{total}}/N_p \approx 0.533$.)

Also, the effective rectified input level is

$$V_x = \frac{V_o}{D_{\text{eq}}} = \frac{24}{0.9} = 26.6667\,\text{V}$$

1-b

First, the output current is

$$I_o = \frac{P_o}{V_o} = \frac{250}{24} = 10.4167\,\text{A}$$

The inductor ripple requirement is 10% of the average inductor current. In CCM, $I_{L,\text{avg}} \approx I_o$, so

$$\Delta I_L^{pp} = 0.1 I_o = 0.1 \cdot 10.4167 = 1.0417\,\text{A}$$

Because the rectifier creates two pulses per switching period, the ripple frequency seen by the output filter becomes

$$f_{\text{eq}} = 2f_s = 400\,\text{kHz}, \qquad D_{\text{eq}} = 2D = 0.9$$

For an ideal buck, inductor current ripple is

$$\Delta I_L^{pp} = \frac{(V_x - V_o)D_{\text{eq}}}{L f_{\text{eq}}}$$

Here,

$$V_x - V_o = 26.6667 - 24 = 2.6667\,\text{V}$$

So,

$$L = \frac{(V_x - V_o)D_{\text{eq}}}{\Delta I_L^{pp} f_{\text{eq}}} = \frac{(2.6667)(0.9)}{(1.0417)(400 \times 10^3)} \approx 5.76 \times 10^{-6}\,\text{H}$$

$$\boxed{L \approx 5.76\,\mu\text{H}}$$

1-c

The voltage ripple requirement is 1% peak-to-peak:

$$\Delta V_o^{pp} = 0.01 V_o = 0.01 \cdot 24 = 0.24\,\text{V}$$

The capacitor current is basically the AC part of the inductor current:

$$i_C(t) = i_L(t) - I_o$$

Since $i_L(t)$ has a triangular ripple with peak-to-peak value ΔI_L^{pp}, the capacitor current is also triangular around zero. For the standard CCM buck approximation (ignoring ESR), the output voltage ripple is

$$\Delta V_o^{pp} = \frac{\Delta I_L^{pp}}{8 C f_{\text{eq}}}$$

Derivation idea: capacitor voltage change comes from charge balance, $\Delta V = \Delta Q / C$, and ΔQ is the area under the capacitor current waveform over the relevant portion of a cycle. Since the capacitor current is triangular, the area scales with ΔI_L^{pp} and $T_{\text{eq}} = 1/f_{\text{eq}}$, which gives the $1/(8Cf)$ form.

Now solve for C:

$$C = \frac{\Delta I_L^{pp}}{8 f_{\text{eq}} \Delta V_o^{pp}} = \frac{1.0417}{8 \cdot 400 \times 10^3 \cdot 0.24} \approx 1.36 \times 10^{-6}\,\text{F}$$

$$\boxed{C \approx 1.36\,\mu\text{F (ideal, ESR neglected)}}$$

In practice, ESR can easily dominate the ripple, so usually a larger and low-ESR capacitor bank is selected.