**Homework Assignment 07**

**Question 1**  For a buck regulator with smoothing capacitor with value $C$ and $ESR = 0$, the output ripple voltage is

$$\Delta v_C = \frac{\Delta i_L}{8f_s C}$$

(a) Derive an expression for the output ripple voltage amplitude for the case when $ESR \neq 0$ (8 points)
(b) Next calculate the ripple voltage for $f_s = 20 \times 10^3$ Hz, $\Delta i_L = 2$ A, $C = 22 \mu F$ and $ESR = 0.5 \Omega$ (4 points)
Question 2 (Buck Converter) (a) Design a buck switching converter to convert a 17 V input voltage to a 10 V output voltage. The converter must always be in continuous mode. The load current will be in the range 1–3 A. The inductor ripple current must be less than 2 A and output ripple voltage must be less than 100 mV. Specify the type of diode, switching frequency, duty cycle, and values for \( L \) and \( C \). For simplicity, assume a perfect switch, neglect diode voltage drop, and capacitor ESR. (15 points)

(b) Sketch the inductor current when the load current is 1 A. (3 points)

(c) Even though there is no feedback/regulation in the circuit, the output voltage will be approximately 10 V for a range of load resistances. What is this range? (5 points)
Part (b)

As long as the converter is in continuous mode, the output voltage is independent of the load. Thus, for resistances less than $10^{-1} = 10\, \Omega$ the output voltage is 10 V. For larger load resistances, the output voltage rises. In practice, losses in the inductor, diode, and switch limit the lowest load resistance.
**Question 3** Consider the gated-oscillator DC/DC regulator below. The hysteresis for $A_1$ is $20 \text{ mV}$, $R_1 = R_2 = 100K$, and the duty cycle $D$ of the oscillator is $30\%$.

a) What is the (mean) output voltage for an input voltage of $20 \text{ V}$? **(5 points)**

b) What is the output ripple voltage? **(5 points)**
**Question 4 (SC Converters)** The figure below shows the oscillator part of a SC DC/DC converter and the numbers in parenthesis are the IC pin numbers. The Schmitt trigger has thresholds 5.2 V and 2 V. Sketch the waveform at pin 7 if $I$ for the constant current generators is 0.5 $\mu$A. Assume the BOOST control voltage keeps the corresponding switches open. On your figure indicate the maximum-, minimum-, average voltages of the waveform, as well as the period of the waveform. (6 points)
**Question 5 (SC Converters)** The figure below shows the LTC1144 SC IC configured to invert a voltage. Assume the switching frequency is 4 kHz, $V^+ = 5\, \text{V}$ and the load at $V_{OUT}$ (i.e., pin 5) is a 1K resistor. What are the minimum values for the capacitors to ensure $V_{OUT}$ is within 10 mV of $-5\, \text{V}$? Assume the LTC1144's internal switches has zero ON resistance. **(6 points)**

![Diagram of LTC1144 SC IC](image)
**Question 6 (Switched Capacitors)** In the switched capacitor circuit below, the voltages are $V_1 = 2$ V, and $V_2 = 1$ V, the capacitor value is $C = 10$ pF, and the clock frequency is $f_c = 100$ kHz.

(a) Determine the charge transferred from $V_1$ to $V_2$ during each clock pulse.
(b) What is the average current that source $V_1$ supplies?
(c) If the “on” resistance of each MOSFET is 1 kΩ, determine the time required to transfer 99% of the charge during each half-clock period.

![Switched Capacitor Circuit Diagram]
Question 7 (Principles) The circuit has been in steady-state prior to the switch closure at $t = 0$. Determine and sketch the voltage $v(t)$ for $t > 0$. 

The circuit at $t = 0^+$ is shown in (b) below. Applying KCL gives $v(0^+) = \frac{52}{3} V = 17.33 V$. 

The circuit at $t = \infty$ is shown in (d) and it is clear the inductor shorts all but the $4 \Omega$ resistor and so that $v(\infty) = 24 V$. The circuit time constant is $\frac{L}{R}$, where $R_{Th}$ is the Thevenin equivalent resistance the inductor sees, see (e) below. This is easily calculated as $R_{Th} = 2 \Omega$ so that the time constant is 2 s. 

Combining gives $v(t) = 24 - (24 - 17.33) e^{-\frac{t}{2}} = 24 - 6.66 e^{-\frac{t}{2}}$ V.