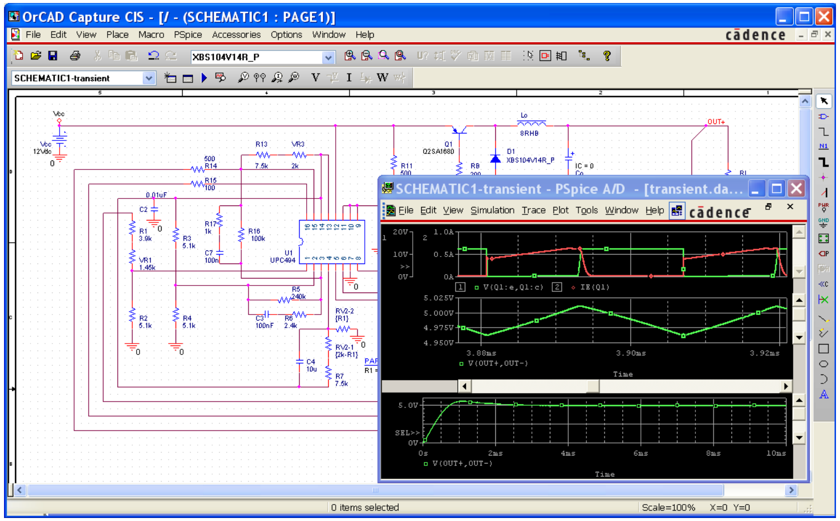
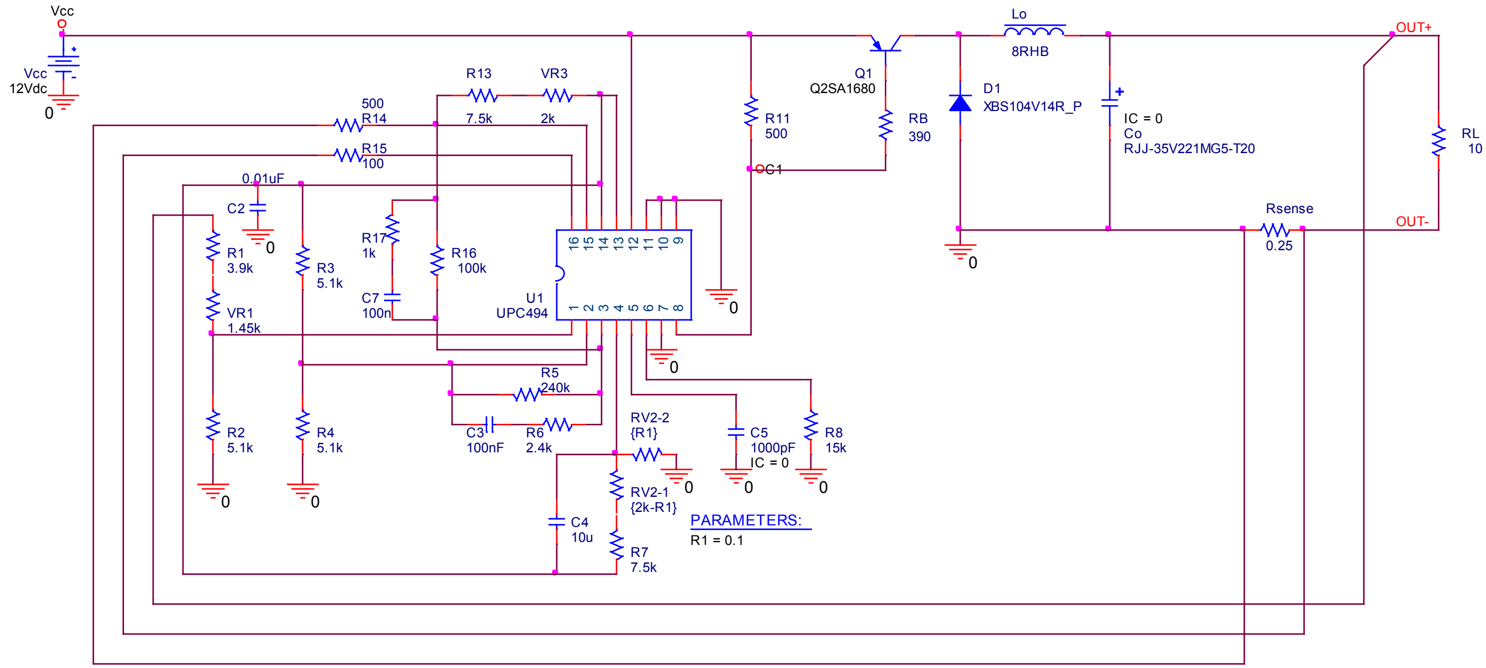


Design Kit

Buck Converter Using μPC494

Contents

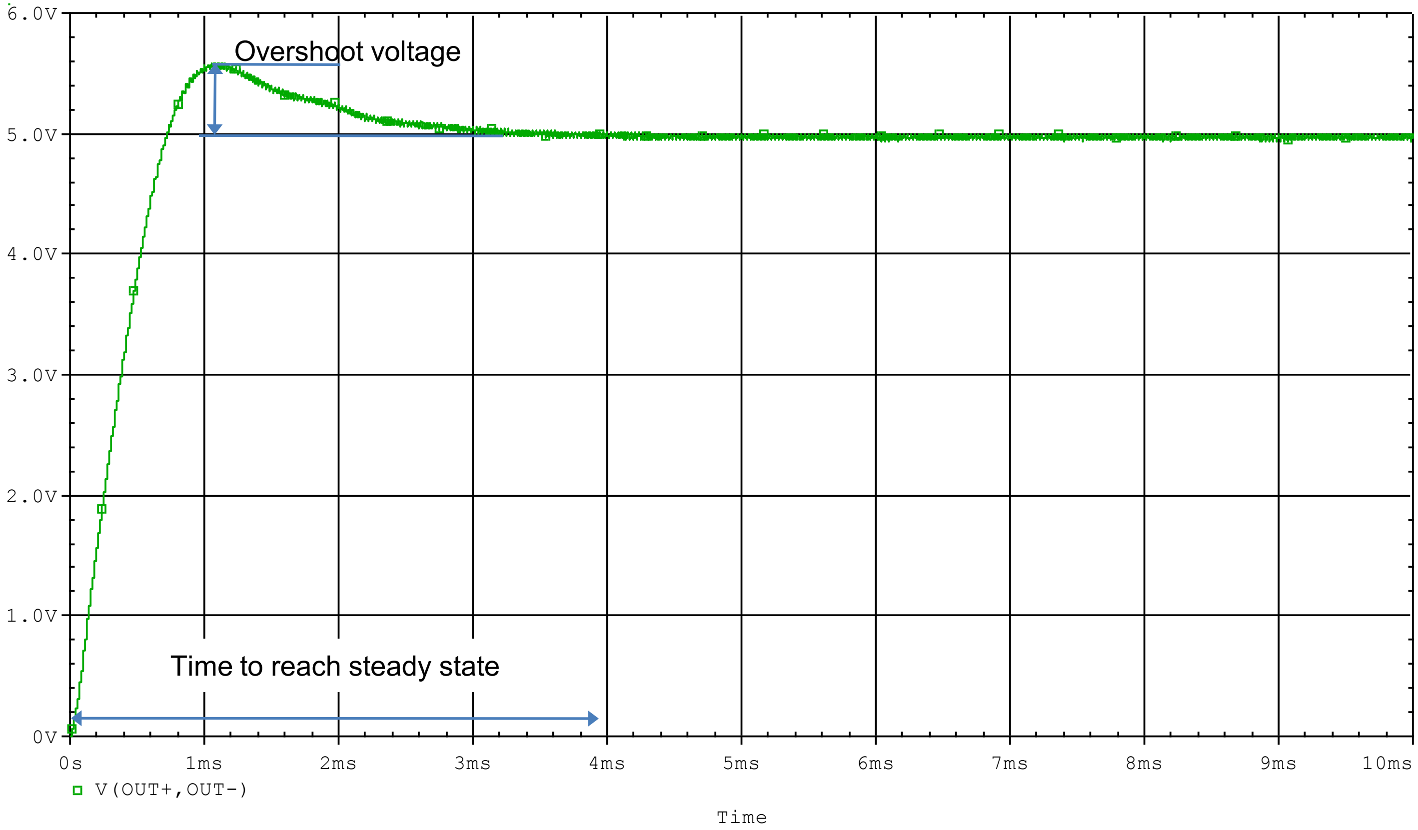
1. Buck Converter using μPC494: V_{IN}=12V, V_{OUT}=5V@0.5A



- V_{IN} = 12V
- V_{OUT} = 5V
- I_{OUT} = 0.15~0.5A , I_{OUT} below 0.15A DCM
- Efficiency = >74% with VIN = 12V, load 0.5A
- Output voltage ripple < 1% VOUT

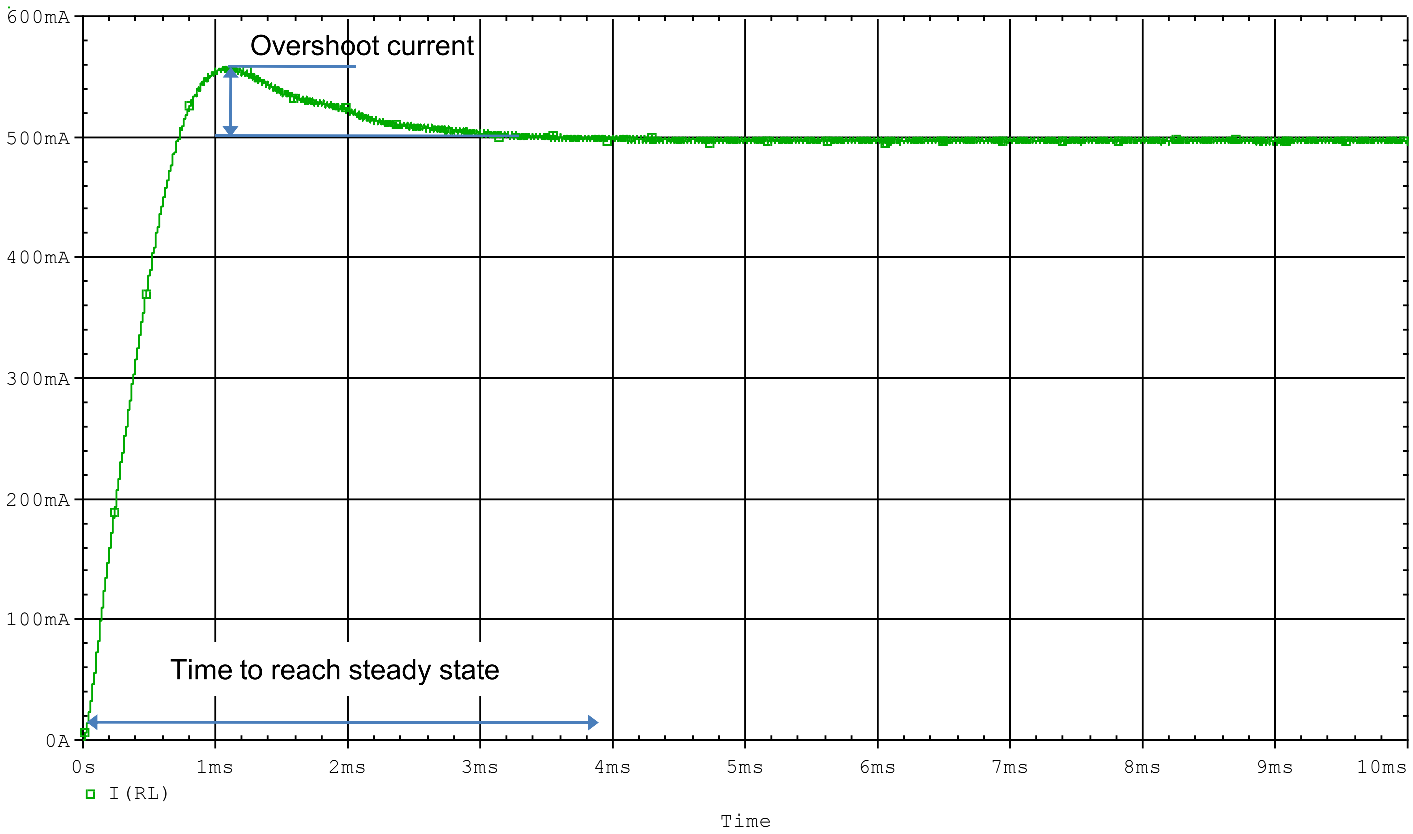
※ Schottky barrier diode (SBD) D1 is simulated using a Professional model.

1.1 Output voltage



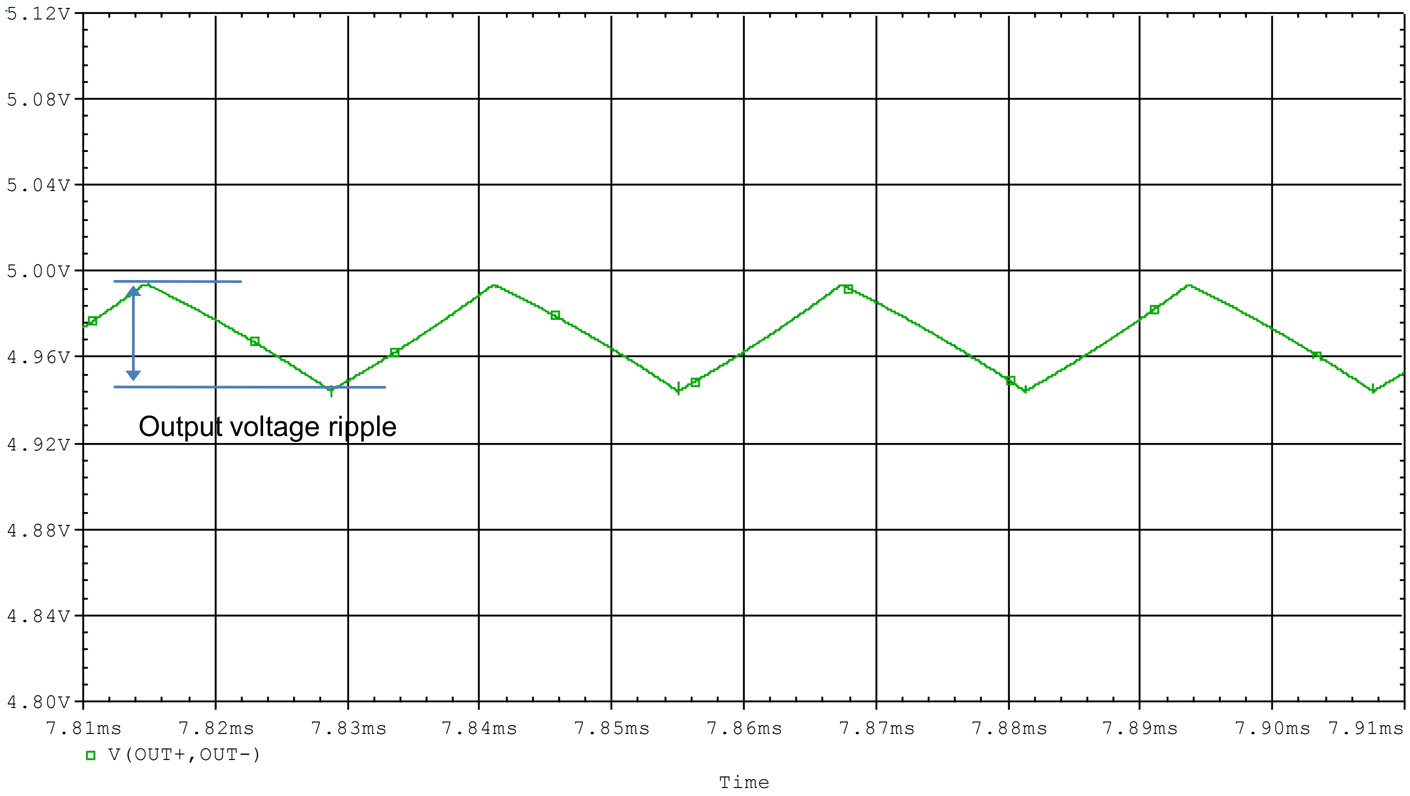
- The output voltage is regulated at 5V (RL=10Ω) ,voltage overshoot at startup is 0.6V. Steady state is reached within 4ms.

1.2 Output current



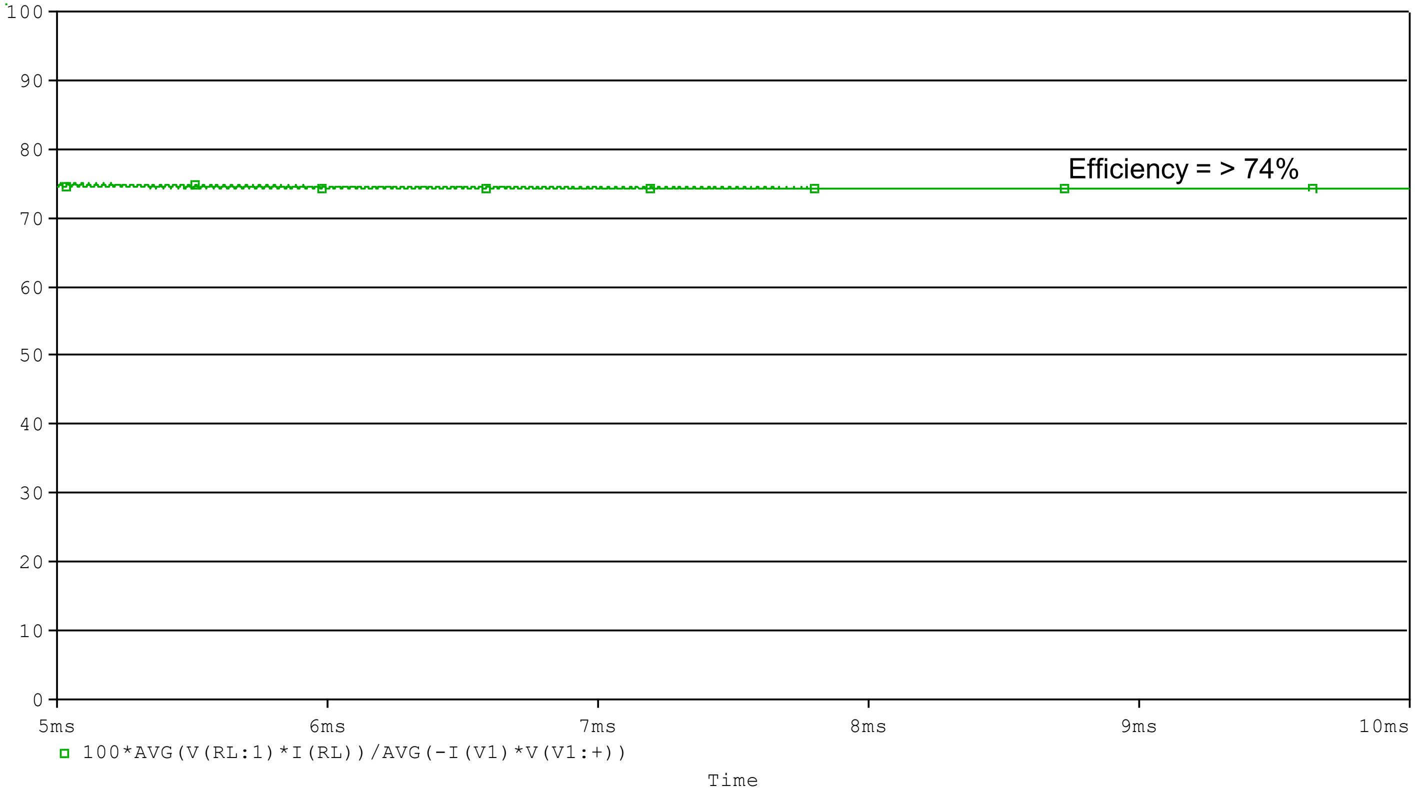
- The output current is 0.5A (RL=10Ω) ,current overshoot at startup is 60mA. Steady state is reached within 4ms.

1.3 Output ripple voltage



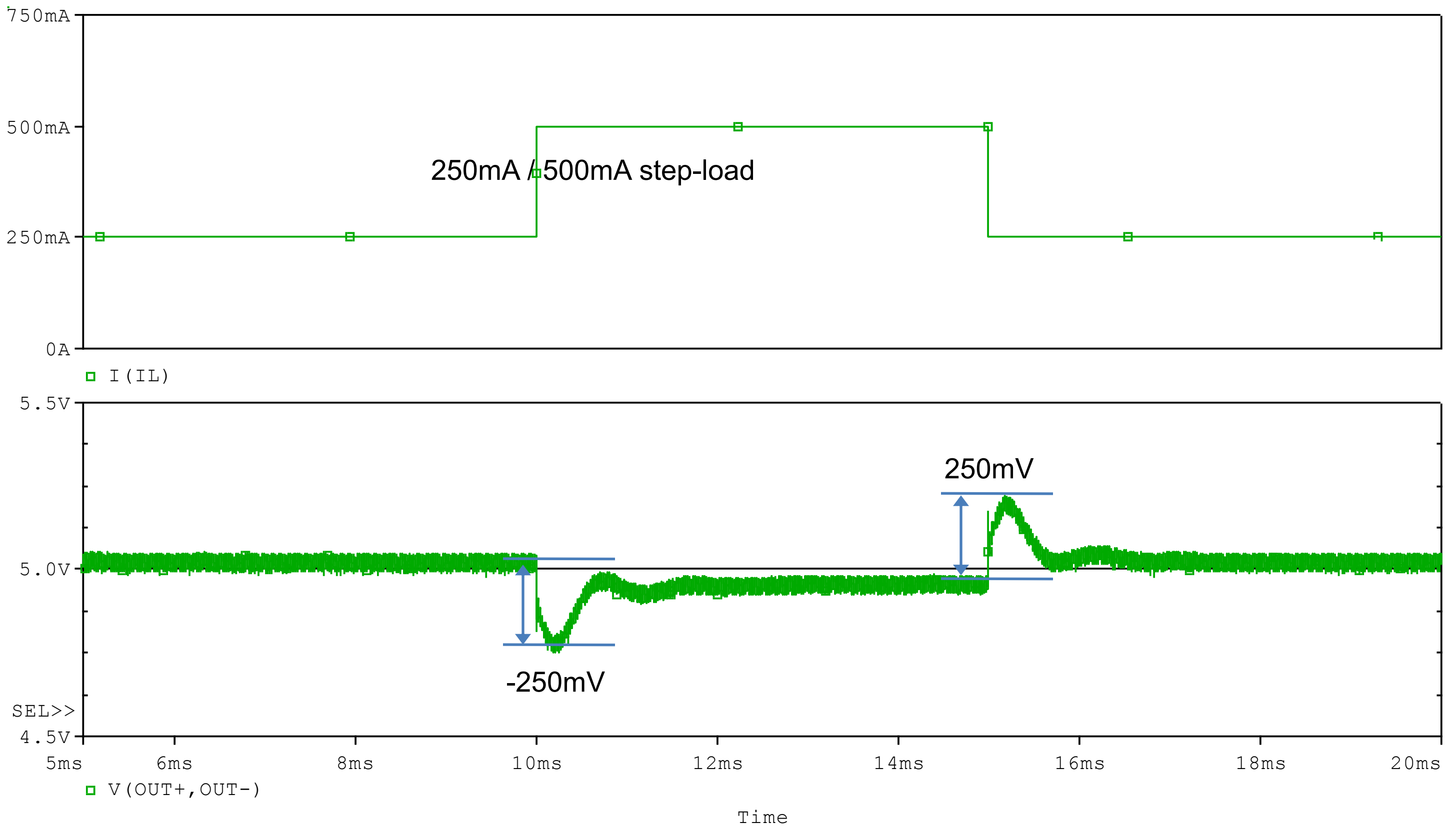
- The output ripple voltage is less than 1% of the output voltage (< 50 mV_{P-P}).

1.4 Efficiency



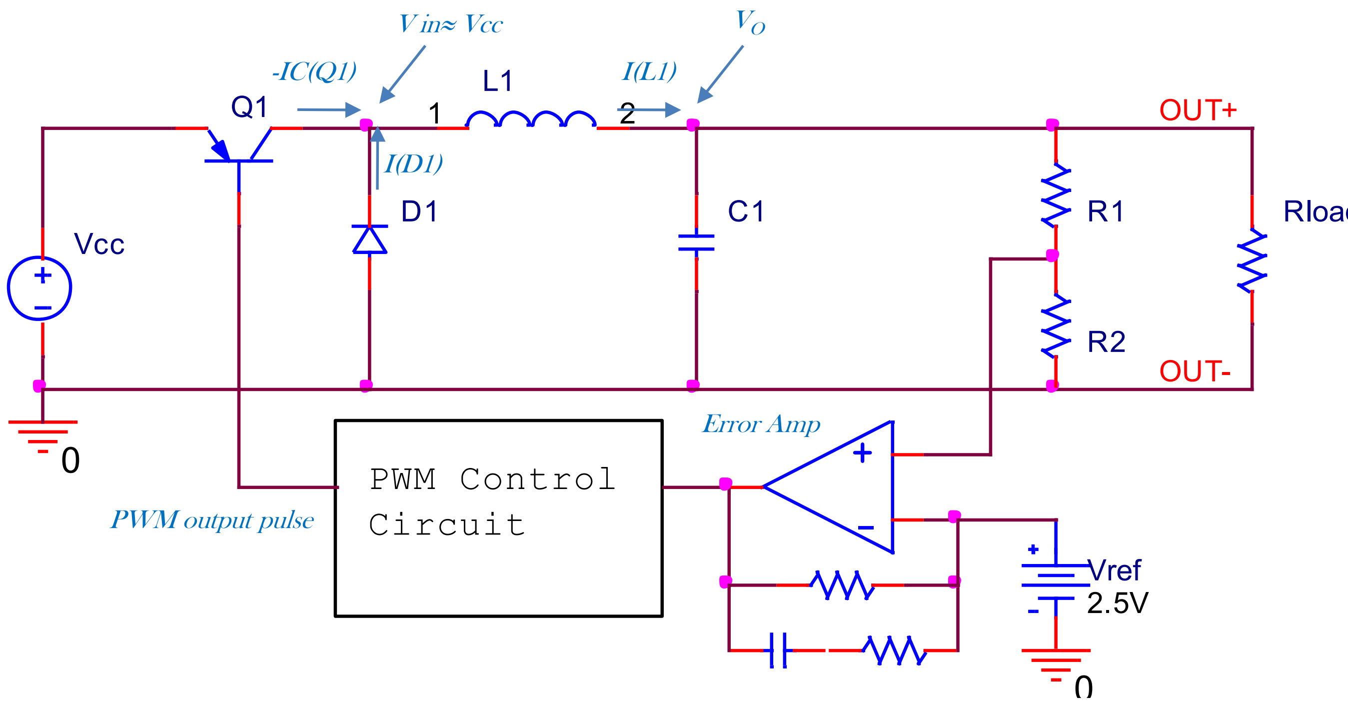
- The efficiency of the converter at VIN=12V and load RL=10Ω is 74% or more. (Efficiency = > 74%)

1.5 Step-load response



- Simulation results shows the transient responses, when load current steps up and steps down.

2. Basic Operation



The basic operation of how the output voltage is regulated at the desired voltage level.

- V_O is sensed by sampling resistors R1, R2 and compare to a reference voltage Vref in the Error Amp.
- The error voltage is modulated with a sawtooth waveform.
- Pulse-width-modulator (PWM) output pulse width T_{ON} is proportional to the Error Amp output DC voltage level.
- V_{OUT} ,which is proportional to T_{ON} ,is regulated at the desired voltage level.

2.1 Output voltage equations

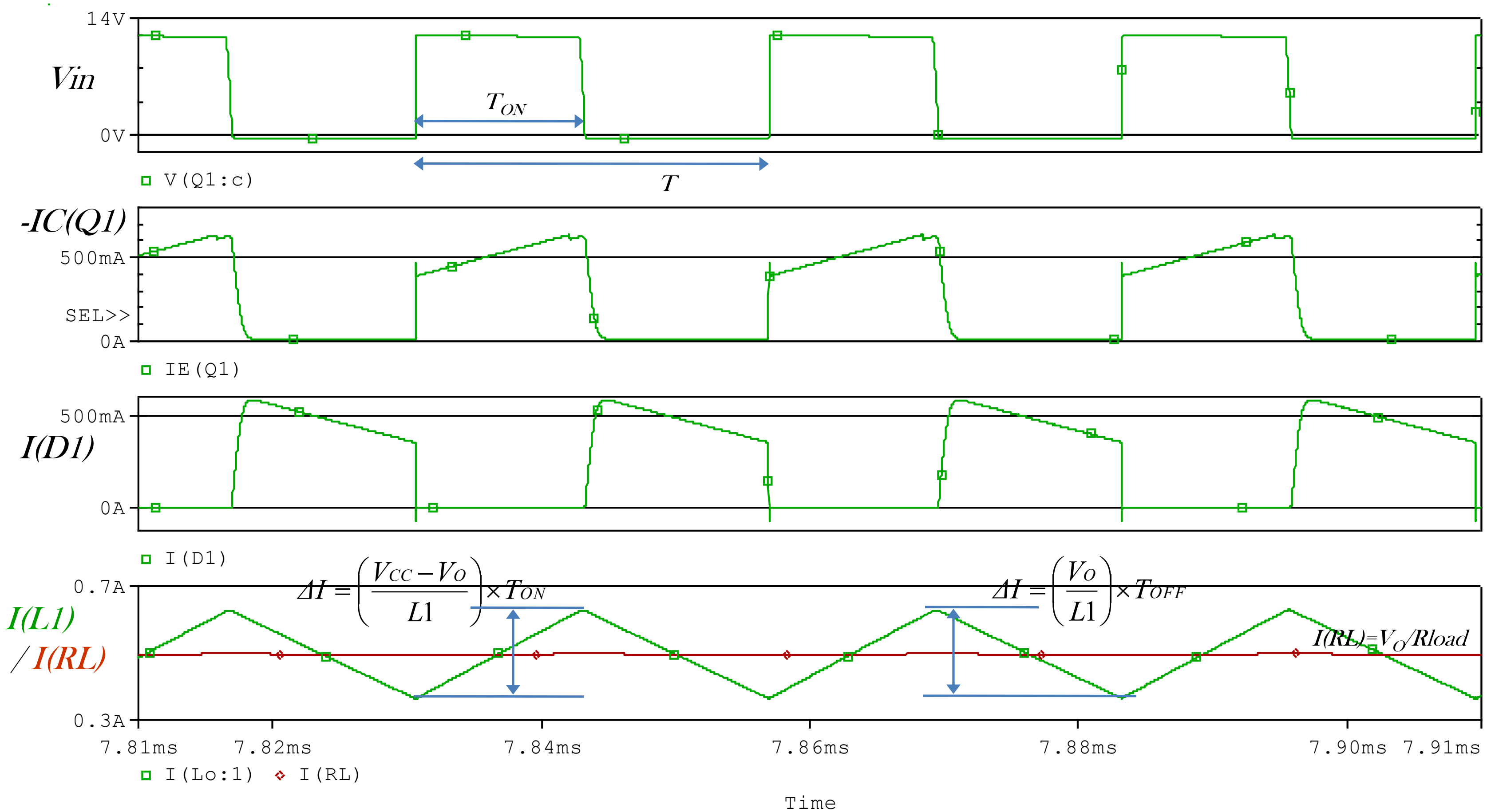
- R1 and R2 are calculated by follow equation. In practical design a variable resistor ,that is higher than the calculated value ,is chosen for R1.

$$V_{OUT} \cong \left(\frac{R1 + R2}{R2} \right) \times Vref \qquad (1)$$

- If the circuit works in continuous conduction mode (CCM) , output voltage and T_{ON} follow the equation below.

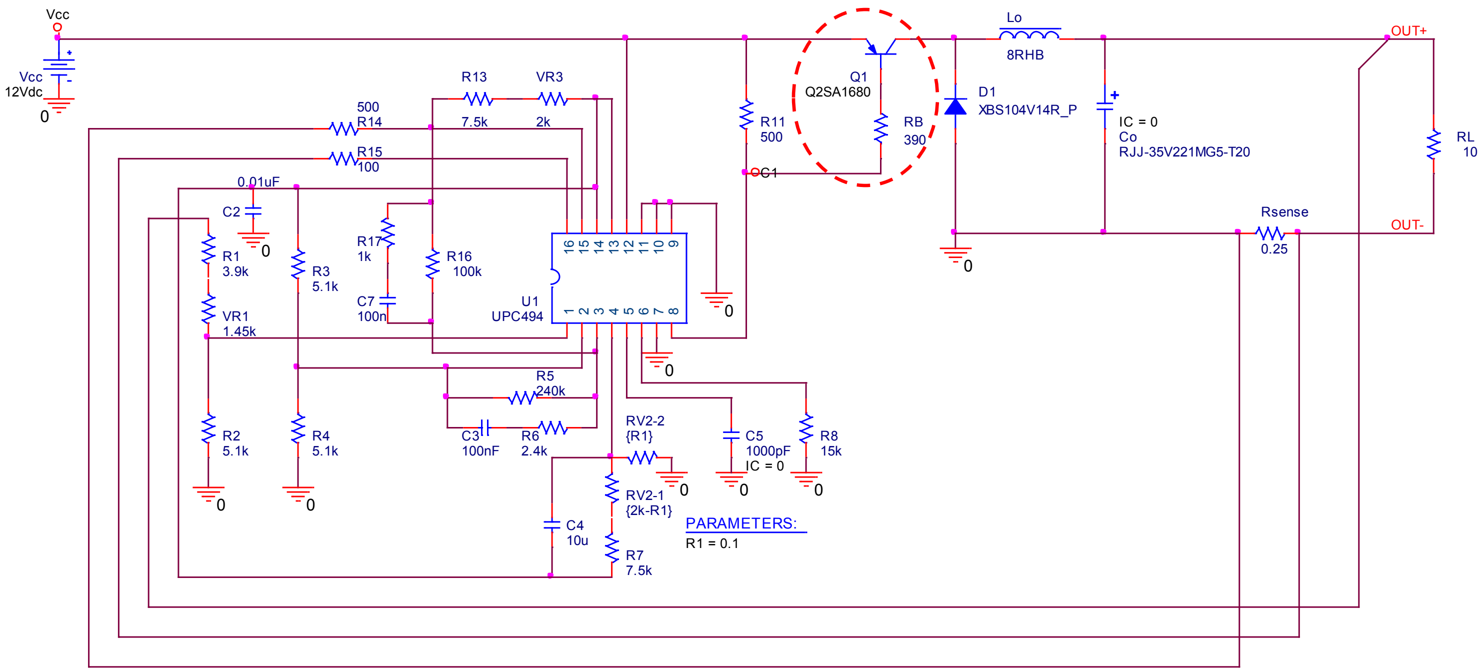
$$V_{OUT} = \left(\frac{T_{ON}}{T} \right) \times Vin \qquad (2)$$

2.2 Basic operation waveforms



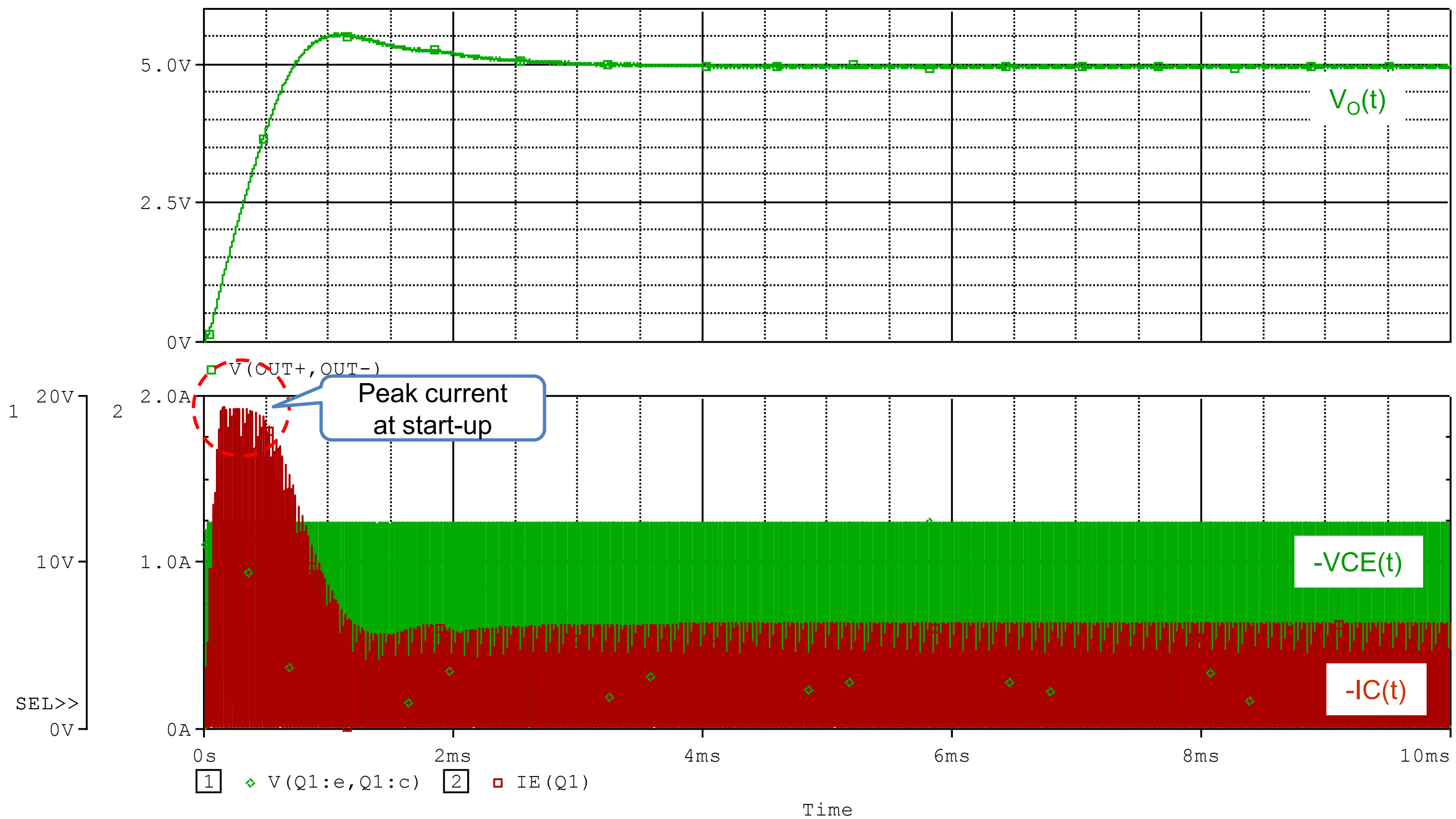
- Simulation result shows the waveforms and magnitude of the current throughout the circuit.

3. Switching Transistor Q1



- V_{IN} = 12V
- V_{OUT} = 5V
- RL = 10Ω
- Switching transistor Q1 is Toshiba 2SA1680 ($I_{C,MAX}$ = 2A, $V_{CE,MAX}$ = 50V)
- RB=390 Ω

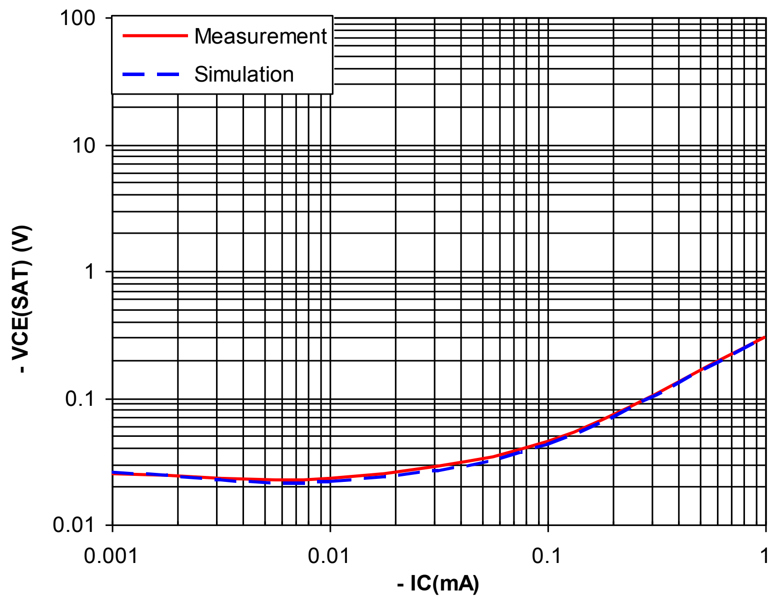
3.1 Voltage and current stresses



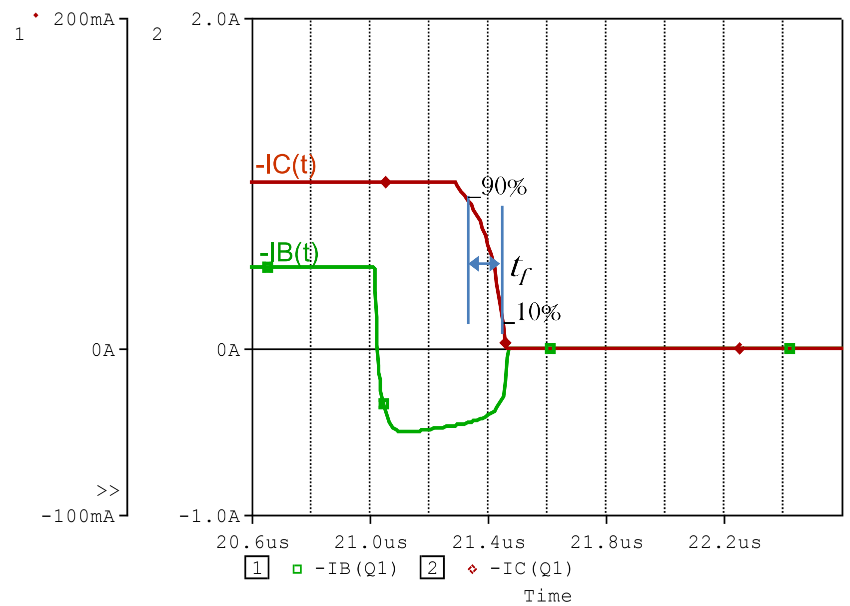
- Simulation result shows the collector peak current at start-up transient. This peak current is limited by the resistor RB. The current should not exceed the maximum current rating of transistor Q1 (2SA1680 $I_{C,MAX}$ = 2A, $V_{CE,MAX}$ = 50V).

3.2 Transistor characteristics

$V_{CE(sat)}$-I_C characteristics

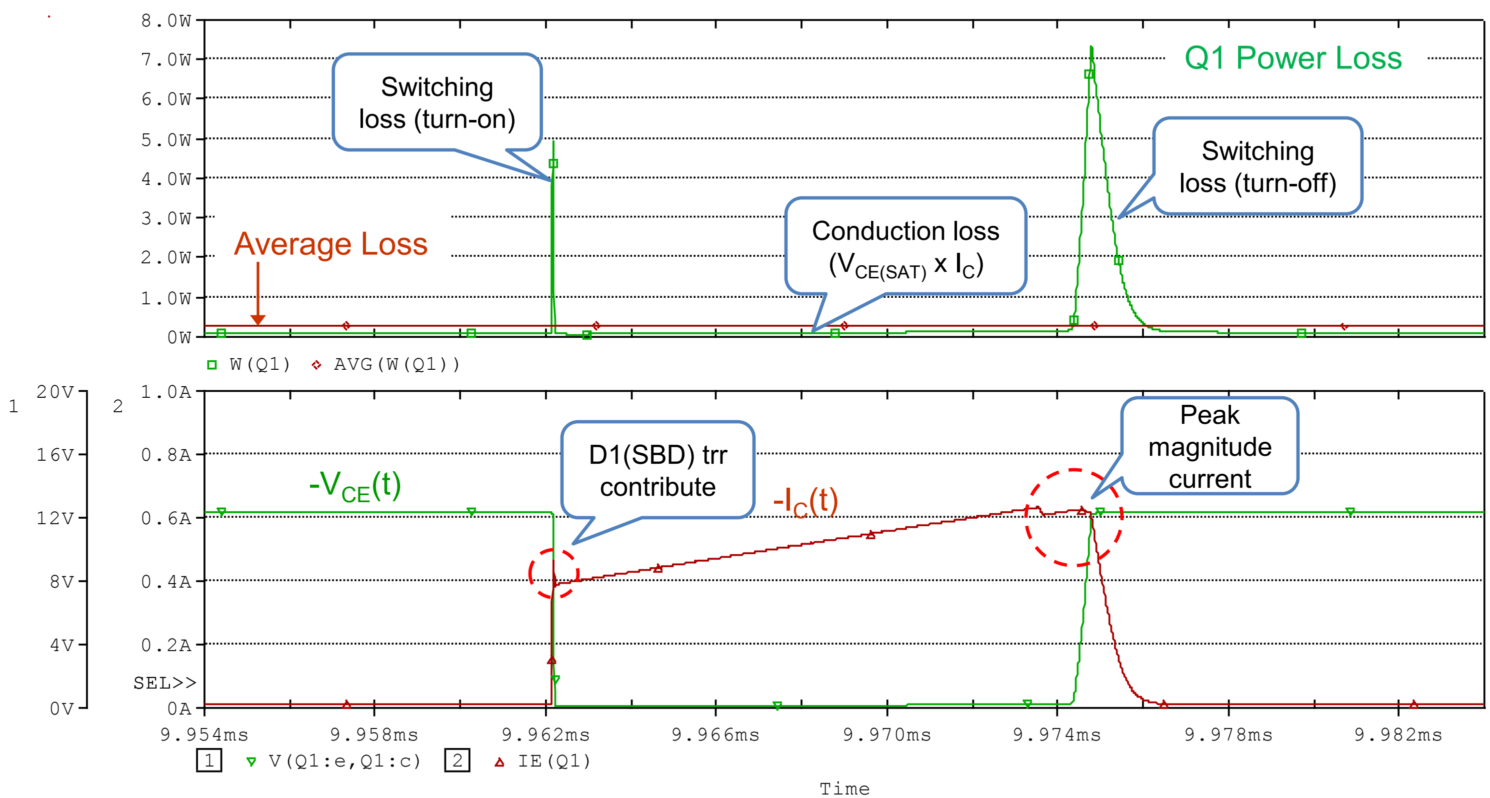


Turn-off characteristics



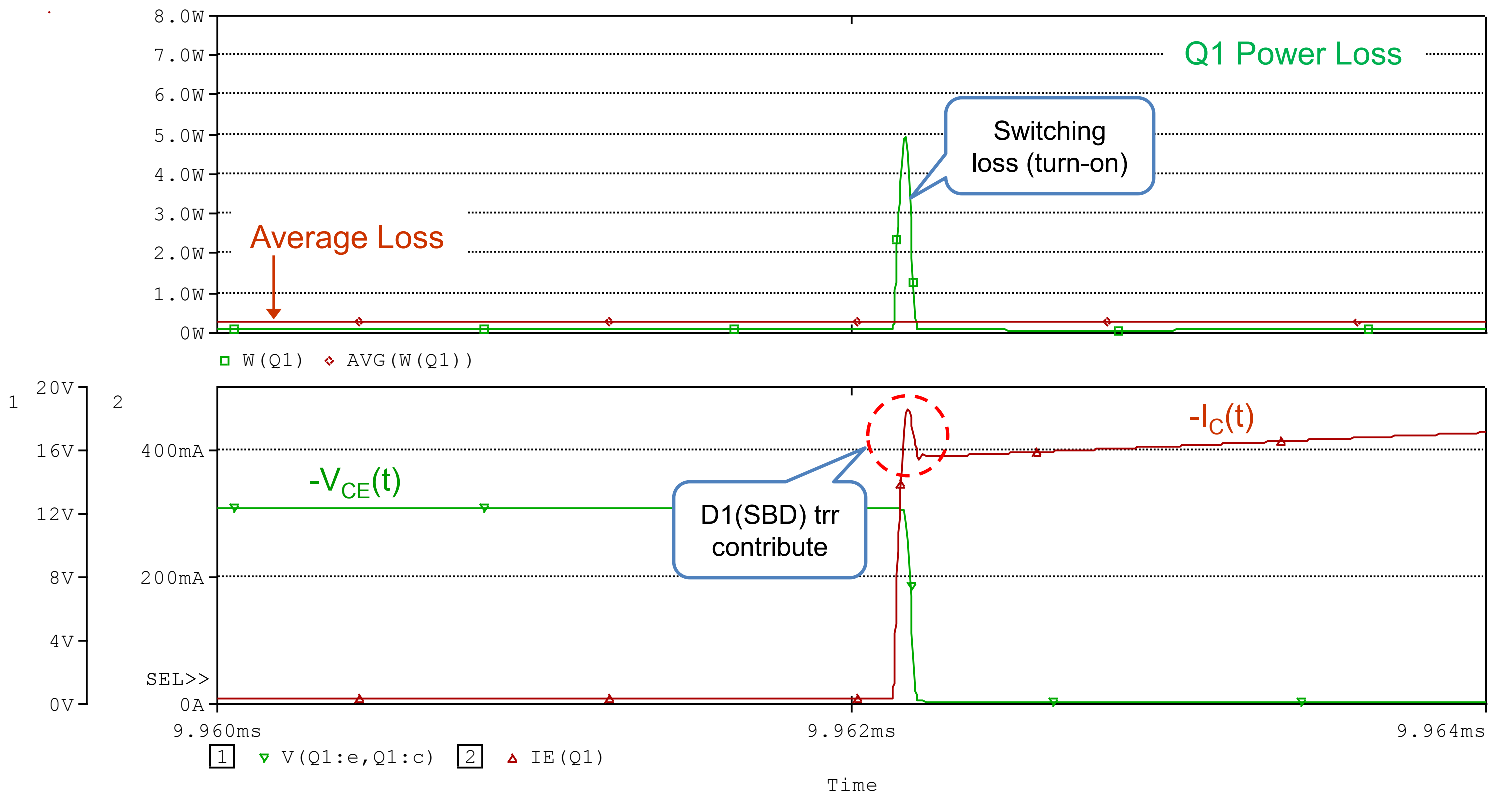
- Losses in Q1 depend on the transistor characteristics. Conduction loss is depends on $V_{CE\ (sat)} - I_C$ and switching loss is depends on Switching time characteristics (turn-on and turn-off)

3.3 Transistor Q1 losses



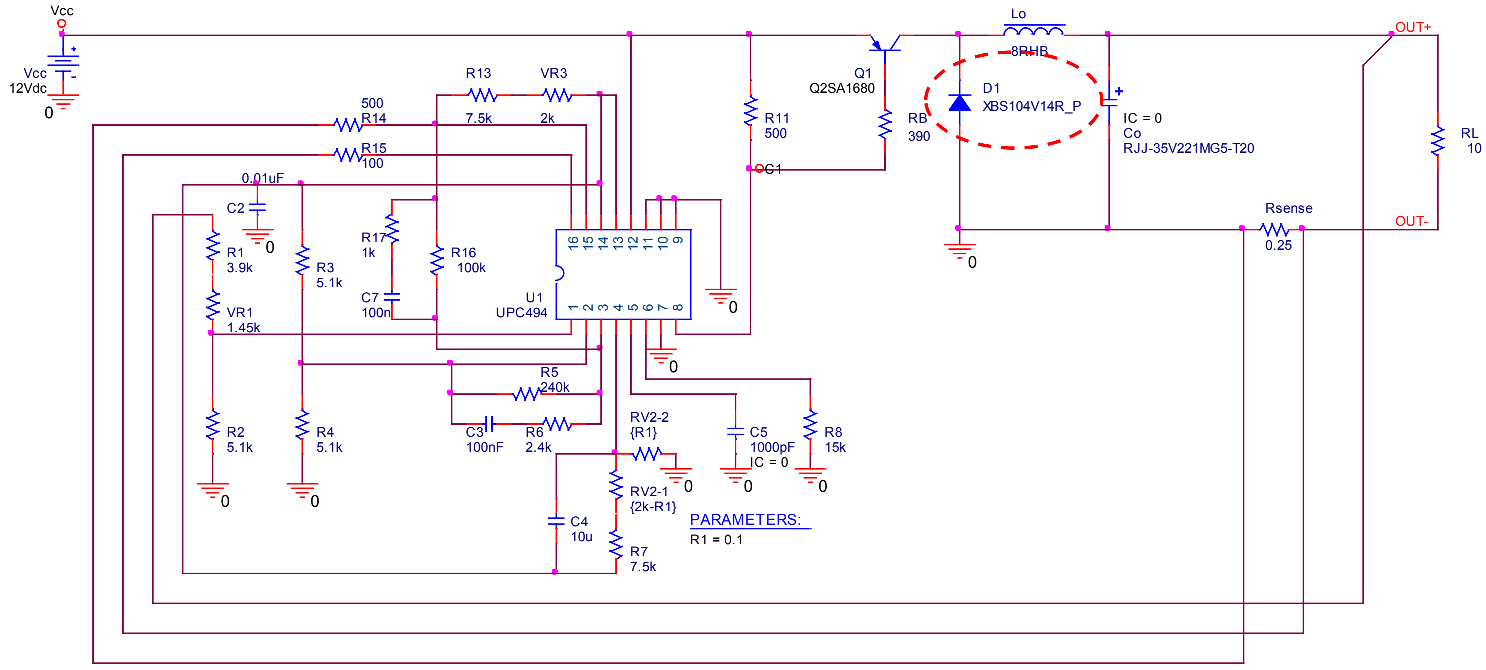
- Simulation results shows waveforms of I_C and V_{CE} of transistor Q1. Switching power loss and average power loss are also shown.

3.3 Transistor Q1 losses (zoomed)

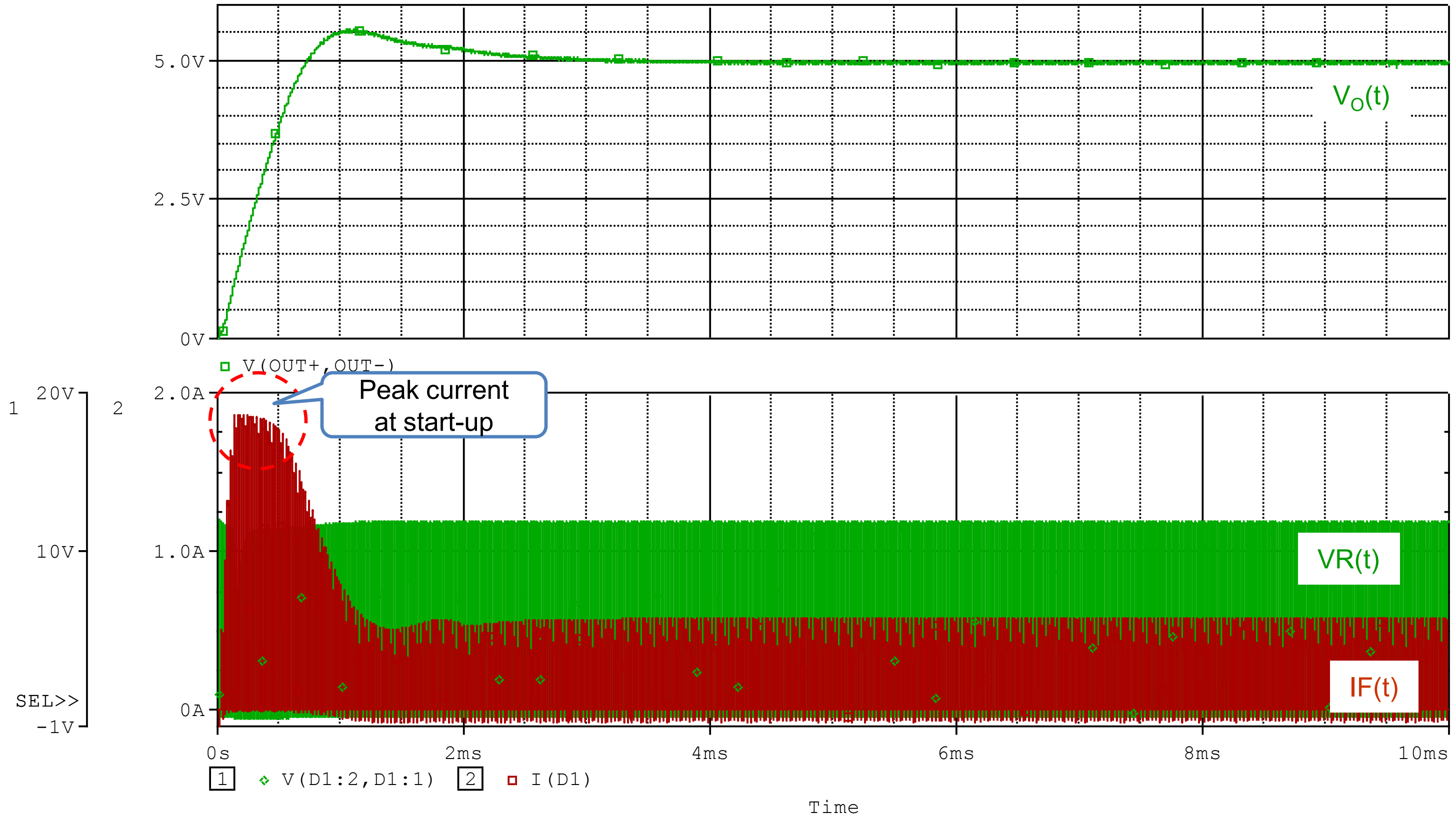


- Simulation results shows the contribute of D1(SBD) recovery time t_{rr} ,that elevate losses in the switch transistor Q1.

4. Freewheeling Diode D1 (SBD)



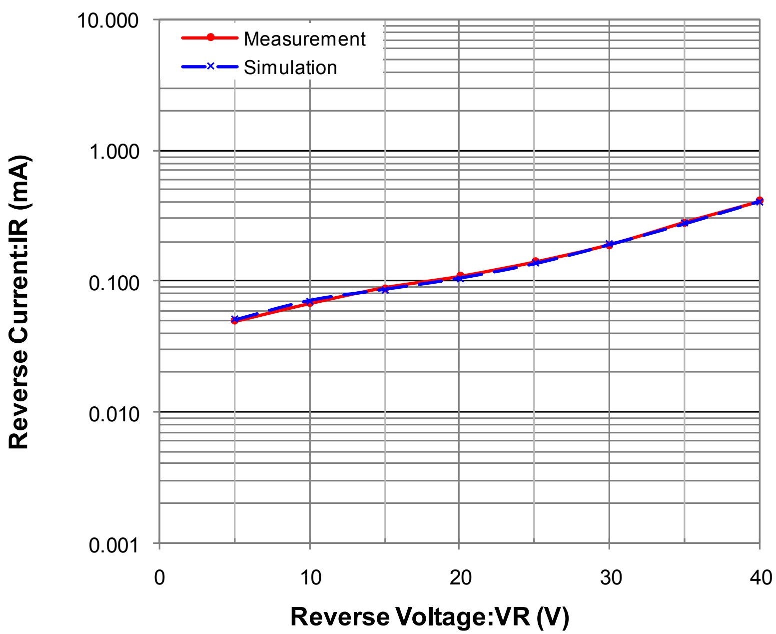
- V_{IN} = 12V
- V_{OUT} = 5V
- RL = 10Ω
- Freewheeling diode D1 is Schottky Barrier Diode (SBD), XBS104V14R (I_{FSM}=20A , V_{RM}=40V) from Torex Semiconductor.



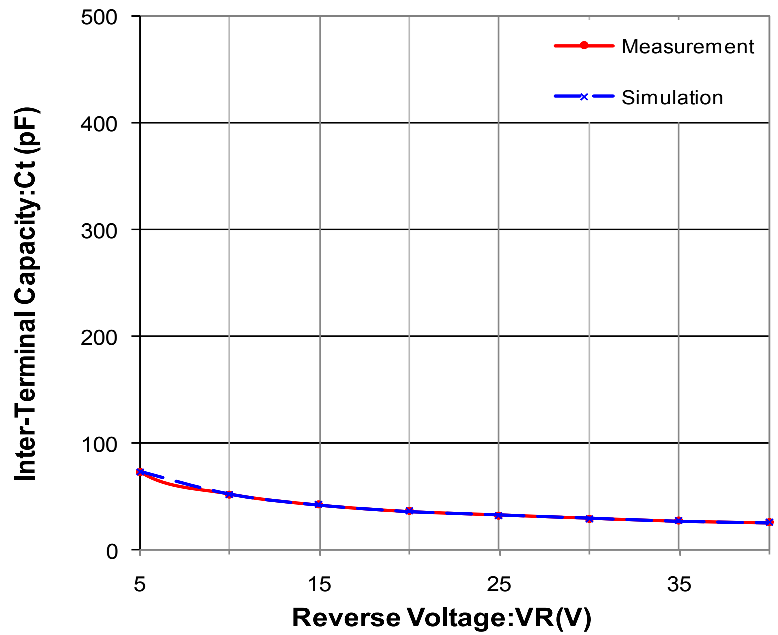
- Simulation result shows the forward peak current at start-up transient. The peak current should not exceed the maximum current rating of shottky barrier diode D1 (XBS104V14R : I_{FSM}=20A , V_{RM}=40V).

4.2 Schottky barrier diode (SBD) characteristics

V_R - I_R characteristics

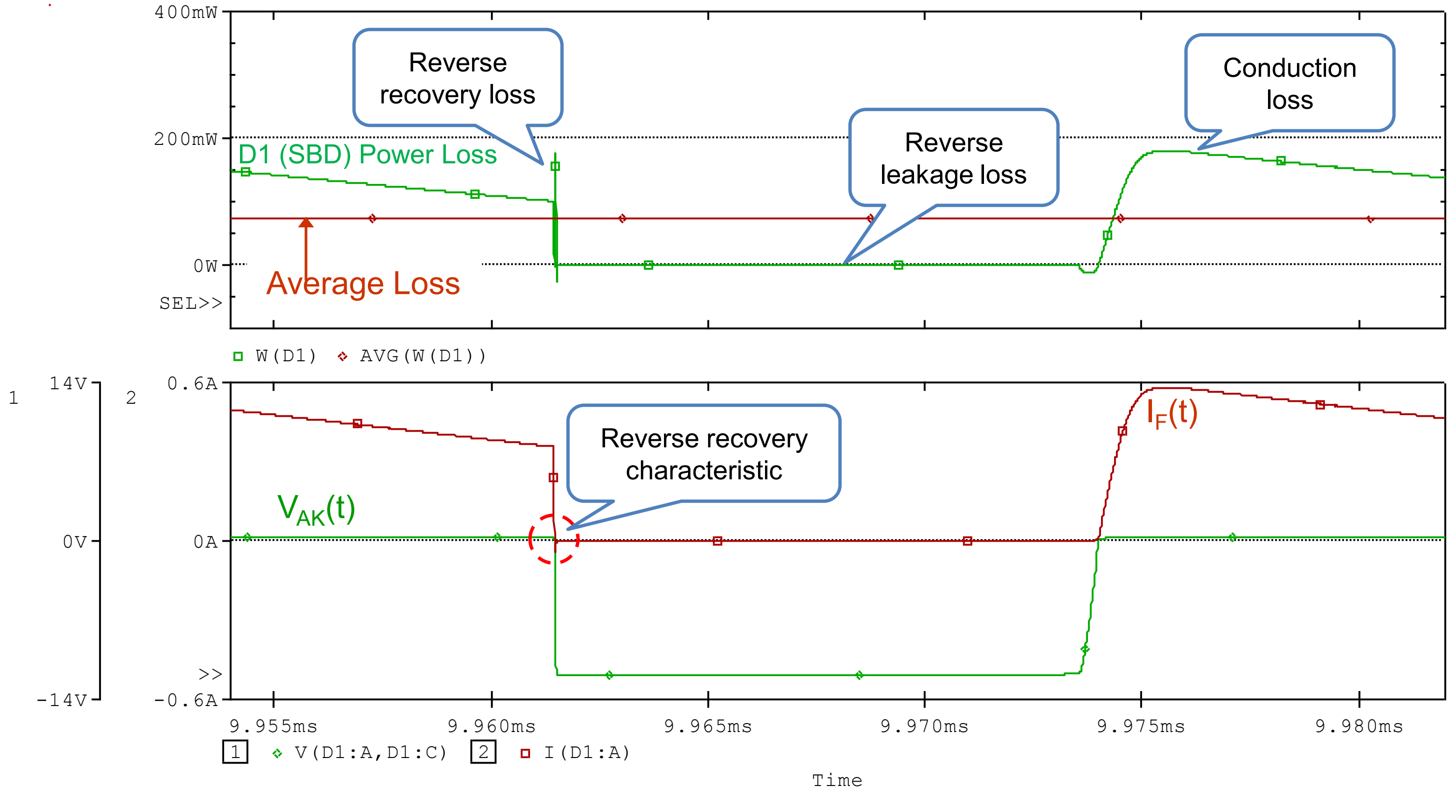


C_T - V_R characteristics



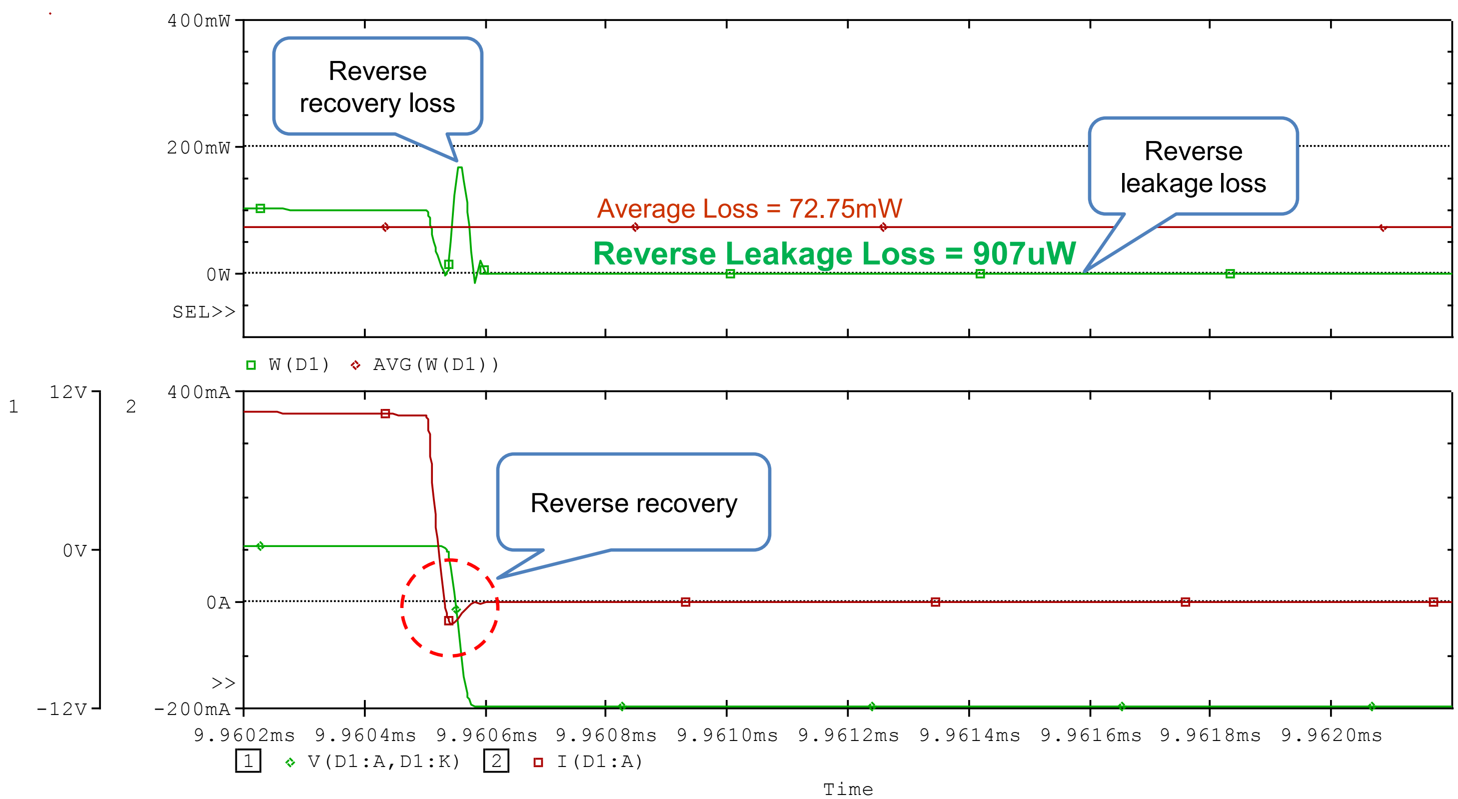
- Losses in D1 depend on the SBD characteristics. Reverse leakage loss is depends on V_R – I_R characteristics and reverse recovery loss is depends on junction capacitance characteristics.
- Graphs show agreement between the simulations and measurements of SBD Professional model.

4.3 Freewheeling diode D1 (SBD) losses



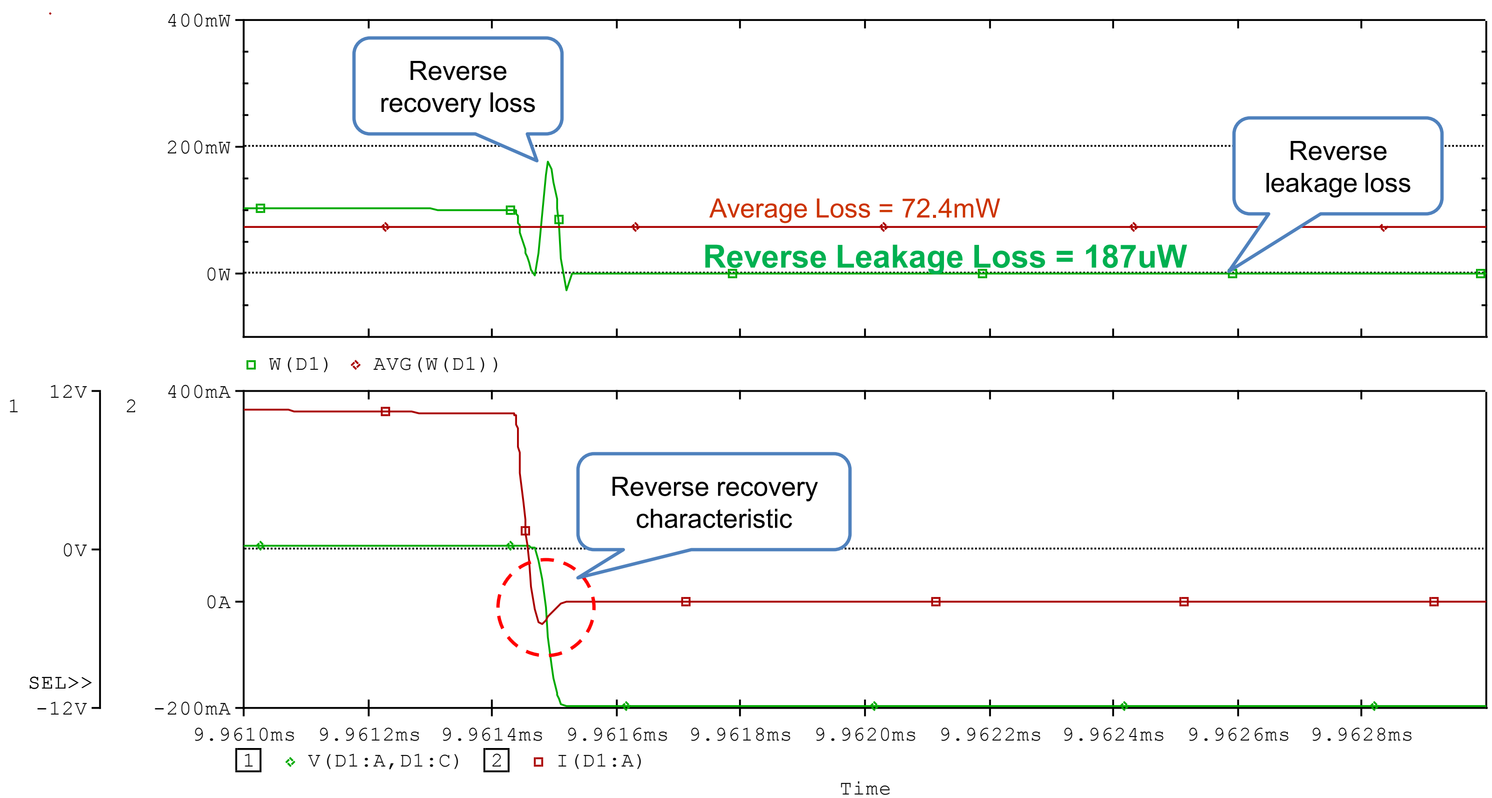
- Simulation results shows waveforms of I_F and V_{AK} of freewheel diode D1 ,which is a Schottky type. Switching power loss and average power loss are also shown.

4.3 Freewheeling diode D1 (SBD) losses (Zoomed)



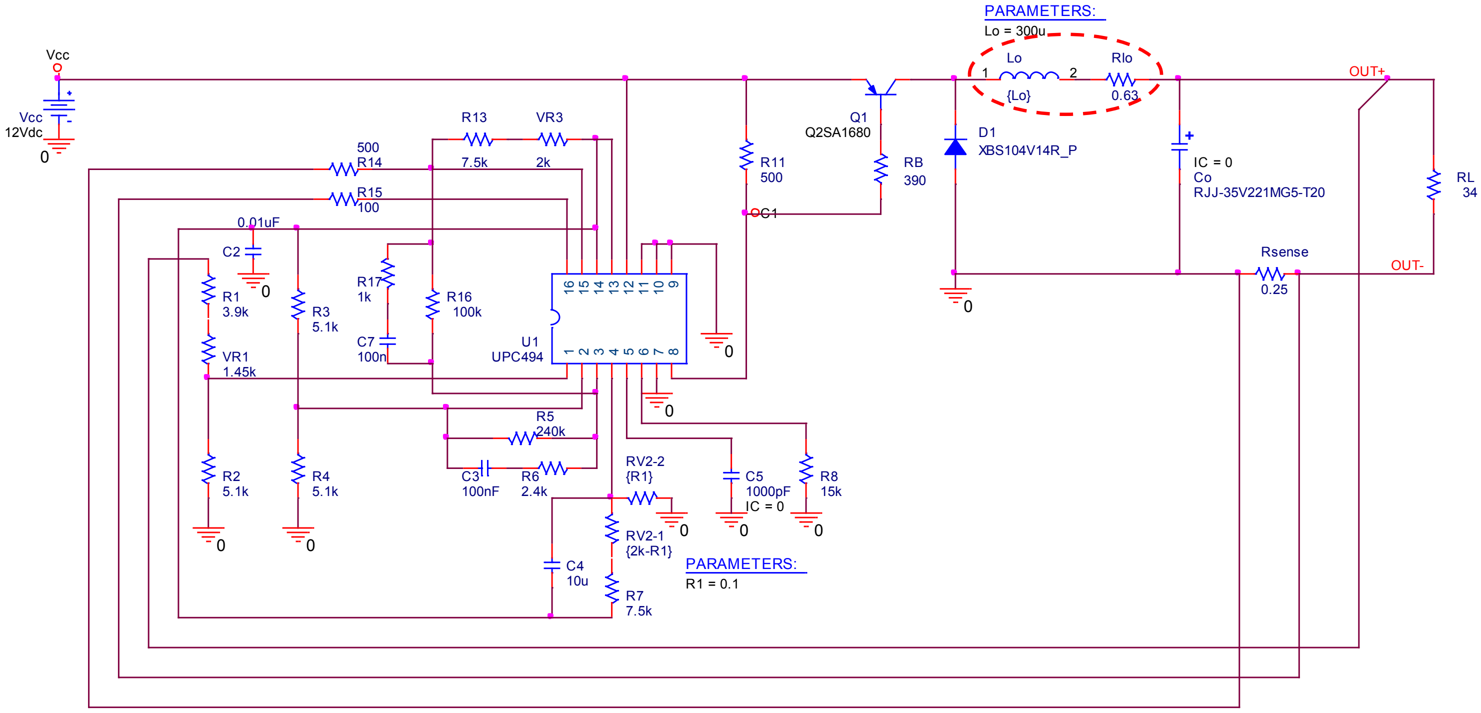
- Simulation results shows the reverse recovery time - t_{rr} of D1.
- Average loss in diode is 72.75mW
- Reverse leakage loss is approximately 907uW.

4.4 Schottky barrier diode Standard model



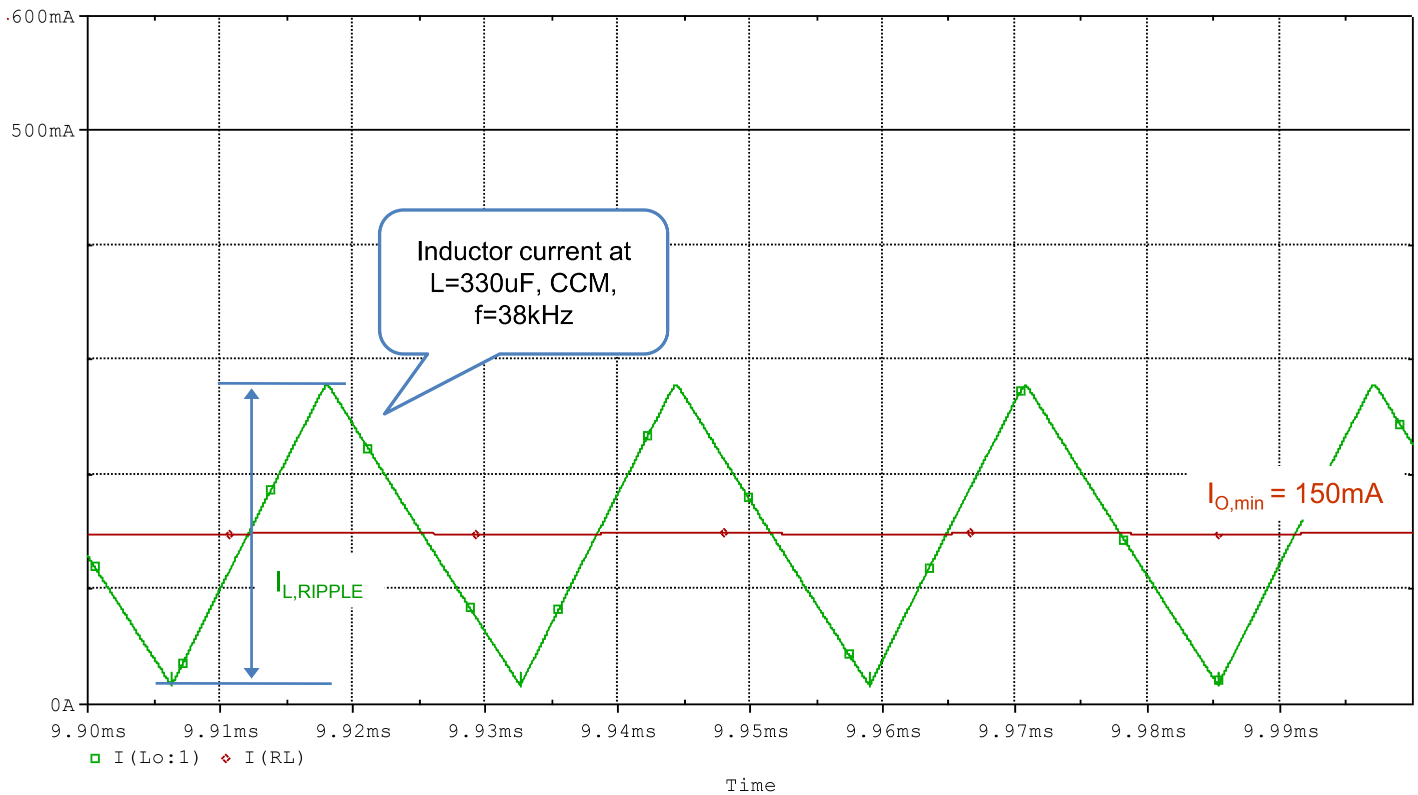
- $V_R - I_R$ characteristics is not included in the Standard model.
- Average loss in diode is 72.4mW (the Professional model result is 72.75mW)
- Reverse leakage loss is approximately 187uW (the Professional model result is 907uW).

5. Output Inductor Value



- V_{IN} = 12V
- V_{OUT} = 5V
- RL=34Ω ($I_{OUT} \approx$ 0.15A)
- Output inductor value Lo are 150uH and 300uH (Parametric sweep)

5. Output Inductor Value



- Simulation results shows the inductor current compare to minimum load current. If $0.5*I_{L,RIPPLE}$ is less than $I_{O,min}$, the inductor will operate in the “continuous” operating mode (CCM)

5. Output Inductor Value

The output inductor value is selected to set the ripple current. The too small value leads to larger ripple current that will lead to more output ripple voltage due to the output capacitor ESR.

The inductor value is calculate by.

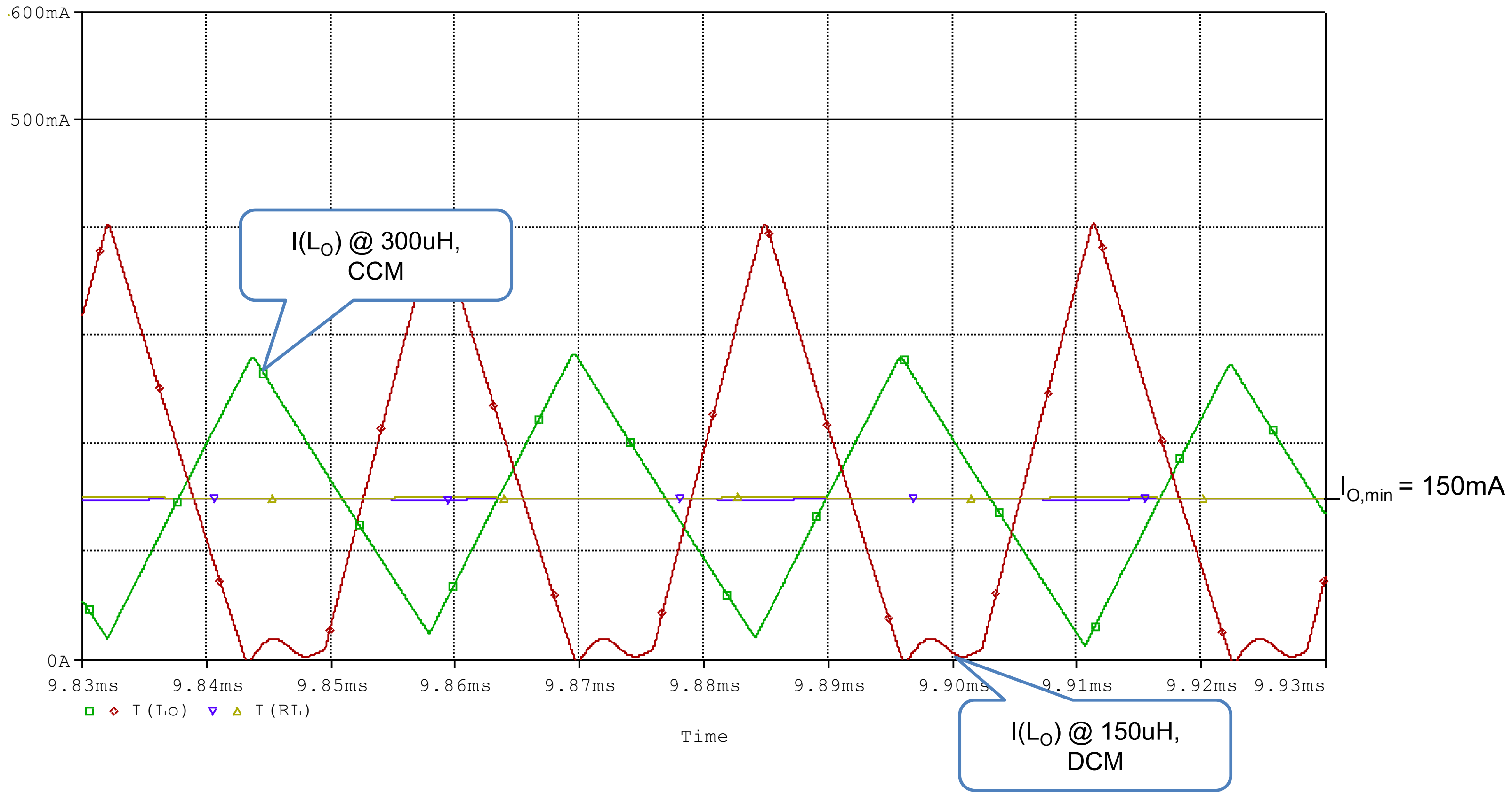
$$L_{CCM} \geq \frac{(V_I - V_O) \times R_L}{2 f V_I} \qquad (3)$$

Where

- L_{CCM} is output inductance that converter at load R_L still working in CCM.
- R_L is load resistance at the minimum output current, $R_L = V_O / I_{O,min}$
- f is switching frequency

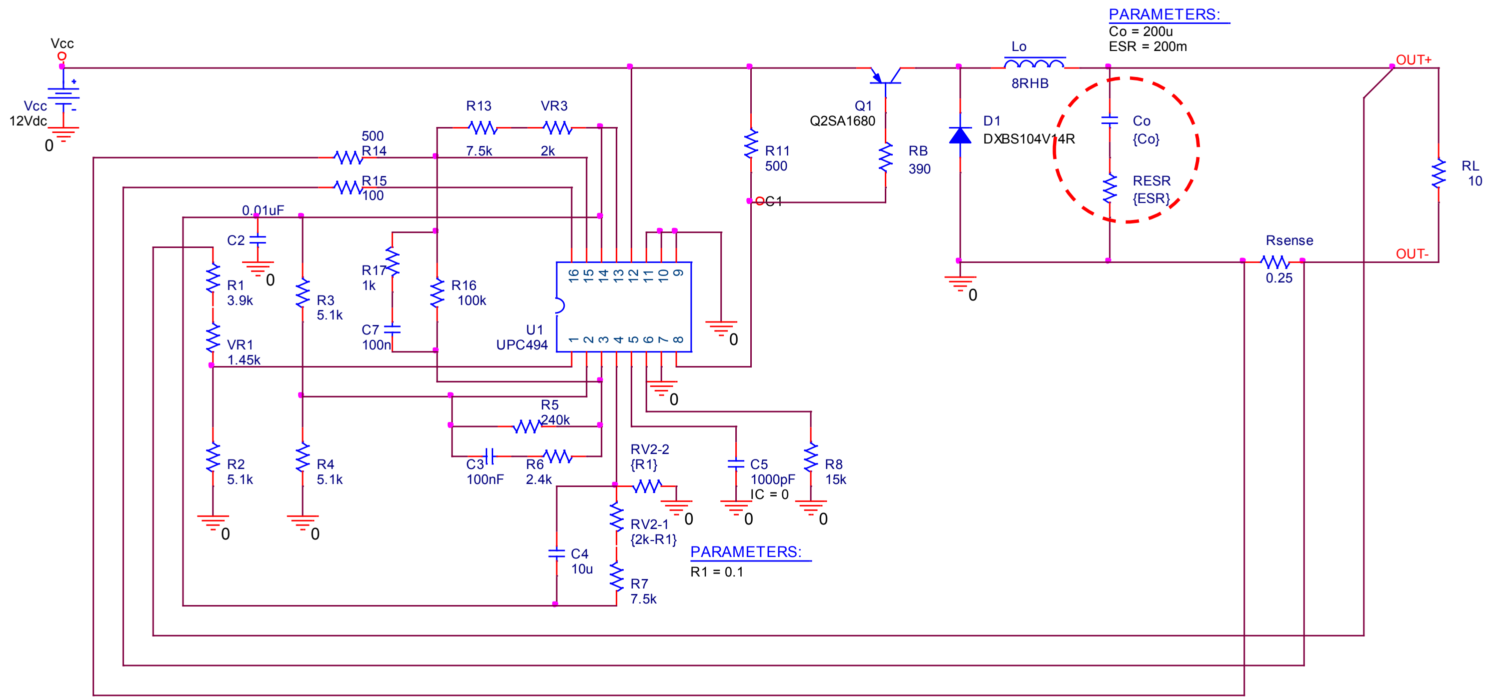
Which the $I_{O,min}$ is 150mA and V_O is 5V, R_L is approximately 34Ω. At V_{IN}=12V and f=38kHz ,this equation calls for $L \geq$ 261uH.

5. Output Inductor Value



- Simulation results shows that the inductor will operates in the “discontinuous” operating mode (DCM), If reduce the inductance value to 150uH.

6. Output Capacitor



- V_{IN} = 12V
- V_{OUT} = 5V
- RL=10Ω
- Output capacitor value Co are 100uF and 200uF (Parametric sweep)

6. Output Capacitor

The minimum output capacitor is determined by the amount of inductor ripple current, and can be calculated by the equation:

$$C_{O,\min} \geq \frac{I_{L,RIPPLE}}{8 \times f \times V_{O,RIIPLE}} \qquad (4)$$

Where

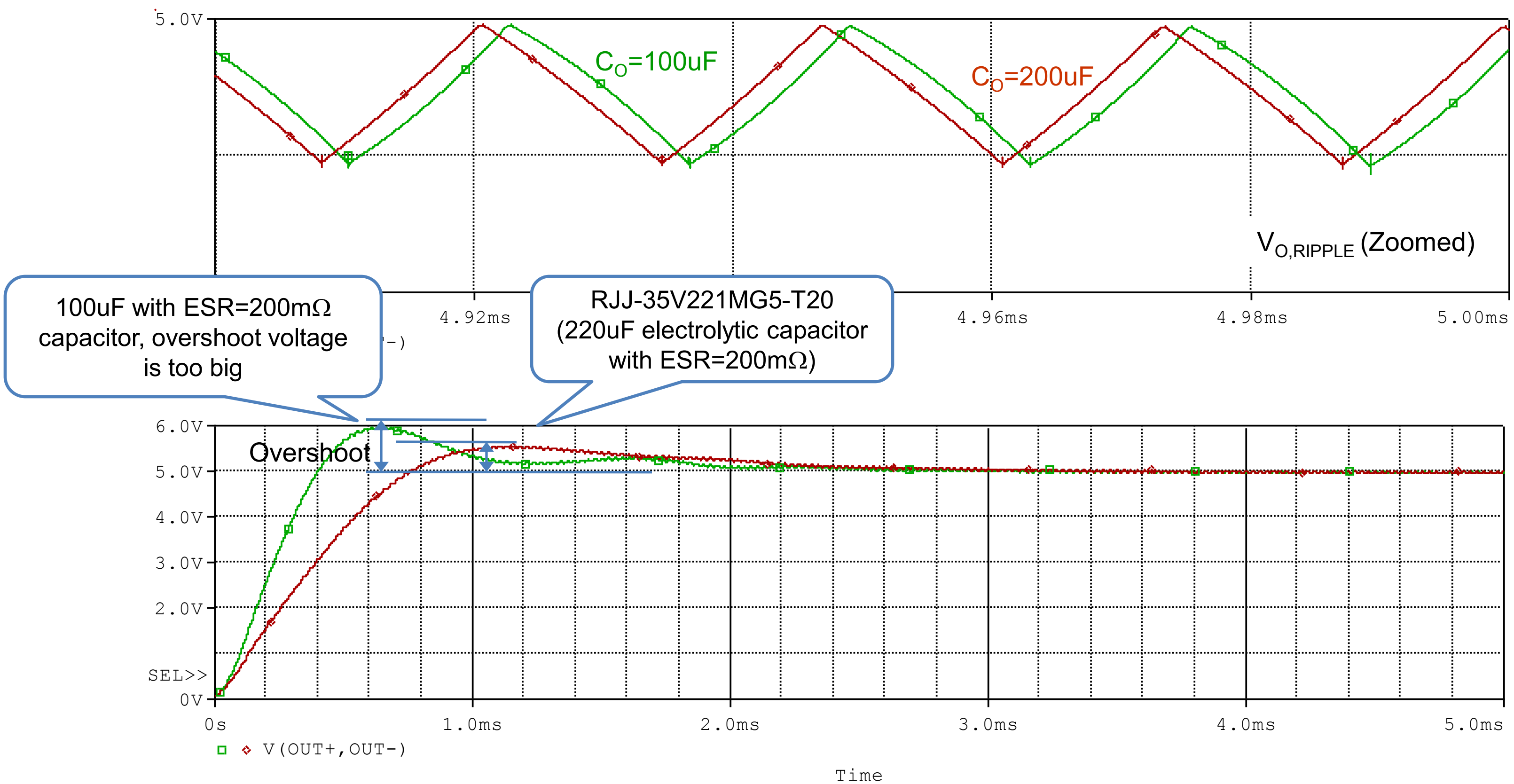
- $I_{L,RIPPLE}$ is an inductor ripple current.
- $V_{O,RIPPLE}$ is an output ripple voltage.
- f is switching frequency

In addition, the voltage component due to the capacitor ESR must be considered, as shown in equation (5).

$$R_{ESR} \leq \frac{V_{O,RIIPLE}}{I_{L,RIPPLE}} \qquad (5)$$

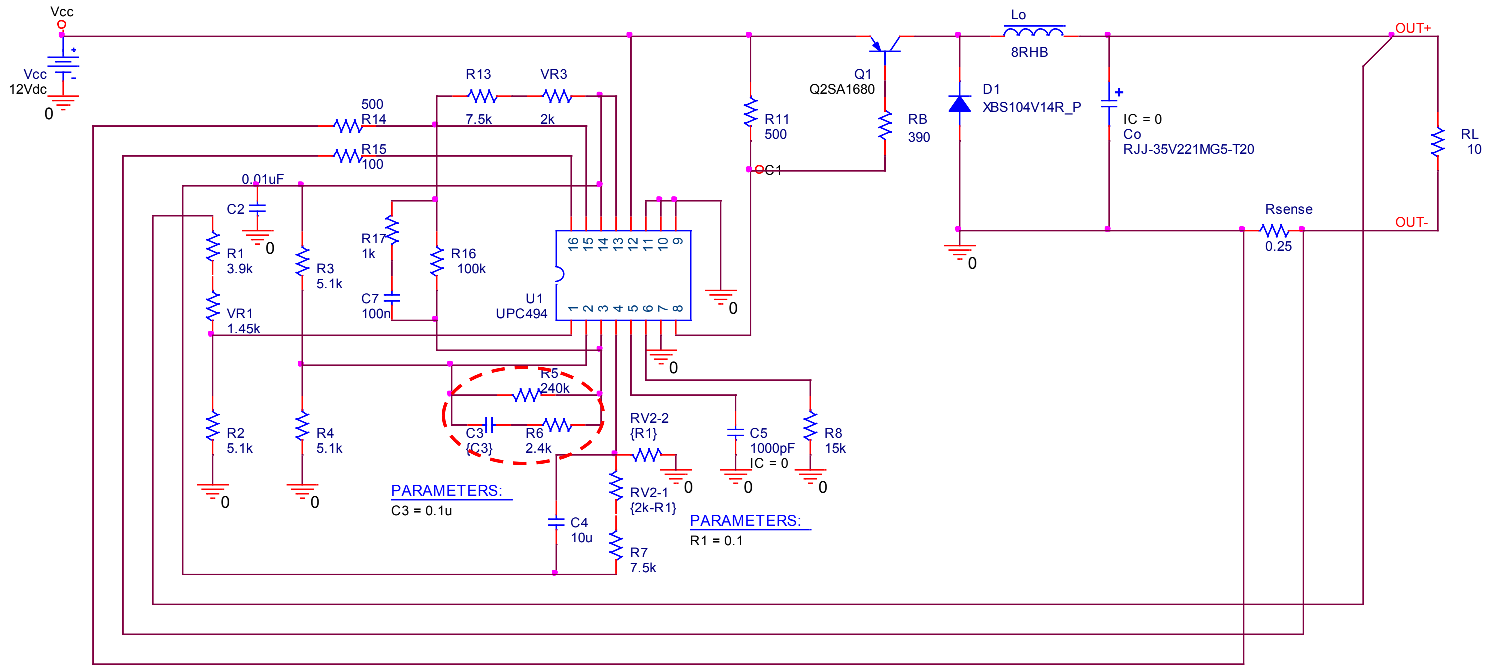
- $R_{ESR} < V_{RIPPLE} / I_{L,RIPPLE}$, At V_{RIPPLE} =50mV and $I_{L,RIPPLE}$ =250mA , this equation calls for R_{ESR} value less than 200mΩ.

6. Output Capacitor



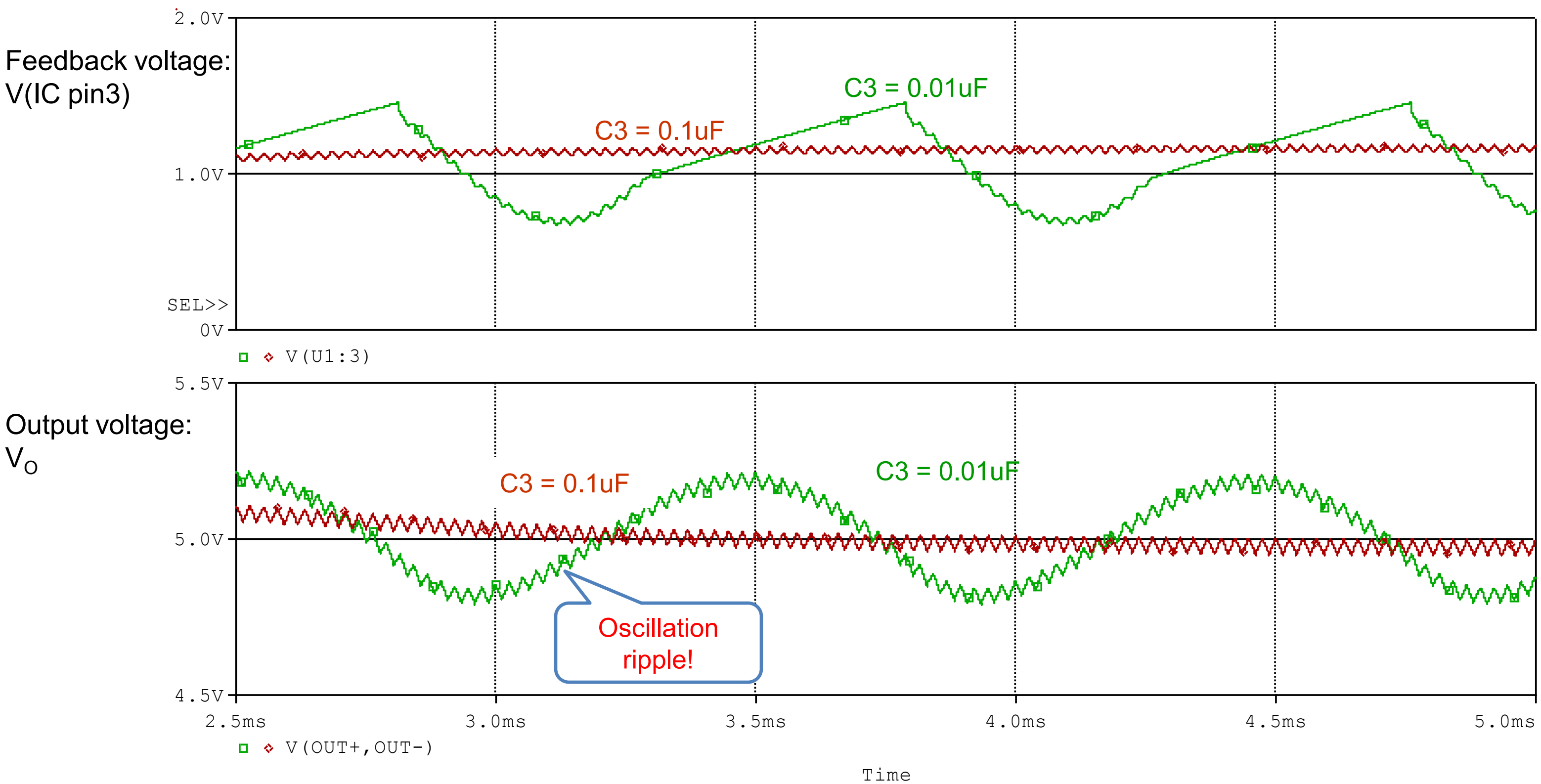
- Overshoot voltage transient is also considered for output capacitor selection,

7. Voltage Control Feedback Loop



- V_{IN} = 12V
- V_{OUT} = 5V
- RL=10Ω
- Capacitor C3 value are 0.01uF and 0.1uF (Parametric sweep)

7. Voltage Control Feedback Loop



- Simulation result shows the oscillation ripple that given from the feed back loop with C3=0.01uF. This circuit calls for C3 more than 0.01uF to avoid oscillation, C3=0.1uF is selected.

Simulation Index

Simulations	Folder name
1. Transient simulation (@ VIN=12V, RL=10Ω)...................................	Transient
2. Efficiency (@ V_{IN}=12V, R_L=10Ω)..	Efficiency
3. Step-load response (@ V_{IN}=12V, I_{OUT}=250mA / 500mA)..................	Step-load
4. Power switch devices losses (Q1 and D1)..	Losses
5. Output inductor..	Lout
6. Output capacitor..	Cout
7. Voltage control feedback loop..	Feedback