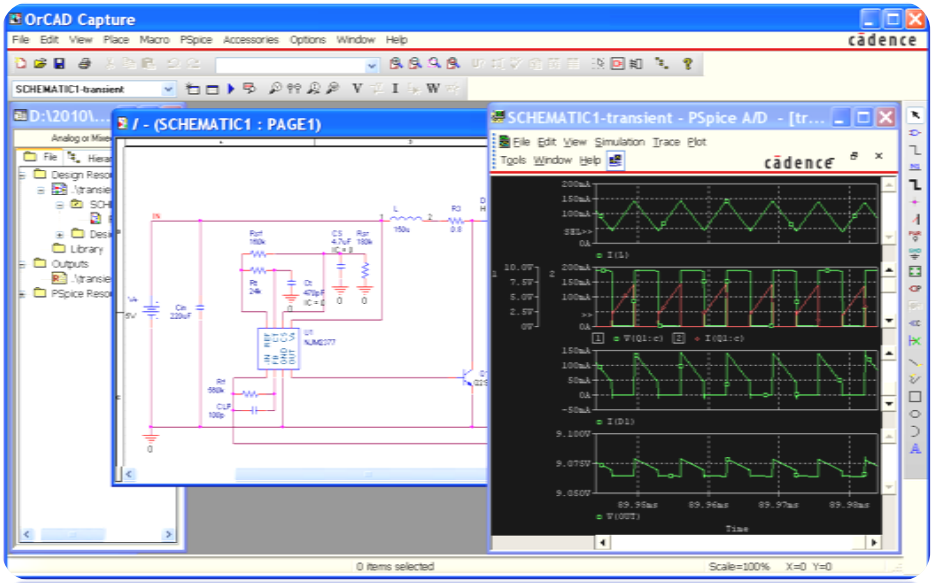


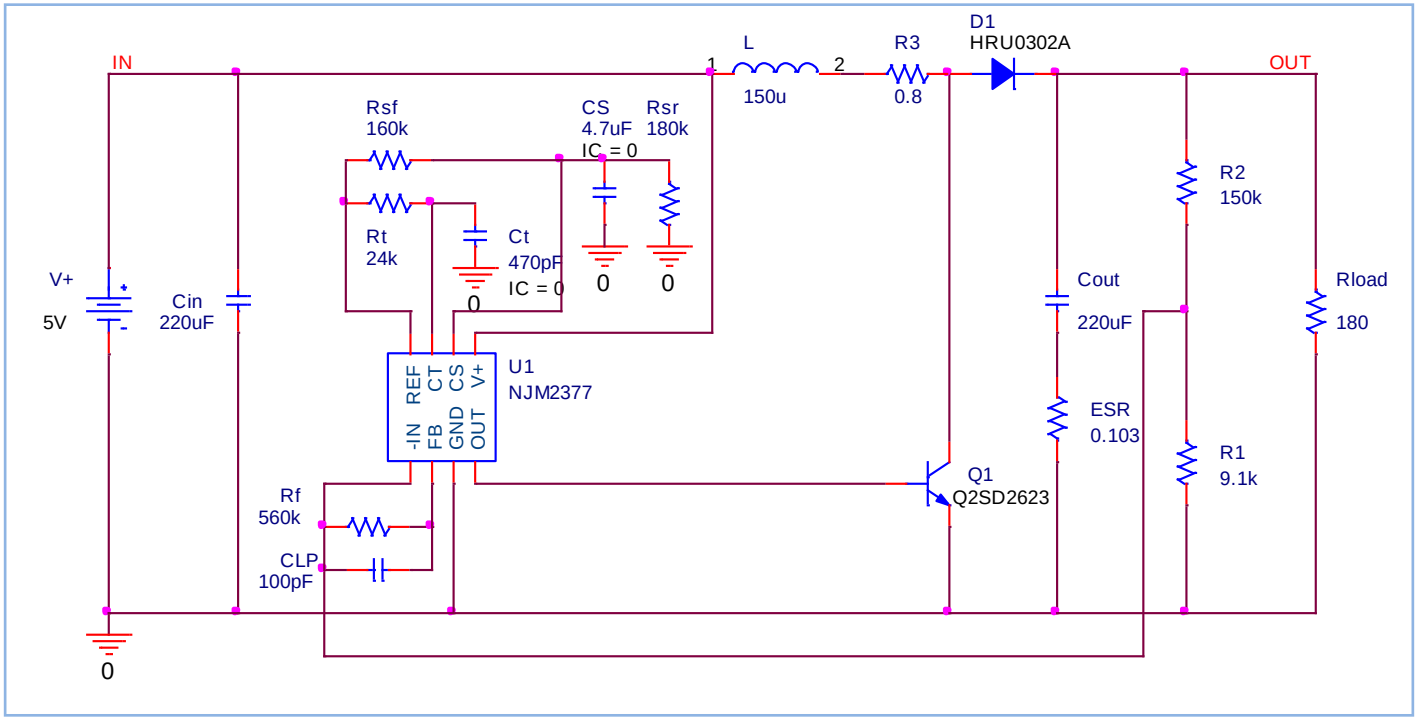
Design Kit

NJM2377–Boost DC/DC Converter

Contents

1. NJM2377 – Boost DC/DC Converter Circuit

5V to 9V at 50mA Boost DC/DC Converter (f_{OSC}=150kHz, V_{ripple}=30mV_{p-p})

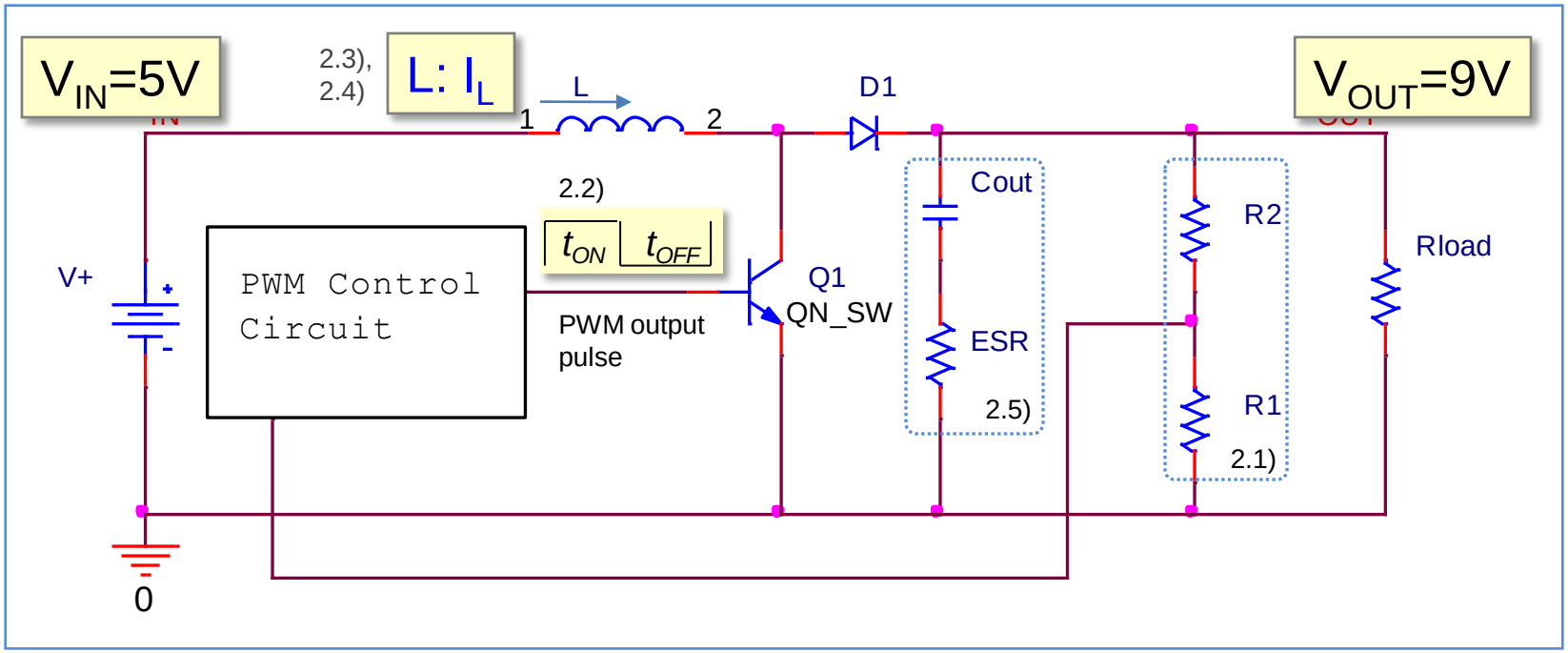


U1: New Japan Radio NJM2377 Control IC

Q1: Panasonic 2SD2623 NPN

D1: Renesas HRU0302A Schottky Barrier Diode

2. PWM – Boost DC/DC Converter Basic Operation and Design



- V_{OUT} is monitored by R_1 and R_2 then compared to reference voltage V_B in NJM2377.
- Error voltage is pulse width modulated with sawtooth waveform.
- PWM output pulse width is proportional to the error level. This signal will control the switch ON/OFF(t_{ON} /t_{OFF}).
- Therefore V_{OUT}, which is proportional to t_{ON} /t_{OFF}, is controlled to the desired voltage.

2.1 Boost DC/DC Converter – V_{OUT}

- V_{OUT} is determined by R1 and R2, without considering I(IN-) of NJM2377 V_{OUT} is calculated as below.

$$V_{OUT} = \left(\frac{R2}{R1} + 1 \right) \times V_{REF}$$

$$= \left(\frac{150\text{k}}{9.1\text{k}} + 1 \right) \times 0.52 = 9.09\text{V}$$

- For V_{OUT}=9V, R1=9.1kΩ, R2=150kΩ are selected.

2.2 Boost DC/DC Converter – t_{ON} /t_{OFF}

- If the circuit works in continuous conduction mode (CCM), output voltage (V_{OUT}) and ON/OFF time (t_{ON} /t_{OFF}) follow the equation below.

$$V_{OUT} = \left(\frac{t_{ON} + t_{OFF}}{t_{OFF}} \right) \times V_{IN}$$

then

$$t_{ON} = \frac{V_{OUT} - V_{IN}}{V_{OUT} \times f_{OSC}}$$

- From V_{IN} =5V, V_{OUT} =9V and f_{OSC} =150kHz, these result as t_{ON} /t_{OFF} are t_{ON}=2.96µs, t_{OFF}=3.71µs, and duty=45%.

2.3 Boost DC/DC Converter – Inductor Selection

- L_{MIN} value for the convertor to work in continuous conduction mode (CCM), is calculated as below.

$$L_{MIN} = \frac{V_{IN}^{\,2}}{2 \times V_{OUT} \times I_{OUT}} \times t_{ON}$$

- From V_{IN} =5V, V_{OUT} =9V, I_{OUT} =50mA and t_{ON}=2.96μs, these result as L_{MIN}=82.2μH.

$$L_{MIN} < L < 2 \times L_{MIN}$$

- A larger value will be used to increase the available output current, but limit it to around twice the L_{MIN} value. L =150μH is selected.

2.4 Boost DC/DC Converter – Inductor Peak Current

- $I_{L,\,PK}$ is calculated as below.

$$I_{L,PK} = \frac{V_{OUT} \times I_{OUT}}{V_{IN}} + \frac{V_{IN}}{2 \times L} \times t_{ON}$$

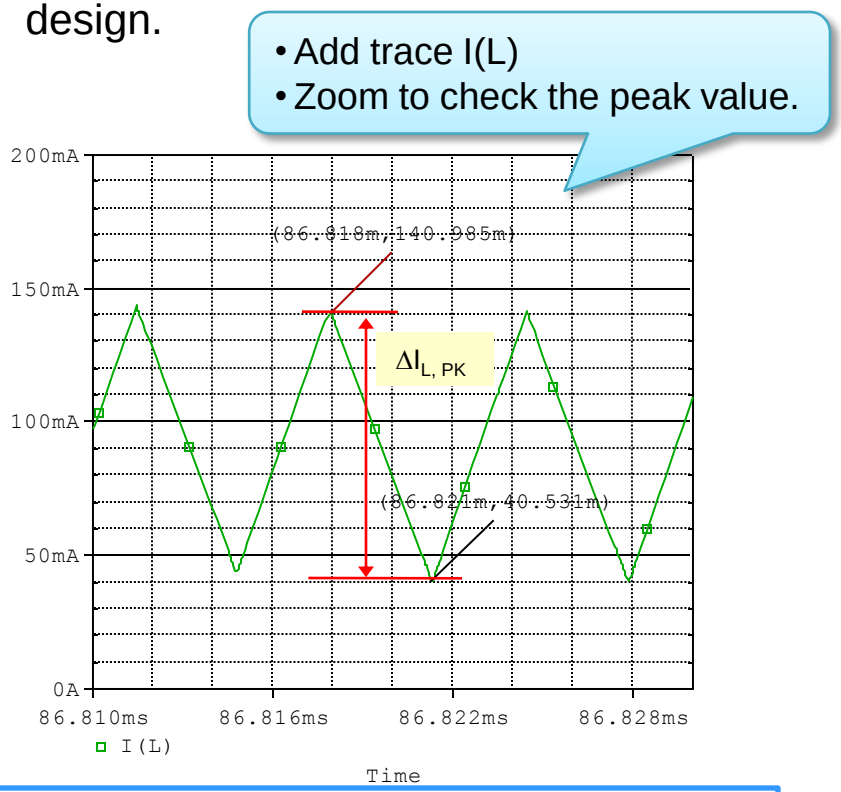
$$= \frac{9 \times 0.05}{5} + \frac{5}{2 \times 150\mu} \times 2.96\mu = 140\text{mA}$$

- And the current ripple - $\Delta I_{L,\,PK}$ is calculated as below

$$\Delta I_{L,PK} = \frac{V_{IN}}{L} \times t_{ON}$$

$$= \frac{5}{150\mu} \times 2.96\mu = 99\text{mA}$$

- PSpice is used to verify the circuit design.



- $I_{L,\,PK}$=140.985mA and $\Delta I_{L,PK}$=140.985m-40.531m=100.454mA

2.5 Boost DC/DC Converter – C_{OUT} Selection

- C_{OUT} is determined from the V_{ripple} Spec ($30mV_{p-p}$).
- If $C_{OUT} >> I_{OUT} \cdot ton/V_{ripple}$ ($50m \cdot 2.96\mu/30m=4.933\mu F$), V_{ripple} will mainly caused by ESR.

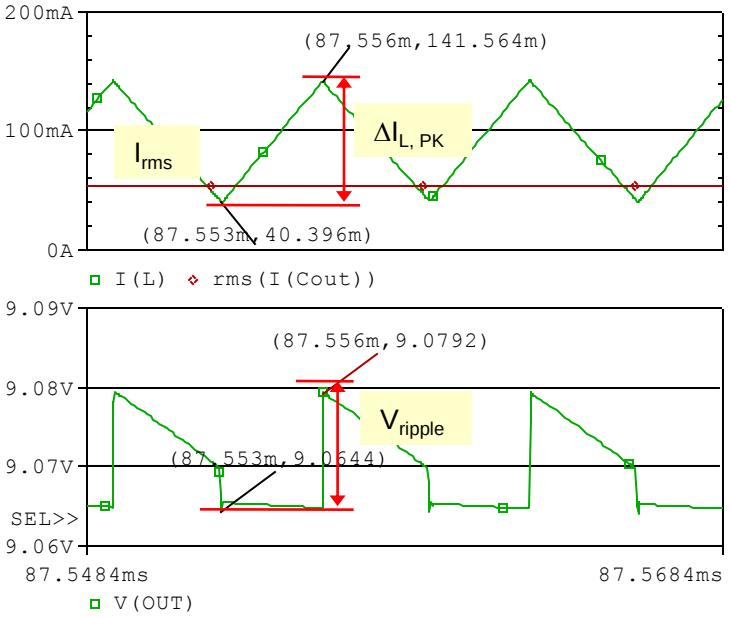
$$ESR < \frac{V_{ripple\,(p-p)}}{\Delta I_L} = \frac{30m}{99m} = 103m\Omega$$

- Select the capacitor that can handle the ripple current I_{rms}.

$$I_{rms} = \frac{\Delta I_L}{2\sqrt{3}} \times \frac{ton}{t} = \frac{99m}{2\sqrt{3}} \times \frac{2.96\mu}{6.67\mu} = 13mArms$$

- C_{OUT}=220μF, ESR=103mΩ is selected.

- PSpice is used to verify the circuit design.

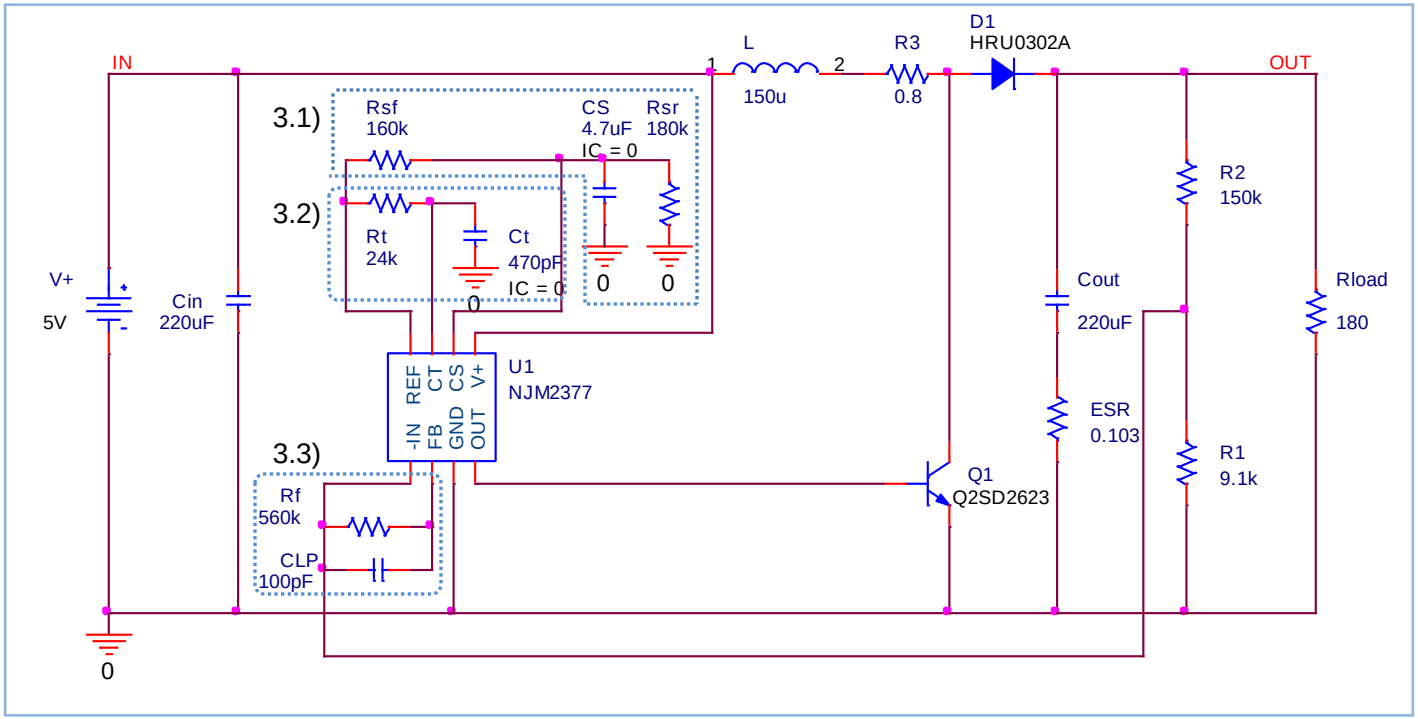


- $\Delta I_{L,PK}$=101.168mA, ton=3μs.
- V_{ripple} =14.8mV_{p-p}
- I_{rms}*=53.856mArms.

※ Irms is larger than calculated value due to feedback loop response ripple current.

3. NJM2377 – Application Circuit Configuration

5V to 9V at 50mA Boost DC/DC Converter (f_{OSC}=150kHz)



U1: New Japan Radio NJM2377 Control IC

Q1: Panasonic 2SD2623 NPN

D1: Renesas HRU0302A Schottky Barrier Diode

3.1 NJM2377 – Soft Start Time Setting

NJM2377 soft-start time is determined by Rsr, CS and Rsf

- First, caculate Rsr by $Rsr > V_{THLA}(max.)/I_{CHG}(min.)$ (1.8V/10μA=180kΩ)
- During steady state operation, I(CS)=I_{BCS}=250ns. Maximum duty cycle is determined by V(CS). Set V(CS)=$V_{THCS(max.)}$=0.8V, Rsf is calculated by

$$V_{THCS\,(max.)} = \frac{Rsr}{Rsr + Rsf} \times V_{REF}$$

$$0.8 = \frac{180k}{180k + Rsf} \times 1.5$$

$$Rsf = 160k\Omega$$

- Soft-start time or $t_{duty(max.)}$ is time needed for V(CS) to reach $V_{THCS(max.)}$ by charging capacitor Cs.
- CS is charged by current Ics, calculated by:

$$I_{CS} = \frac{V_{REF}}{Rsr + Rsf}$$

$$= \frac{1.5}{180k + 160k} = 4.41uA$$

then

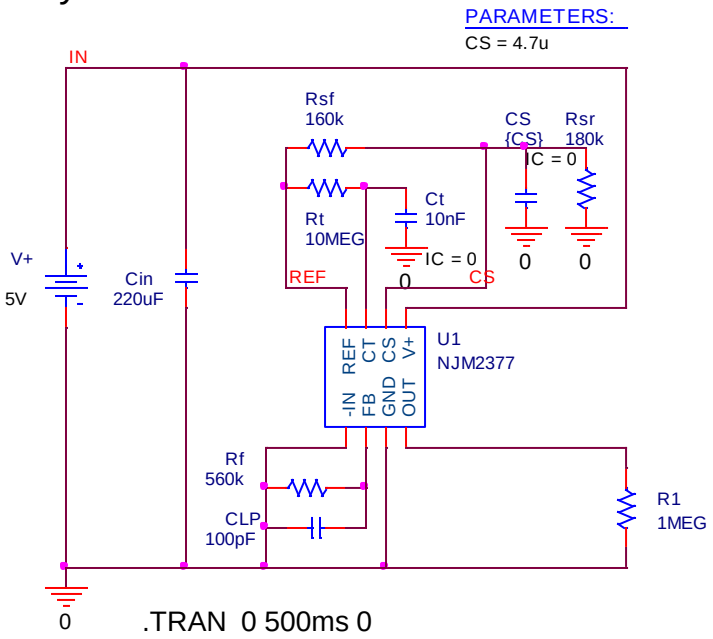
$$t_{duty\,(max.)} = \frac{V_{THCS\,(max.)} \times Cs}{I_{CS} + I_{CHG}}$$

$$= \frac{0.8 \times 4.7\mu}{4.41\mu + 30\mu} = 109ms$$

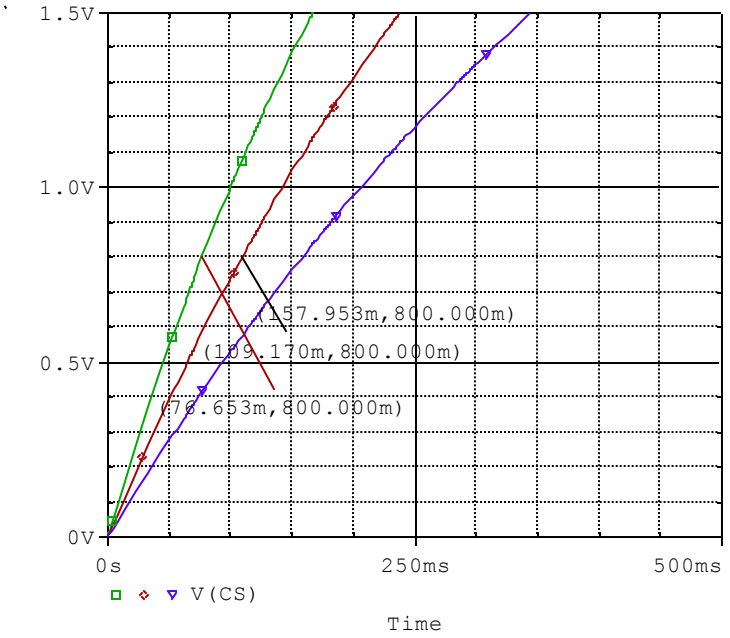
3.1 NJM2377 – Soft Start Time Setting (Simulation)

NJM2377 soft-start time is determined by Rsr, Rsf and CS

- Select Rsr, Rsf, and CS then check $t_{duty(max.)}$ by simulation.



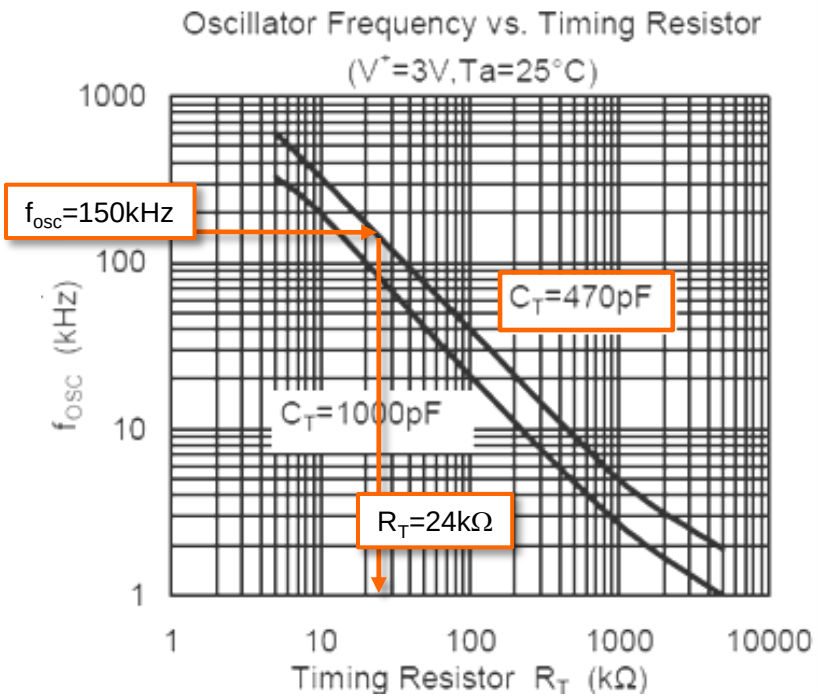
- $t_{duty(max.)}$=109.170ms. for CS=4.7uF

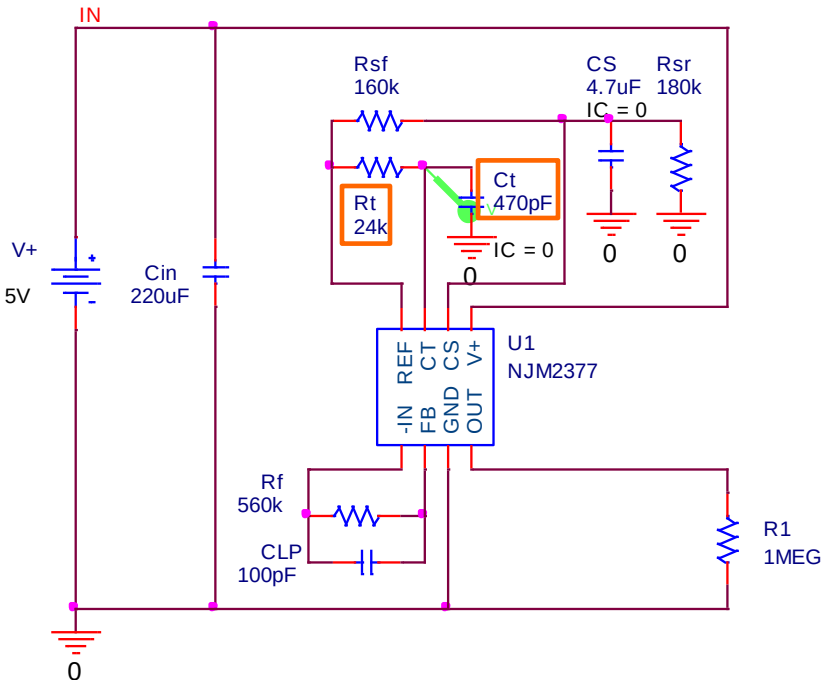


- $t_{duty(max.)}$=76.653ms for CS=3.3uF and $t_{duty(max.)}$=157.953ms for CS=6.8uF.

3.2 NJM2377 – Oscillation Frequency Setting

NJM2377 oscillation frequency f_{OSC} is determined by C_T and R_T





- CT = 470pF and RT = 24kΩ to set an oscillation frequency to be 150kHz.

3.3 Error Amp Feed Back Loop Setting

Error Amp Feed Back Loop is determined by R1, R2, Rf and CLP

- For F.B loop gain G > 100, Rf is calculated as:

$$G = \frac{Rf}{R1 // R2}$$

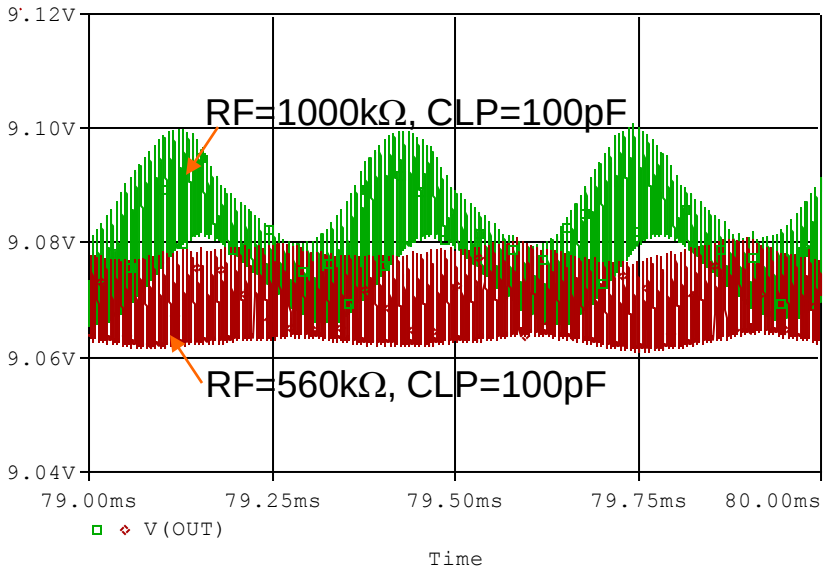
$$= \frac{1{,}000k}{150k // 9.1k} = 177$$

$$Rf = 1000k$$

- CLP is suggested to use value between 100pF~1,000pF

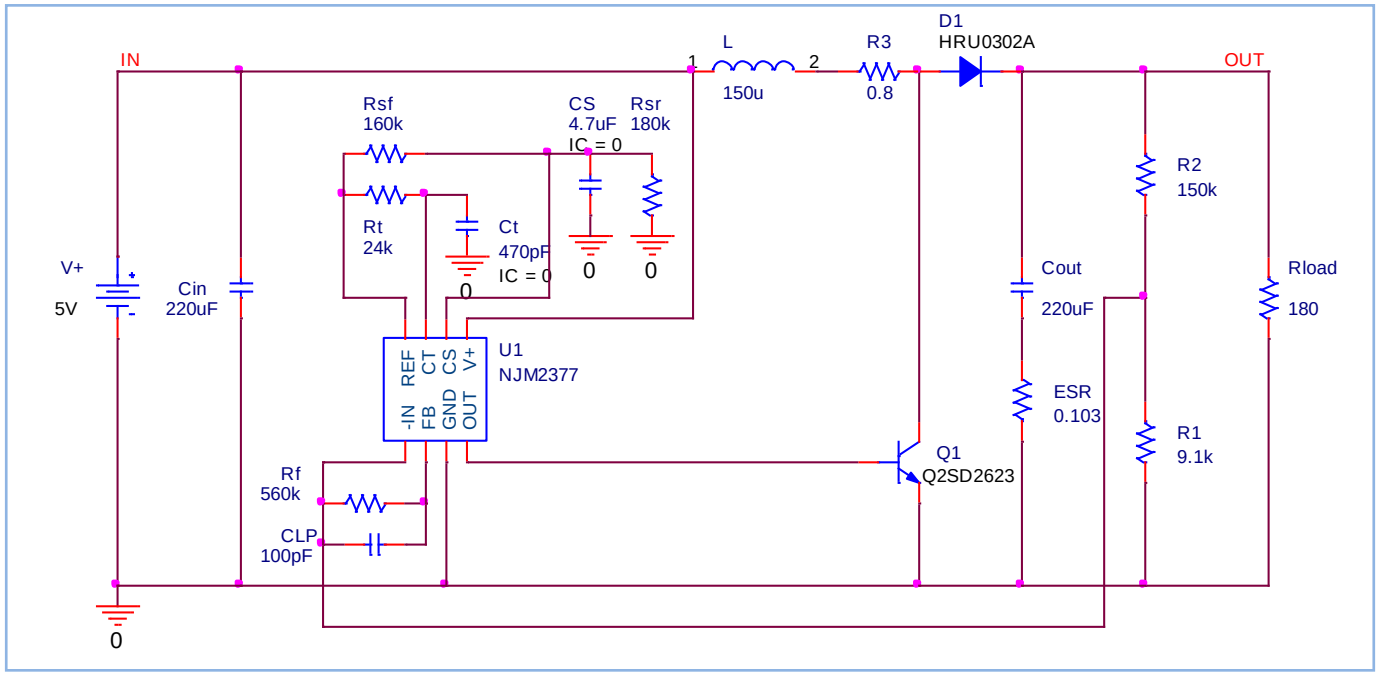
- Inappropriate F.B loop design can cause an oscillation. PSpice is used to verify the ripple voltage vs. Rf and CLP values.

- Simulation result shows V_{ripple} of the circuit with RF=1000k Ω compare to the circuit with RF=560kΩ.



- Changing RF to be 560k Ω can reduce V_{ripple} from 34mV_{p-p} to less than 20mV_{p-p}.

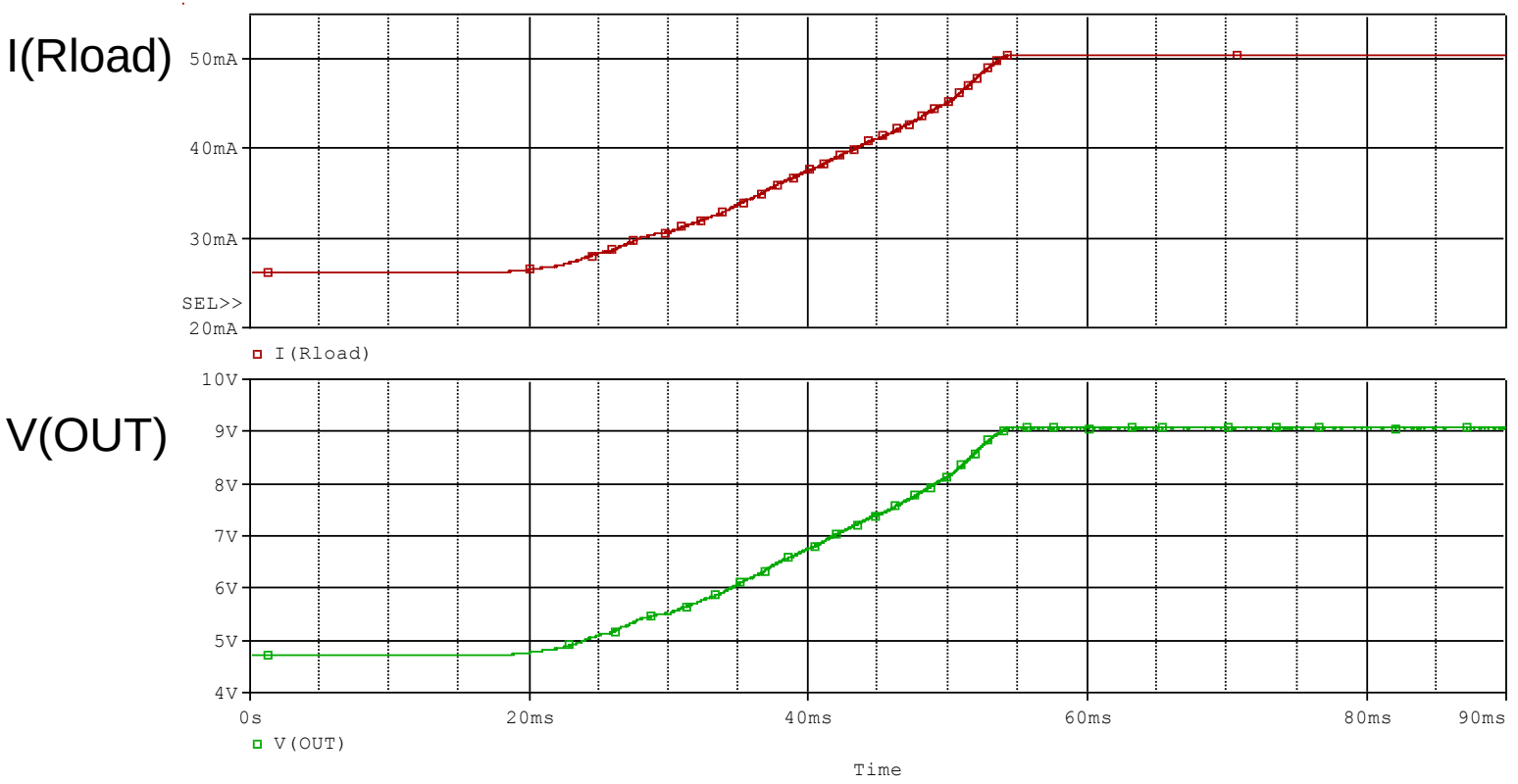
4. Performance Characteristics



- V_{IN}=5V
- V_{OUT}=9V
- I_{OUT}=50mA
- $V_{ripple(P-P)}$= less than 30mV
- Efficiency= 75% at I_{OUT}=50mA

U1: New Japan Radio NJM2377 Control IC
Q1: Panasonic 2SD2623 NPN
D1: Renesas HRU0302A Schottky Barrier Diode

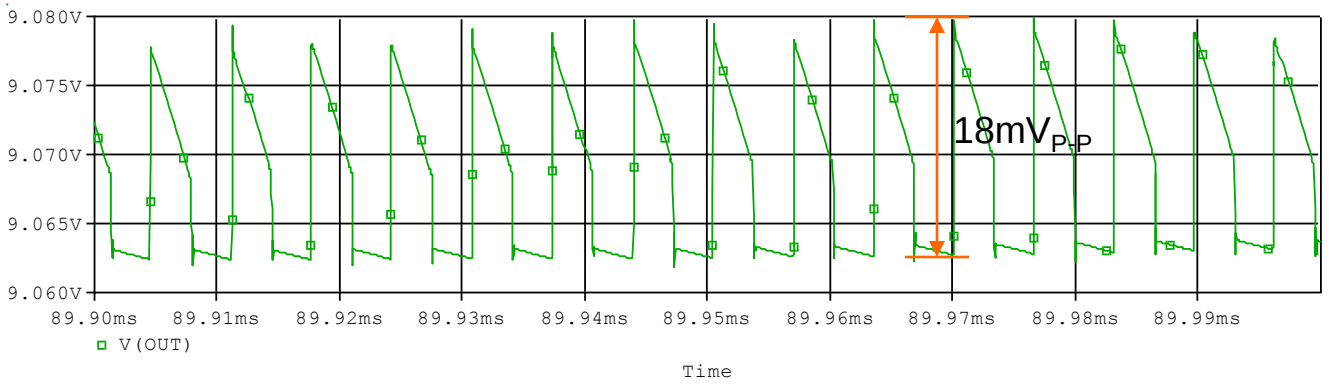
4.1 Output Start-Up Voltage and Current



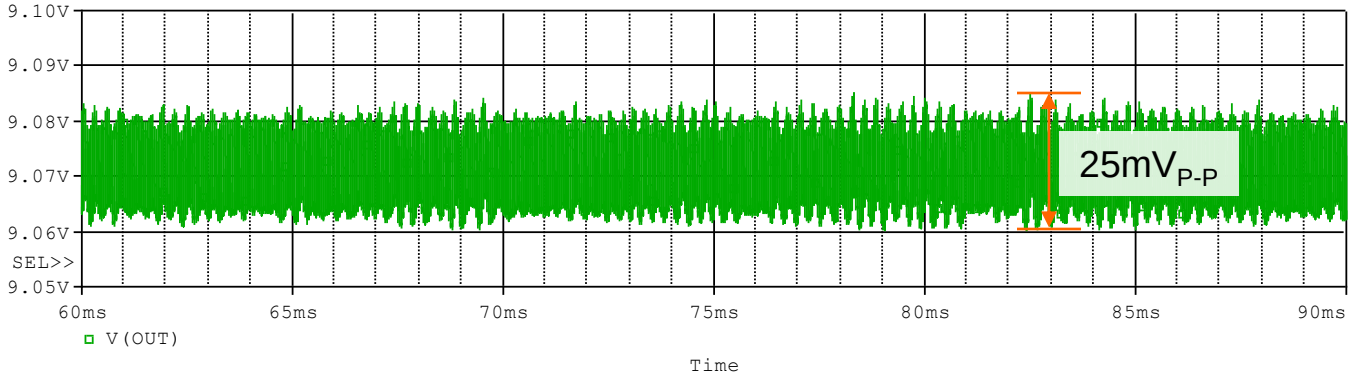
- Simulation result shows output start-up time of the circuit. This circuit needs 55ms to reach steady state.

4.2 Output Ripple Voltage

V(OUT) [ZOOM]

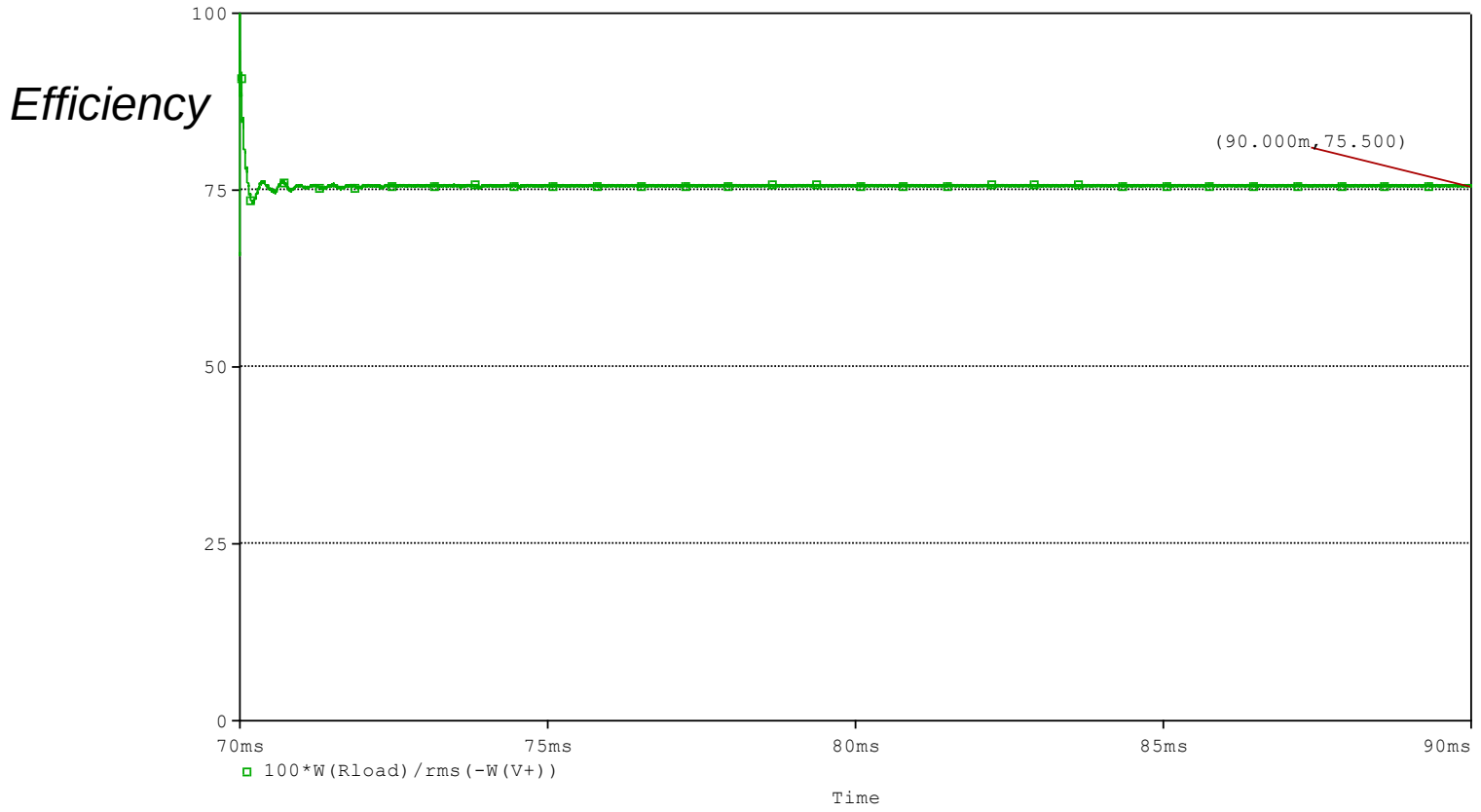


V(OUT)



- Simulation result shows output ripple voltage caused by switching(18mV$_{P-P}$) and F.B loop oscillation(25mV$_{P-P}$).

4.3 Efficiency



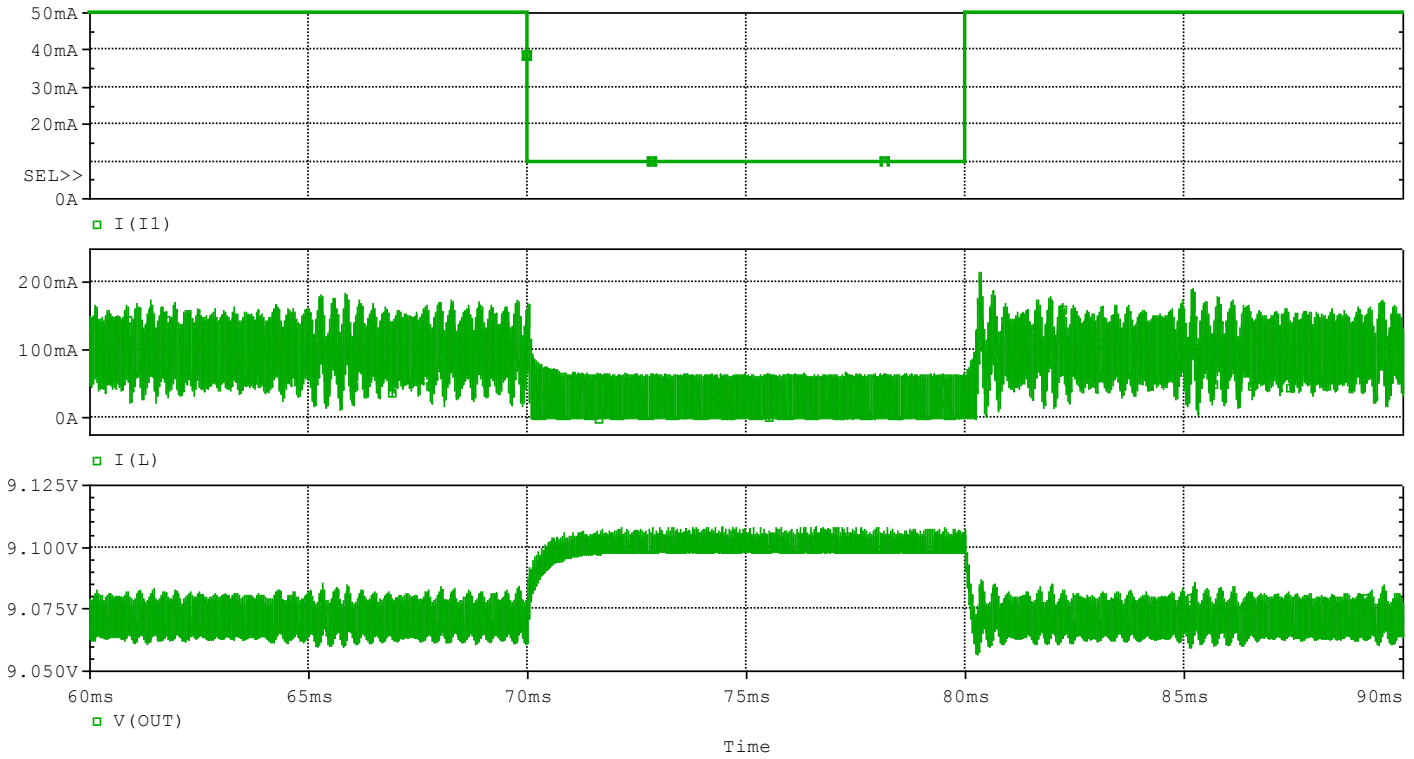
- Efficiency of the converter at load I_{OUT}=50mA is 75.5%.

4.4 Step-Load Response

I(Load)

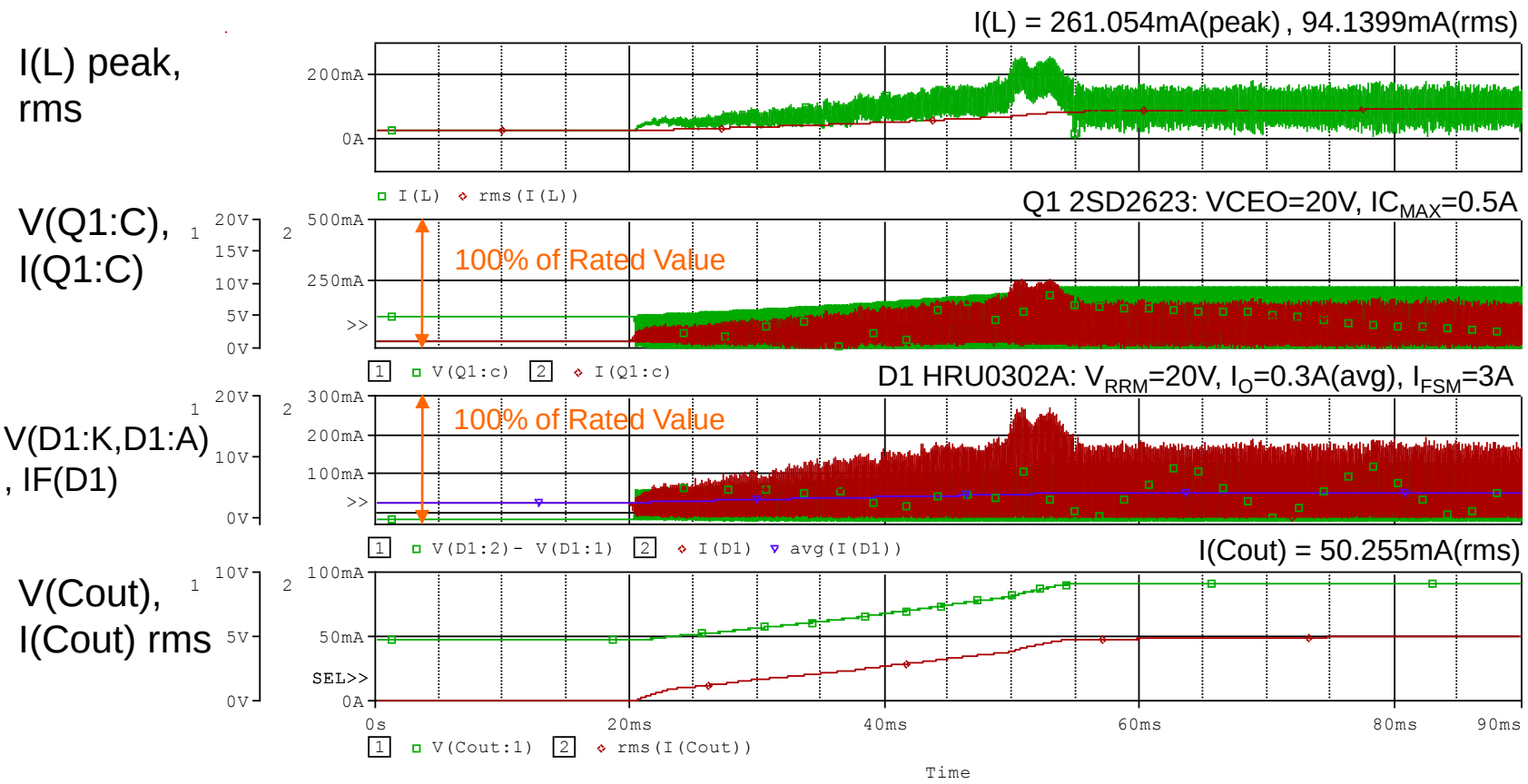
I(L)

V(OUT)



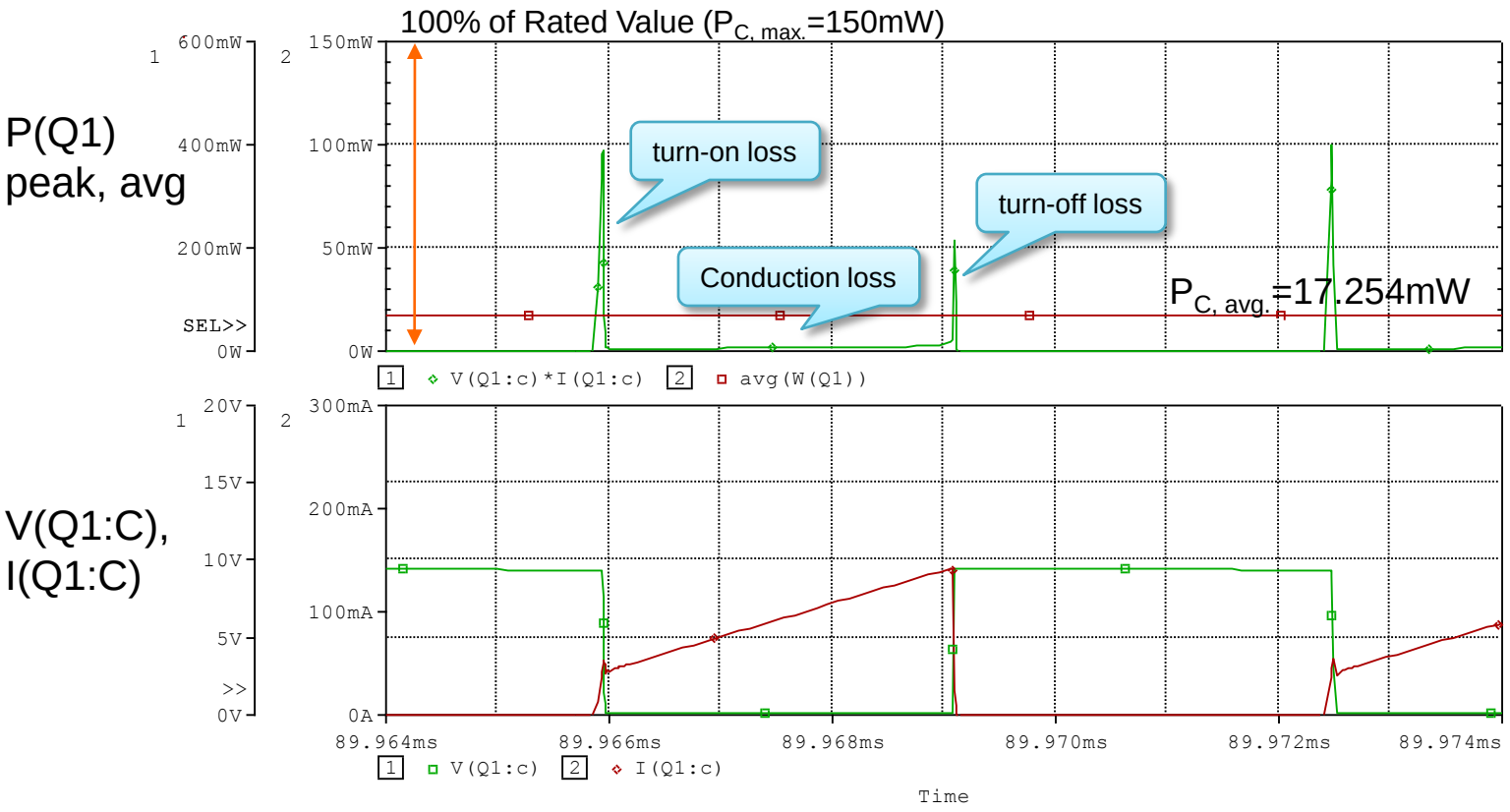
- Simulation result shows the transient response of the circuit, when load currents are 50mA to 10mA to 50mA steps .

5. Voltage and Current Simulation Result



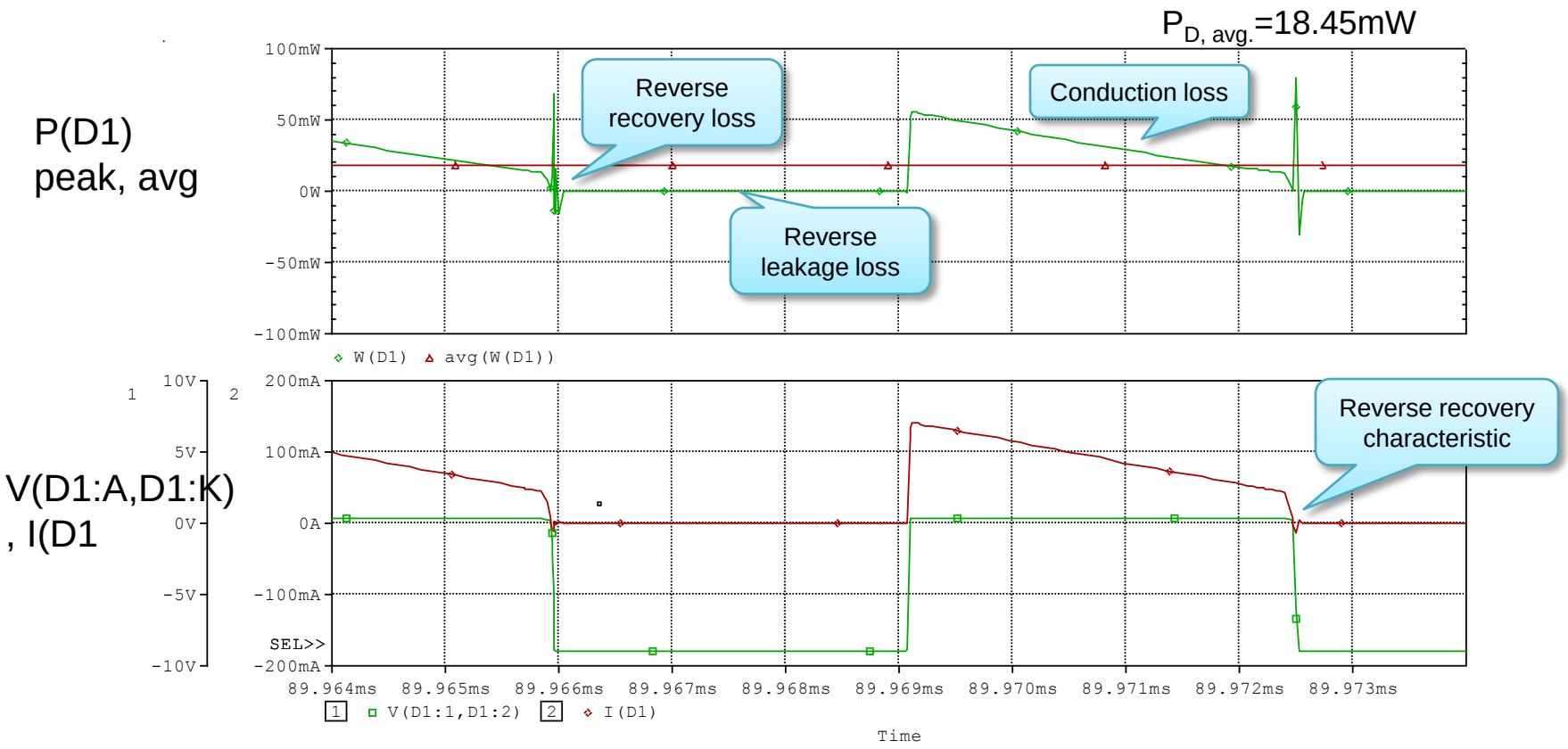
- Simulation result shows voltage and current of the devices.
- Select L and Cout that can handle their I_{rms} value.
- The absolute maximum value of Q1 and D1 are compared to simulation result for stress analysis.

6.1 Bipolar Junction Transistor Losses



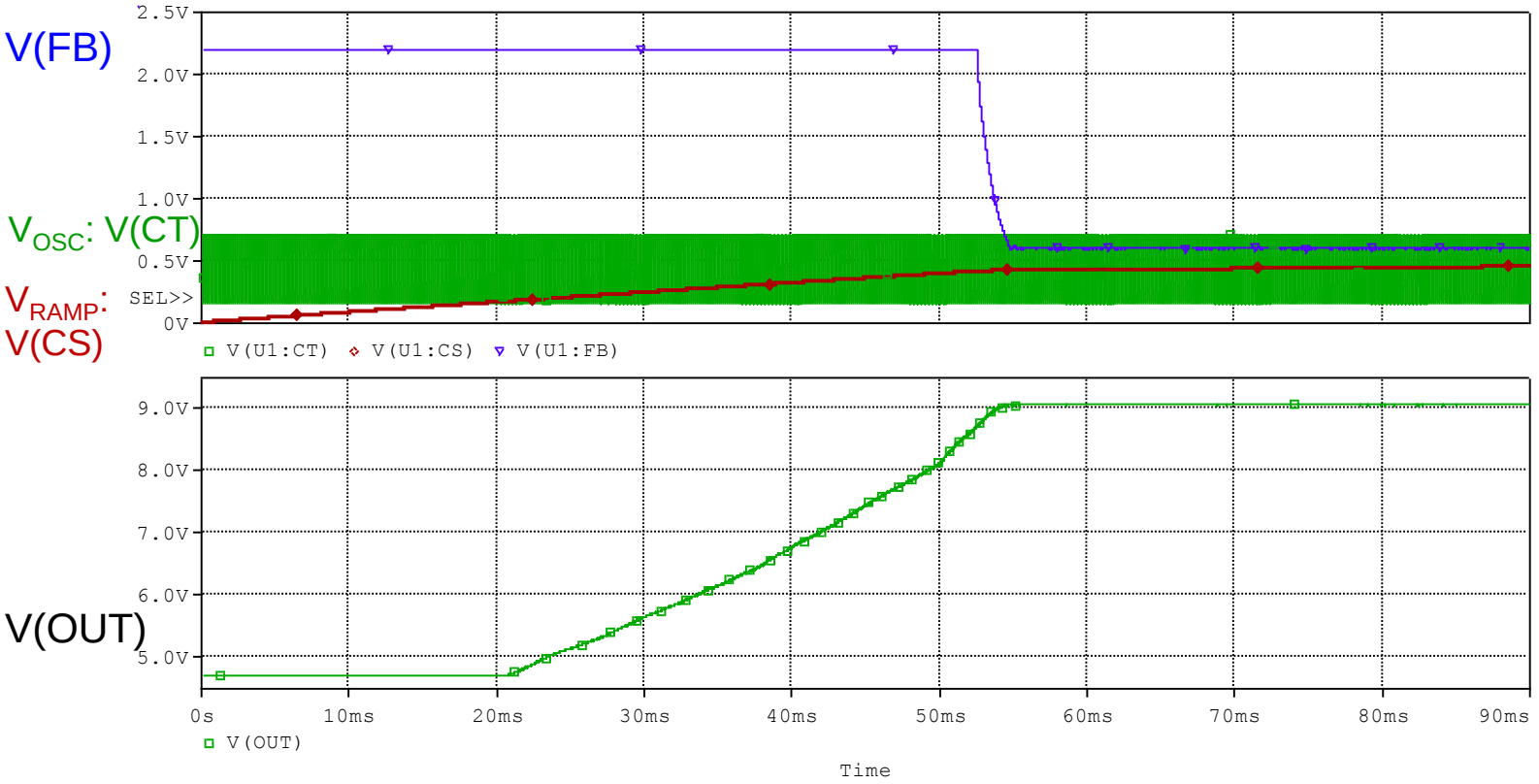
- Simulation result shows waveforms of I_C and V_{CE} of transistor Q1.Loss in peak and average values are also shown.

6.2 Schottky Barrier Diode Losses



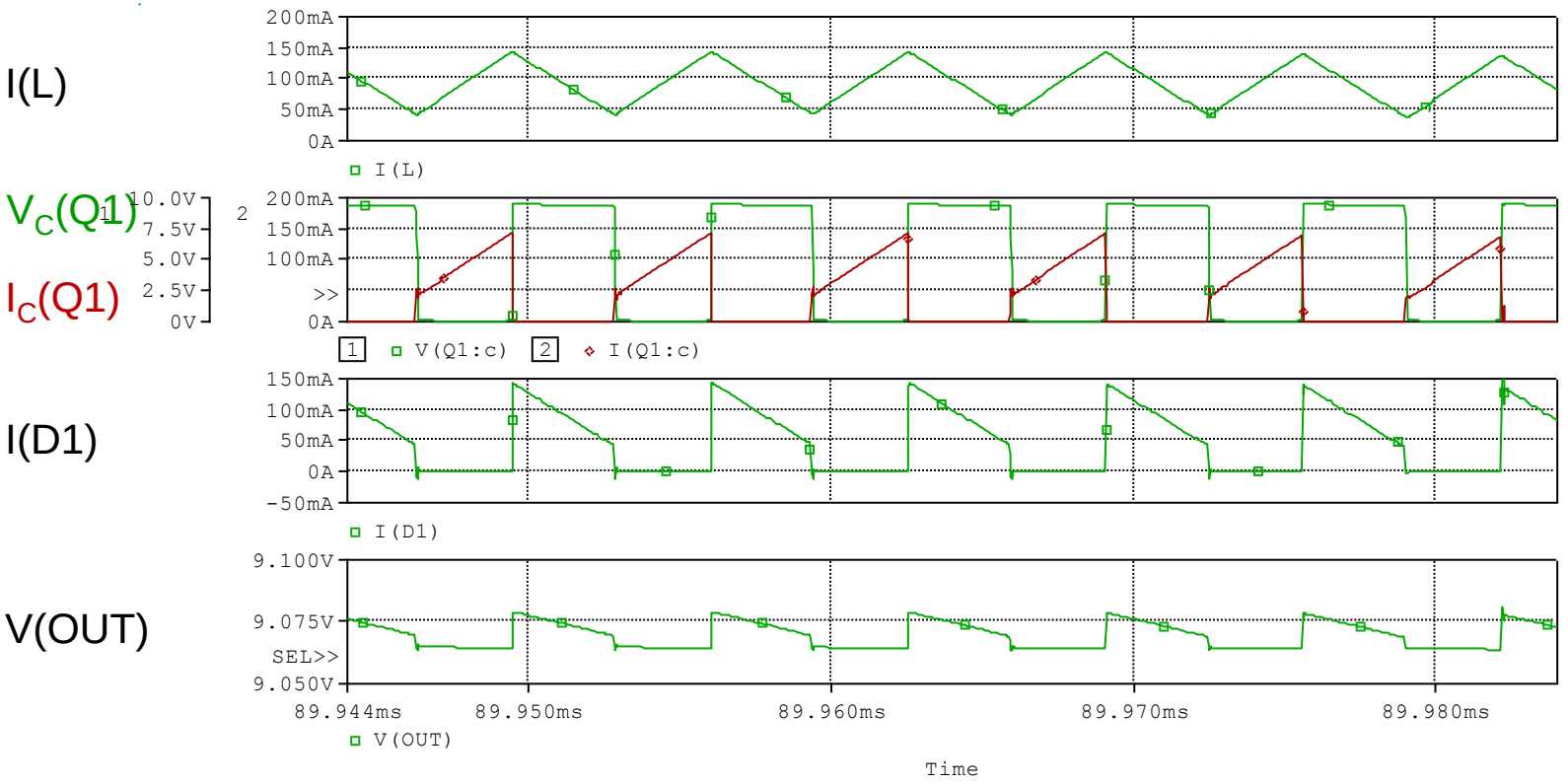
- Simulation result shows waveforms of I_F and V_{AK} of diode D1.Loss in peak and average values are also shown.

7.1 Start-Up Sequencing Waveforms



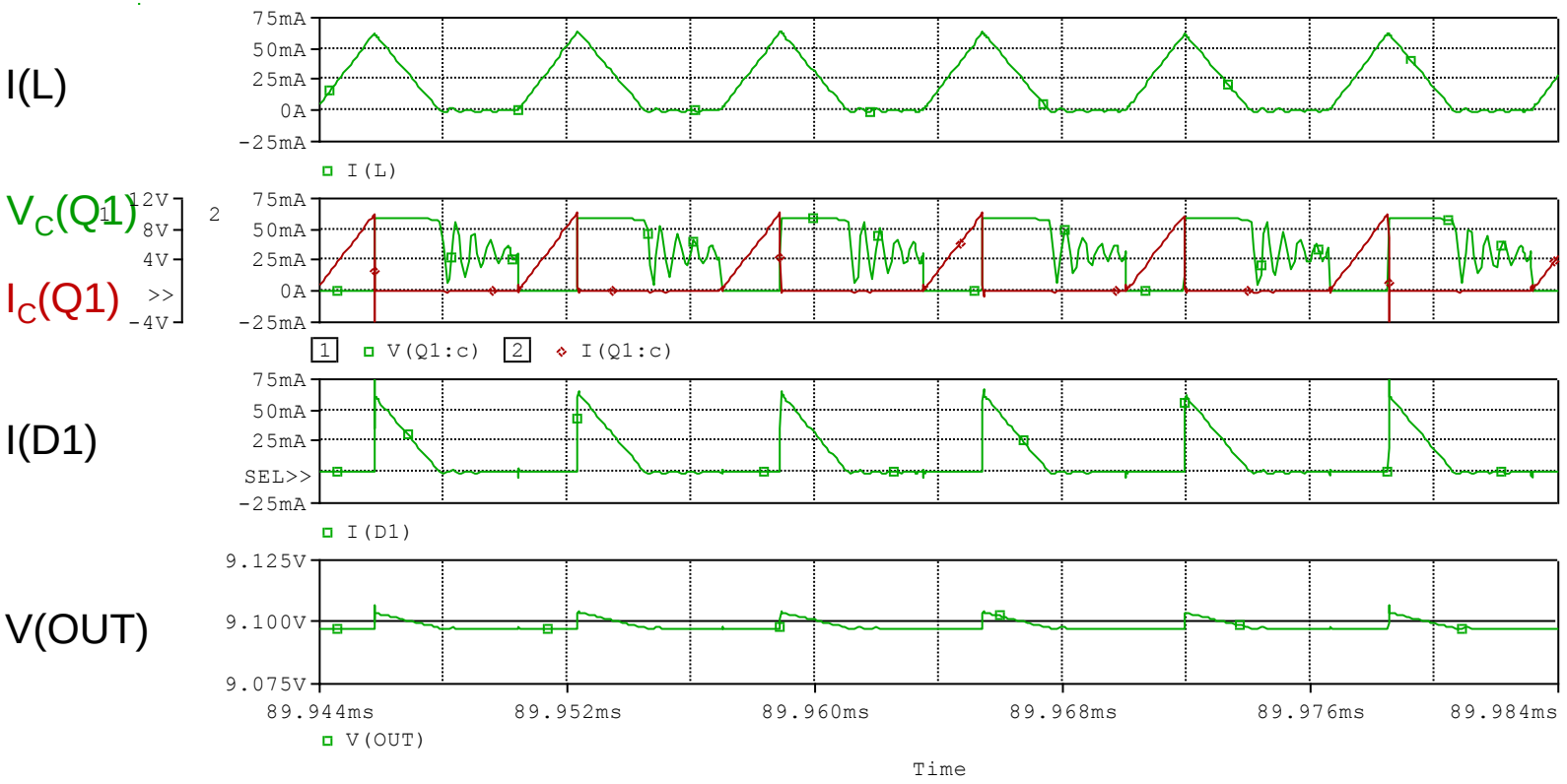
- Simulation result shows start-up sequencing waveforms, including V(OUT) and control signal (V_{RAMP}, V_{OSC}, and V_{FB}).

7.2 Switching Waveforms at Load 50 mA (RL=180Ω)



- Simulation result shows boost converter switching waveforms at load 50mA, including I_L, V_C(Q1), I_C(Q1), I(D1) and V(OUT)

7.3 Switching Waveforms at Load 10 mA (RL=900Ω)



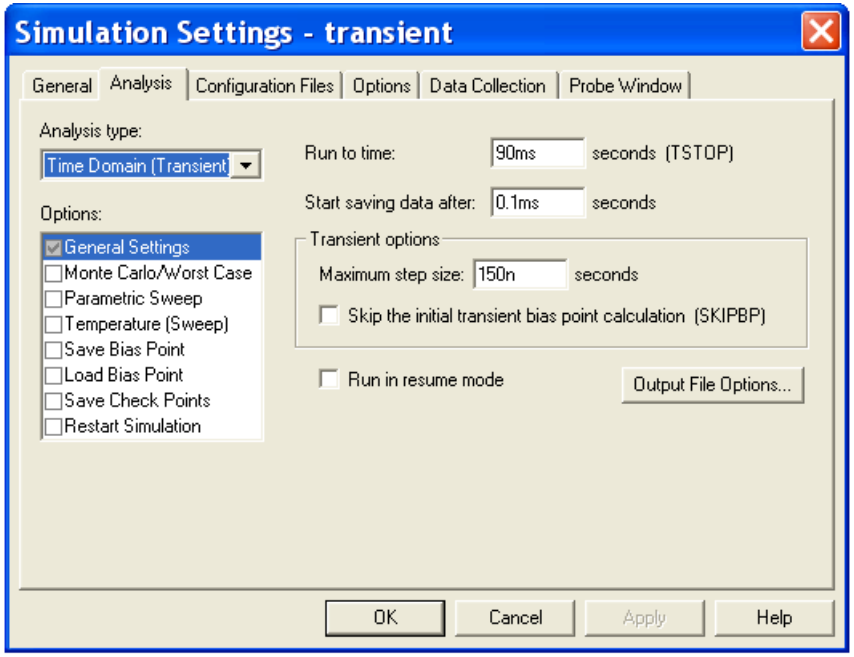
- Simulation result shows boost converter switching waveforms at load 10mA, including I_L, V_C(Q1), I_C(Q1), I(D1) and V(OUT)

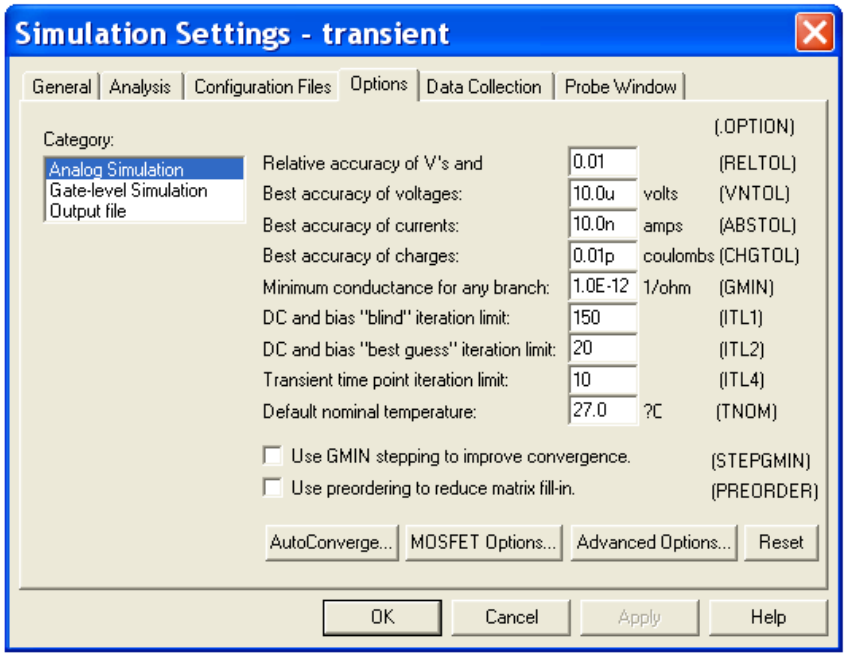
Simulation Index

SIMULATION SETTINGS 1

These settings are for:

- Start-Up Transient Simulation (0~90ms.)
- Voltage and Current Simulation
- Step-Load Response



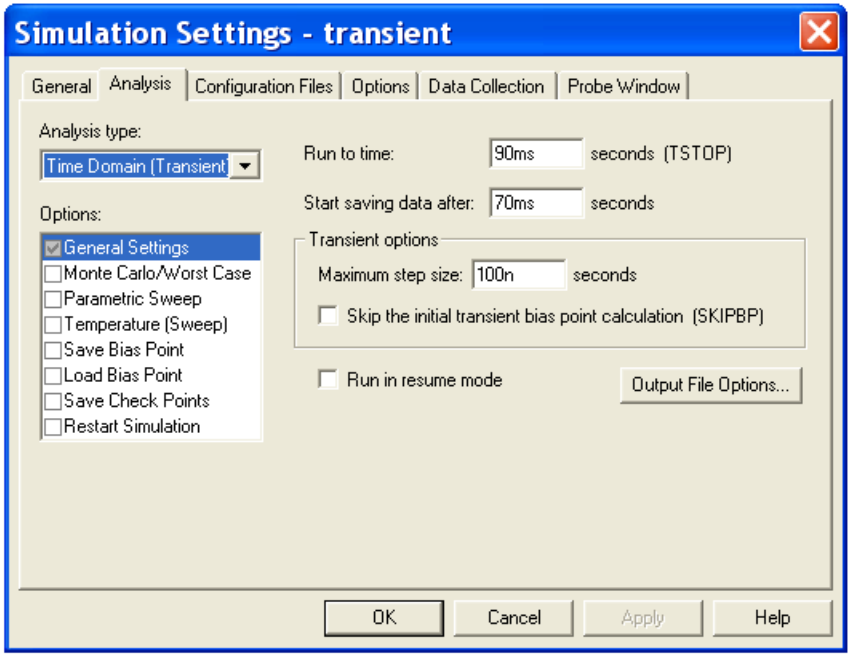


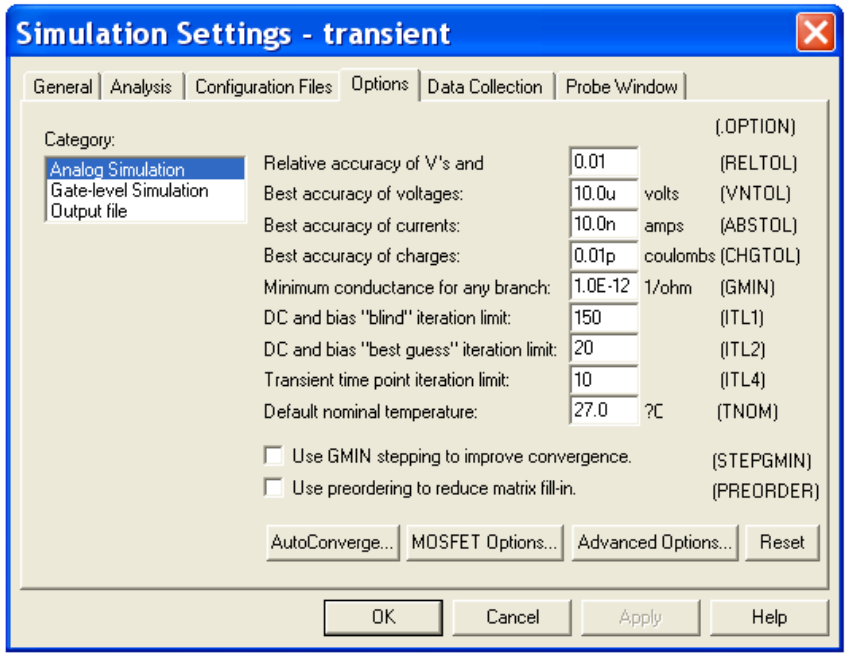
- .TRAN 0 90ms 0.1ms 150n
- .OPTIONS ABSTOL= 10.0n
- .OPTIONS RELTOL= 0.01
- .OPTIONS VNTOL= 10.0u

SIMULATION SETTINGS 2

These settings are for:

- Efficiency and Losses
- Switching Waveforms





- .TRAN 0 90ms 70ms 100n
- .OPTIONS ABSTOL= 10.0n
- .OPTIONS RELTOL= 0.01
- .OPTIONS VNTOL= 10.0u