Individual Demonstration

<u>Basic open loop Converter:</u>

Components:

Ideal Condition:

Turn ratio N1:N2 = 7:4

$$V_o = \frac{N_2}{N_1} dV_s$$

Duty cycle = 0.4

L = 32.85μH

$$L = \frac{VTA}{\Delta i_L}$$

C = 234.375μF

$$C = \frac{ITA}{\Delta V_o}$$

Ripple:

$$\Delta V_o = 0.01 \ (R_{load} = 8.53\Omega)$$
$$\Delta V_o = 0.01 \ (R_{load} = 1.28\Omega)$$

Real condition:

Turn ratio N1:N2 = 9:9

Magnetic Inductance:

$$L_{mag} = 210.6\mu H$$

Duty cycle = 0.27

L = 42.5μH

C (Output) = 300μF ESR = 0.05467Ω (0.164Ω for each)

AC Input = $230 \times \sqrt{2} = 325.269\ V$

AC Series Resistance = 0.1Ω

AC Series Inductance = 0.001μH

C (Input) = 2mF ESR = 0.022Ω (0.044Ω for each)

Rectifier Diode: $V_f = 1.2V, R_{on} = 0.51\Omega$

Diode: $V_f = 1.9V, R_{on} = 0.041\Omega$

MOSFET: $R_{on} = 0.11\Omega$

Ripple:

$$\Delta V_o = 0.09597 \ (R_{load} = 8.53\Omega)$$
$$\Delta V_o = 0.08477 \ (R_{load} = 1.28\Omega)$$

Main Transformer (9:9):

$$N = \frac{VTA\ (Worst)}{\Delta BA_{core}}$$

$$N = \frac{37 \times 0.45 \times 10 \times 10^{-6}}{200 \times 10^{-3} \times 97.1 \times 10^{-3}} = 8.573635$$

$$N = 9$$

$$L_{mag} = A_L N^2 = 2600 \times 10^{-9} \times 9^2$$

$$L_{mag} = 210.6\mu H$$

$$\hat{\imath}_{mag} = \frac{V_s dT}{L_{mag}} = 0.49245A$$

Area of copper required:

$$A_{turn} = \frac{i_{RMS}}{J} = \frac{2.68479}{5 \times 10^6} = 0.53664\mu m^2$$

$$A_{cu} = N\frac{i_{RMS}}{J} = 4.833\mu m^2$$

$$A_{turn} = \frac{\pi d^2}{4}$$

$$K_{fill} = \frac{A_{cu}}{A_w} = 0.0396$$

Skin depth:

$$\delta = \sqrt{\frac{2\rho}{2\pi f \mu_r \mu_0}} = 0.2062mm$$

Effective Area for one wire of (Wire 26 AWG)

$$Effective\ Area = 0.2^2 \times \pi \times 10^{-6}$$

Number of wires required:

$$number\ of\ wires = \frac{0.53664 \times 10^{-6}}{0.2^2 \times \pi \times 10^{-6}} = 4.27044 \approx 5$$

$$\therefore Five\ wires\ are\ required$$

Loss:

$$R_{DC} = \frac{\rho l_{winding}}{A_{turn}} = \frac{1.77 \times 10^{-8} \times 2 \times 9 \times (11.1 + 25.6) \times 10^{-3}}{0.53664 \times 10^{-6}}$$

$$R_{DC} = 0.0209\Omega$$

$$R_{AC} = \frac{\rho l}{A_{eff}} = 0.0158\Omega$$

$$R_{AC} < 2 \times R_{DC}$$

Inductor:

Air gap =0.5mm

Number of turns:

$$N = \sqrt{\frac{gL}{\mu_0 A}} = \sqrt{\frac{0.5 \times 10^{-3} \times 42.5 \times 10^{-6}}{4\pi \times 10^{-7} \times 97.1 \times 10^{-6}}} = 13.1967 \approx 14$$

$$N = 14$$

Peak Flux Density:

$$\hat{B} = \sqrt{\frac{\mu_0 L}{gA}}\,\hat{\imath} = \sqrt{\frac{4\pi \times 10^{-7} \times 42.5 \times 10^{-6}}{0.5 \times 10^{-3} \times 97.1 \times 10^{-6}}} \times 6.41246 = 212.68mT$$

$$B_{hat} < B_{sat}(400mT)$$

Area of copper required:

$$A_{turn} = \frac{i_{RMS}}{J} = \frac{5.16309}{5 \times 10^6} = 1.032618\mu m^2$$

$$A_{cu} = N\frac{i_{RMS}}{J} = 14.456652\mu m^2$$

$$A_{turn} = \frac{\pi d^2}{4}$$

$$K_{fill} = \frac{A_{cu}}{A_w} = 0.11849$$

Skin depth:

$$\delta = \sqrt{\frac{2\rho}{2\pi f \mu_r \mu_0}} = 0.2062mm$$

Effective Area for one wire of (Wire 26 AWG)

$$Effective\ Area = 0.2^2 \times \pi \times 10^{-6}$$

Number of wires required:

$$number\ of\ wires = \frac{1.032618 \times 10^{-6}}{0.2^2 \times \pi \times 10^{-6}} = 8.2173 \approx 9$$

$$\therefore Nine\ wires\ are\ required$$

Loss:

$$R_{DC} = \frac{\rho l_{winding}}{A_{turn}} = \frac{1.77 \times 10^{-8} \times 60.5 \times 14 \times 10^{-3}}{0.53664 \times 10^{-6}}$$

$$R_{DC} = 0.0145\Omega$$

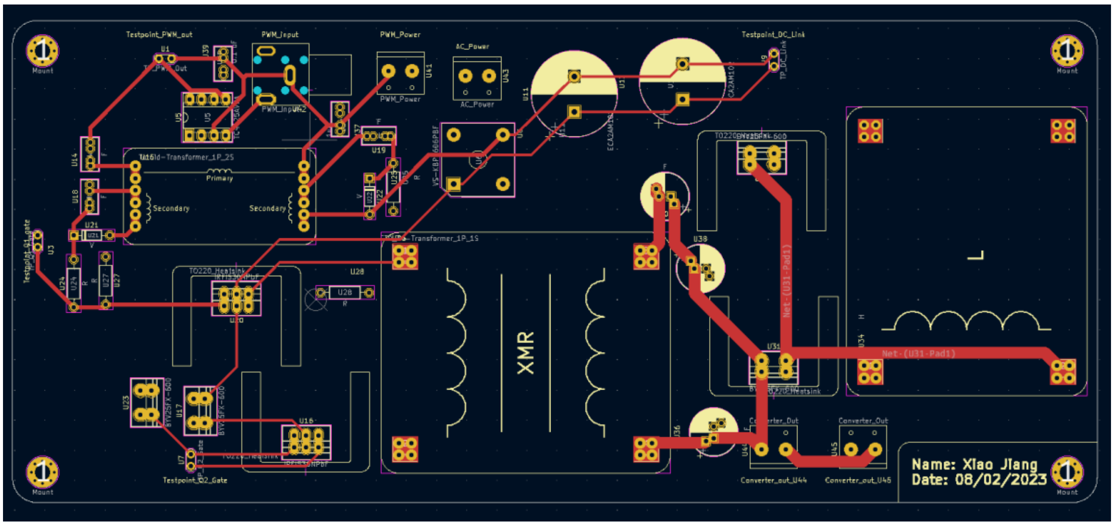
$$R_{AC} = \frac{\rho l}{A_{eff}} = 0.0195\Omega$$

$$R_{AC} < 2 \times R_{DC}$$

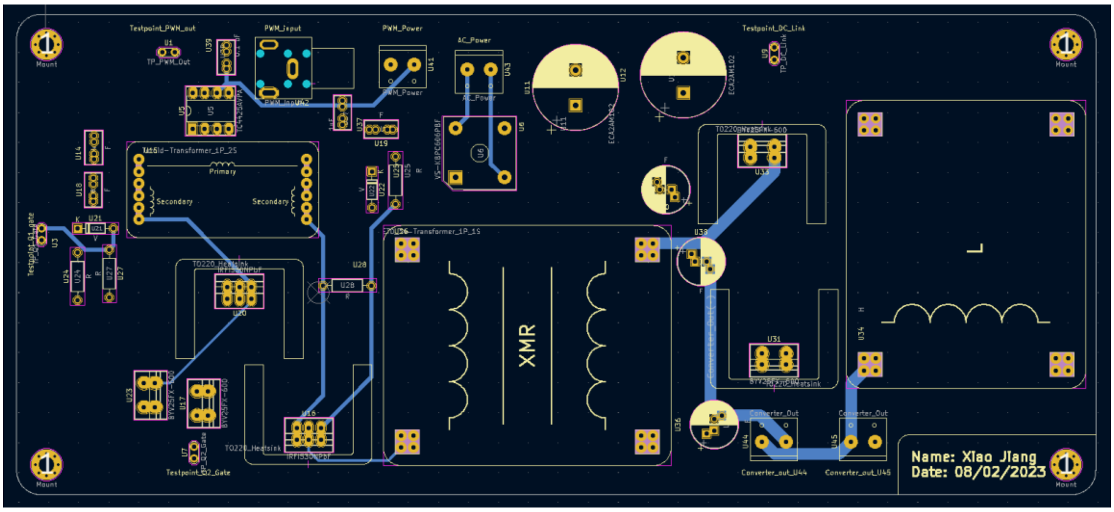
<u>PCB:</u>

Original:

Front:

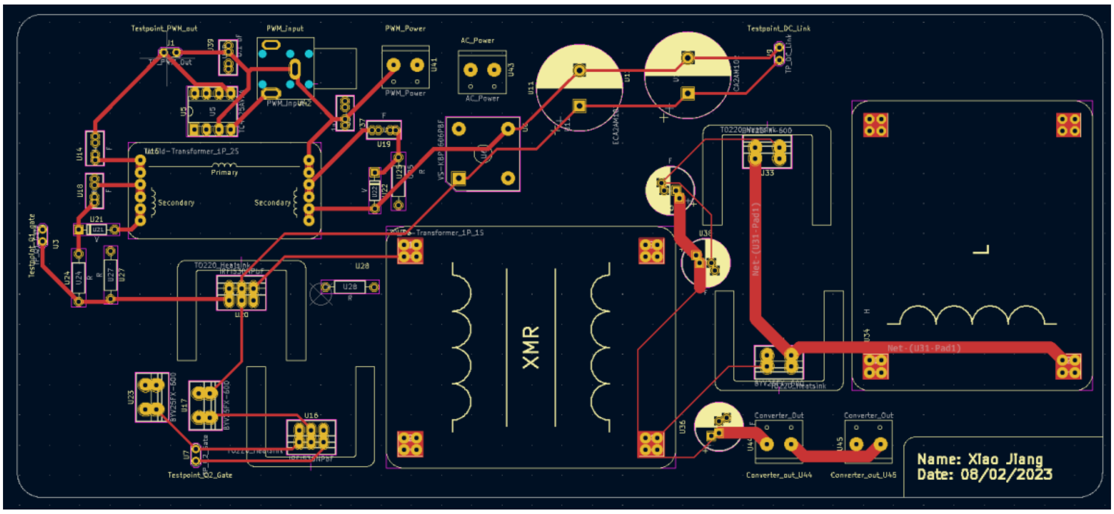


Back:

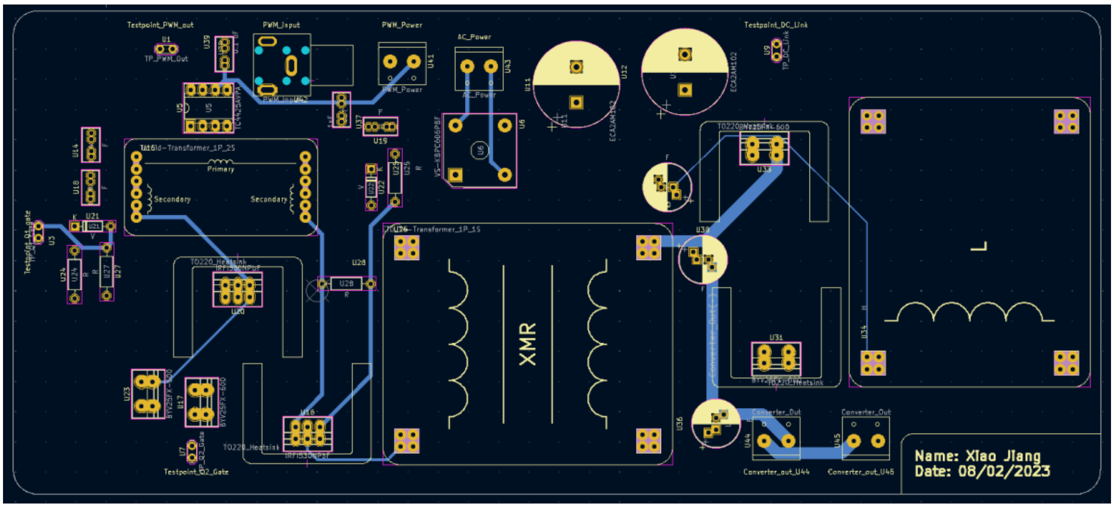


Modified:

Front:



Back:



Control and Closed Loop:

Calculation code:

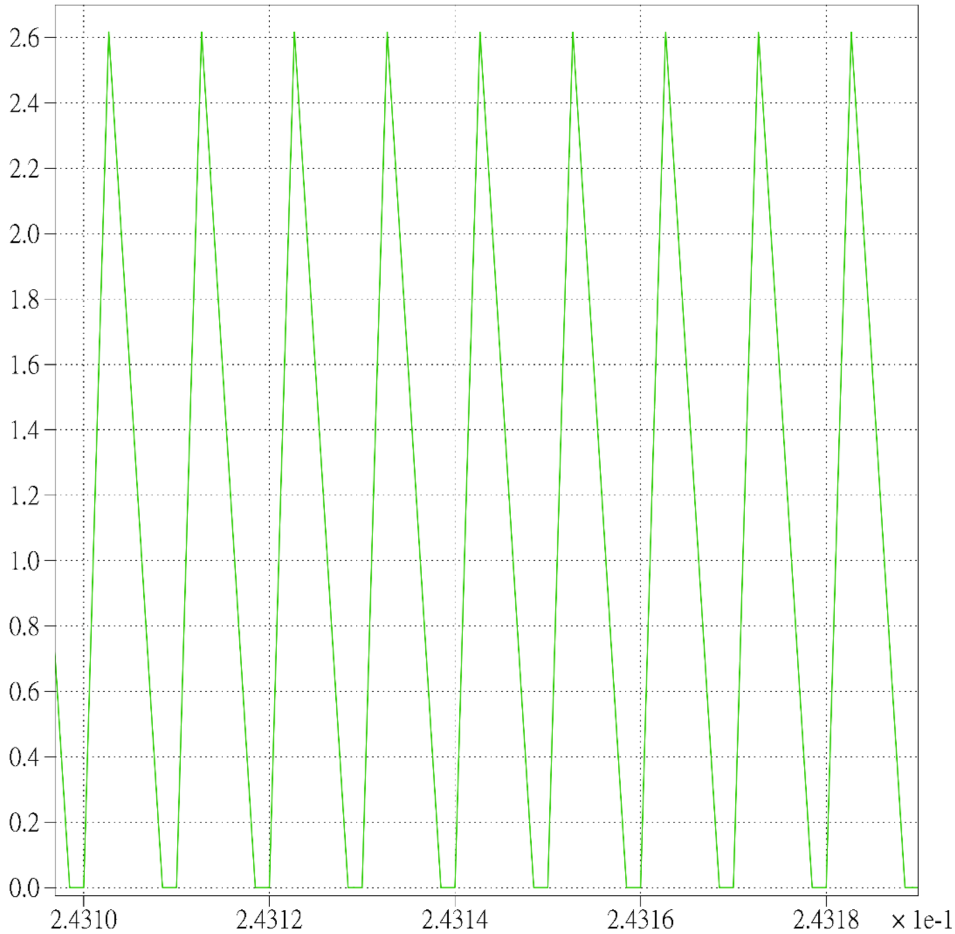
Type1:

```
% Parameters
Rc = 0.05477;
Rload_thres = 8.53;
L = 42.5e-6;
C = 300e-6;
Wc = 1/(10*sqrt(L*C));
n = 1;                          % Transformer turns ratio
Ra1 = 22000;                     % Amplifier Potential Divider 1
Ra2 = 10000;
a = Ra2/(Ra1+Ra2);              % Amplifier Potential Divider Ratio
Vin = 39.5;                       % Max Voltage Input (AC)
dmax = 0.45;                    % PWM
Kpwm = dmax/(3.8-0.5);
Kmisc = n*a*Vin*Kpwm;
% Transfer function for filter circuit
Gf = tf([Rc*C 1], [L*C (L/Rload_thres)+C*Rc 1])
% bode(Gf)
% margin(Gf)
% Magnitude of Gc at wc
%Gfjwc = (Rc*C*Wc*i+1)/(-1*L*C*(Wc)^2+((L/Rload_thres)+C*Rc)*Wc*i+1);
[mag, phase]=bode(Gf,Wc);
G = 1/Kmisc*abs(mag);
A = G*Wc;
Gc = tf([A], [1 0])
Gloop = Gc*Gf*Kmisc;
margin(Gloop);
R1=12000;
C1=1/(A*R1)
```

Type 3:

```
%%
% Parameters
Rc = 0.05477;
Rload_thres = 8.53;
L = 42.5e-6;
C = 1410e-6;
Wc = 7*1/sqrt(L*C)
n = 1;                          % Transformer turns ratio
Ra1 = 22000;                     % Amplifier Potential Divider 1
Ra2 = 10000;
a = Ra2/(Ra1+Ra2);              % Amplifier Potential Divider Ratio
Vin = 50;                       % Max Voltage Input (AC)
dmax = 0.45;                    % PWM
Kpwm = dmax/(3.8-0.5);
Kmisc = n*a*Vin*Kpwm;
% Transfer function for filter circuit
Gf = tf([Rc*C 1], [L*C (L/Rload_thres)+C*Rc 1])
% bode(Gf)
% margin(Gf)
% Magnitude of Gc at wc
%Gfjwc = (Rc*C*Wc*i+1)/(-1*L*C*(Wc)^2+((L/Rload_thres)+C*Rc)*Wc*i+1);
[mag,phase]=bode(Gf,Wc)
%margin(Gf);
phaseMargin=60;
boost=phaseMargin-180+90-phase;
k=(tand((boost/4)+45))^2;
R1=2200;
G=1/(Kmisc*mag);
A=G*Wc/k;
C2=1/(R1*Wc*G);
C1=C2*(k-1);
R2=sqrt(k)/(Wc*C1);
```

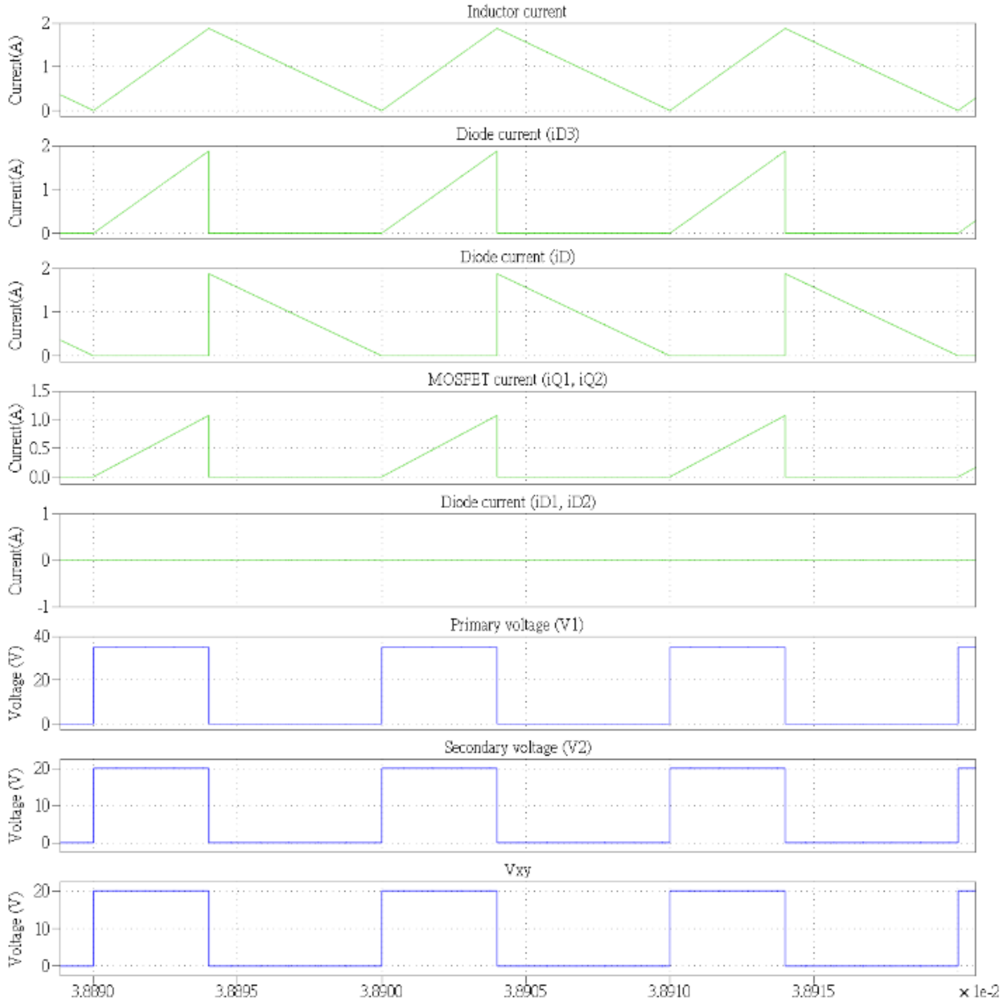
```
R3=R1/(k-1);
C3=1/(R3*Wc*sqrt(k));
Wz1=1/(C1*R2);
Wp1=(C1+C2)/(C2*C1*R2);
Wz2=1/(C3*(R1+R3));
Wp2=1/(C3*R3);
Ga=tf([A], [1 0]);
Gb=tf([1/Wz1 1], [1/Wp1 1]);
Gc=Ga*Gb*Gb;
Gloop=Gc*Gf*Kmisc;
margin(Gloop);
```



Waveform:

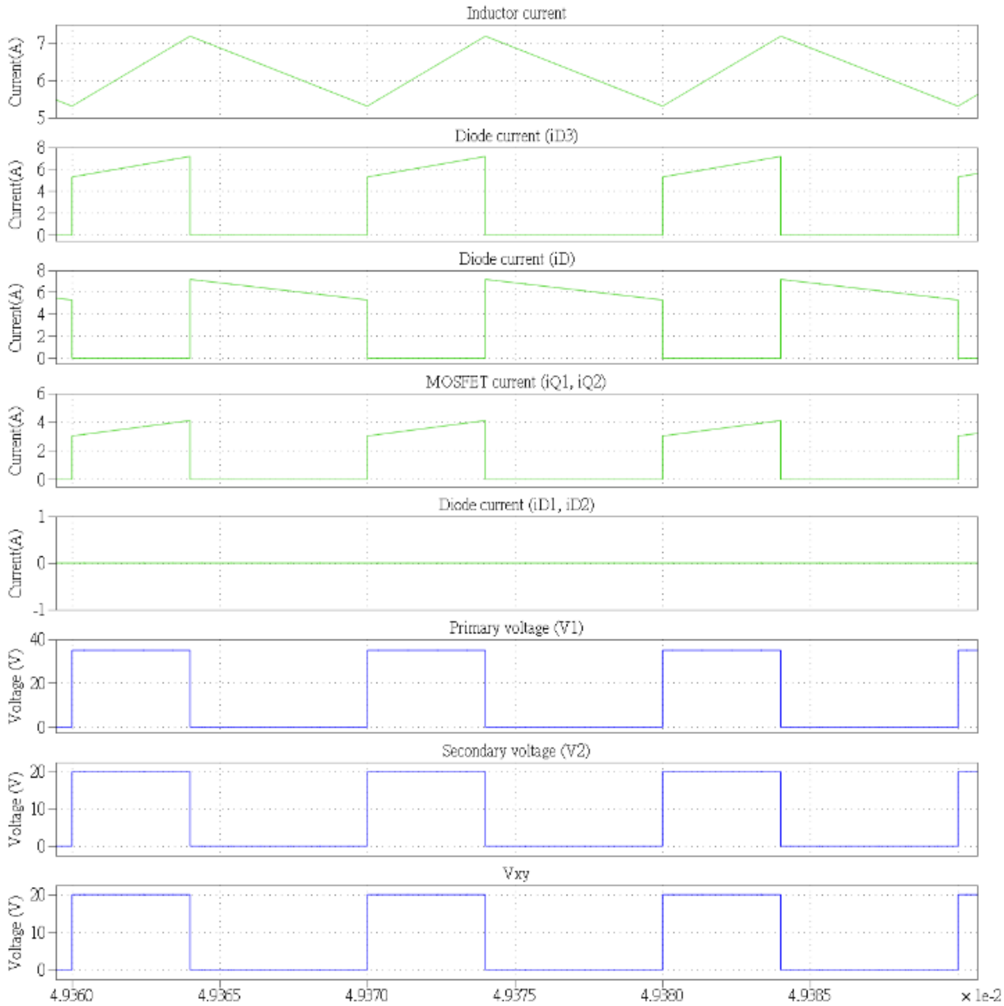
Ideal:

Threshold:



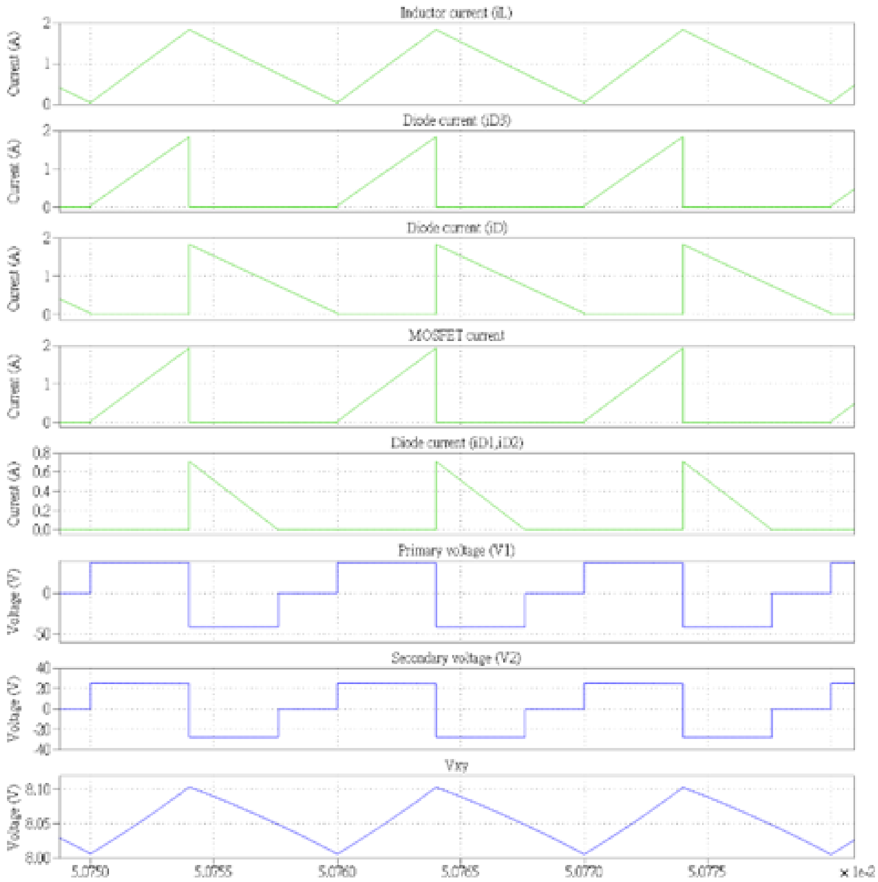
Inductor current
Current(A)
Diode current (iD3)
Current(A)
Diode current (iD)
Current(A)
MOSFET current (iQ1, iQ2)
Current(A)
Diode current (iD1, iD2)
Current(A)
Primary voltage (V1)
Voltage (V)
Secondary voltage (V2)
Voltage (V)
Vxy
Voltage (V)
3.8890
3.8895
3.8900
3.8905
3.8910
3.8915
× 1e-2

Rated:



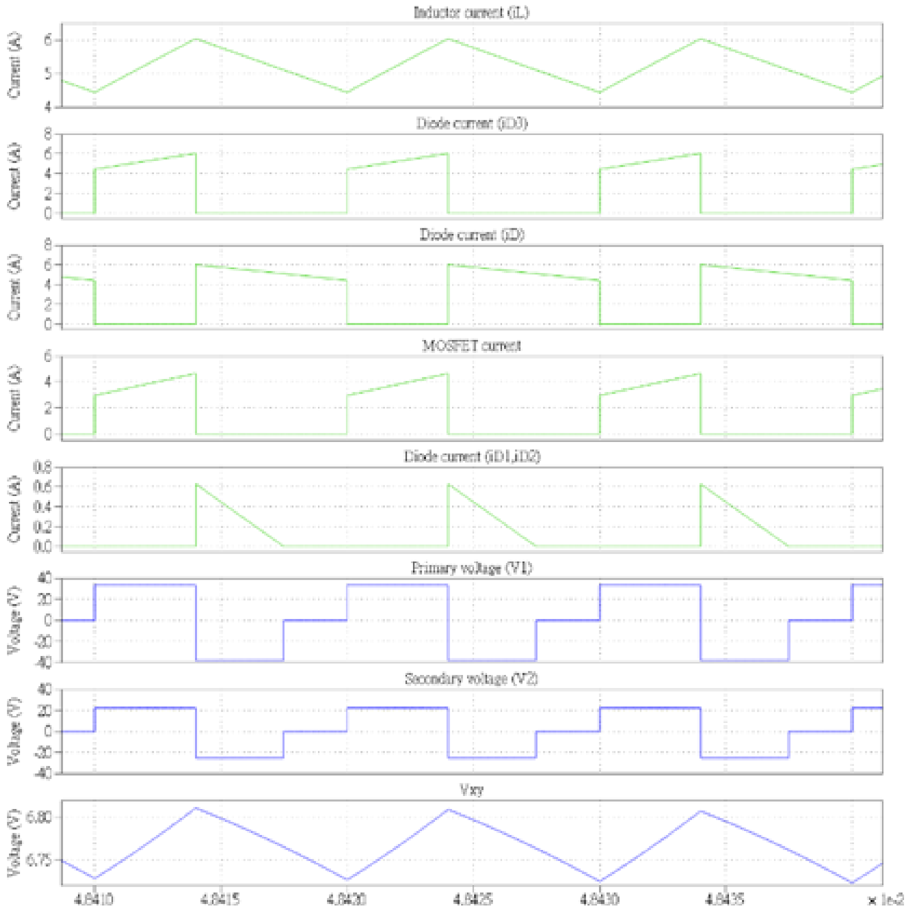
Real:

Threshold:



Inductor current (iL)
Current (A)
Diode current (iD3)
Diode current (iD)
MOSFET current
Diode current (iD1,iD2)
Primary voltage (V1)
Voltage (V)
Secondary voltage (V2)
Vxy
5.0750
5.0755
5.0760
5.0765
5.0770
5.0775
× 1e-2

Rated:



Imag:

Calaulated:0.49245