Ideal Simulation

Now, simulate your ideal synchronous buck converter using the component sizes you selected in Module 0. For the configurable switch blocks, double-click each block and select *Configuration/Ideal Sw.* You can ignore the 'Parameters' for now. **Make sure to define the deadtime ('Turn-on Delay' block) as 0** [s]. Based on your converter simulation, determine the following:

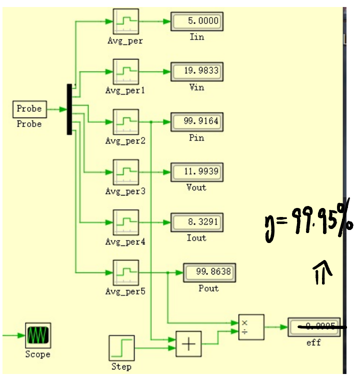
1. The efficiency of your power converter at the nominal operating point and at each corner operating point.
2. The maximum peak-to-peak ripple (as a percentage) on v_{out}, considering the entire operating range.
3. The maximum peak-to-peak ripple (as a percentage) on i_L, considering the entire voltage range at full power.
4. The maximum voltage stress on each of your switches, considering the entire operating range.
5. The maximum current stress on each of your switches, considering the entire operating range.

PLECS Tip: If waveforms look jagged instead of smooth, try increasing the refine factor. A higher refine factor improves the rendering of an output from the scope without increasing simulation time. The refine factor can be set in the Solver pane of the Simulation Parameter window. A refine factor less than 10 is recommended.

Check-off: Confirm (a) that chosen components satisfy ripple requirements and can tolerate maximum stress, and (b) that your switch selections are appropriate for your design.

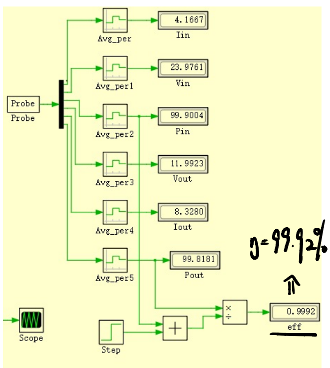
(1)

1. norminal operating points



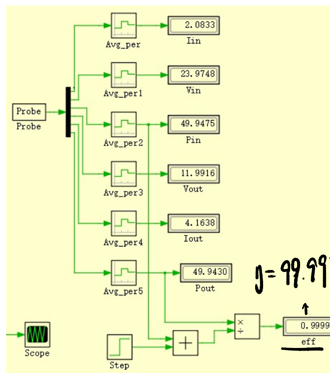
η=99.95%

2. Vin max = 24V, Pmax = 100W



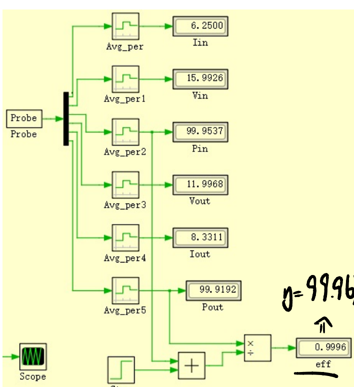
η=99.92%

3. Vin max = 24V, Pmin = 50W



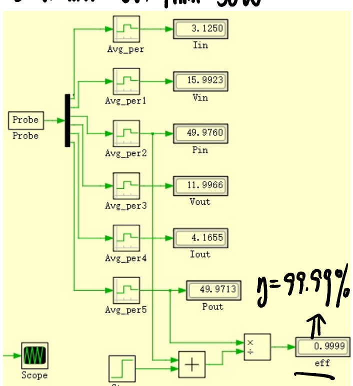
η=99.99%

4. Vin min = 16V Pmax = 100W



η=99.96%

5. Vin min = 16V, Pmin = 50W

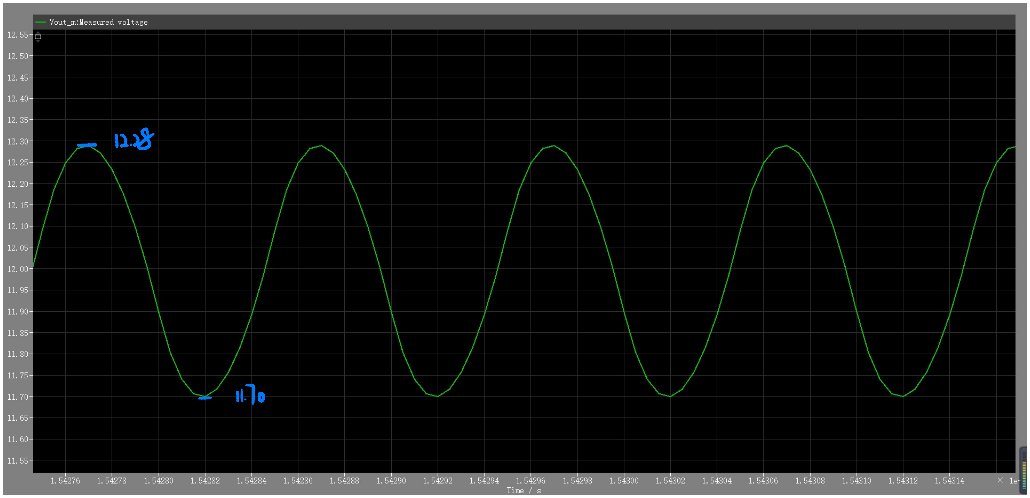


η=99.99%

(2). V_{out} ripple: (worst-case). — $V_{in\,max} = 24V$ ⇒ ripple max. $\underline{P_{min} = 50W} \Rightarrow I_L$ min.

$$\text{ripple\%} = \frac{12.28 - 11.70}{12} \approx 4.83\%$$ $= 0.58A$

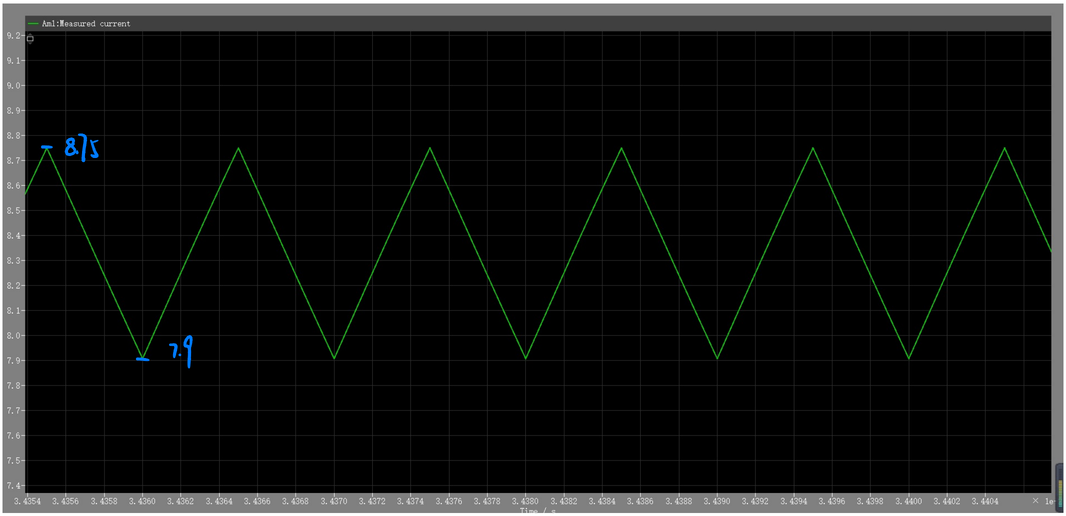
≈ 5% ideally



ripp max

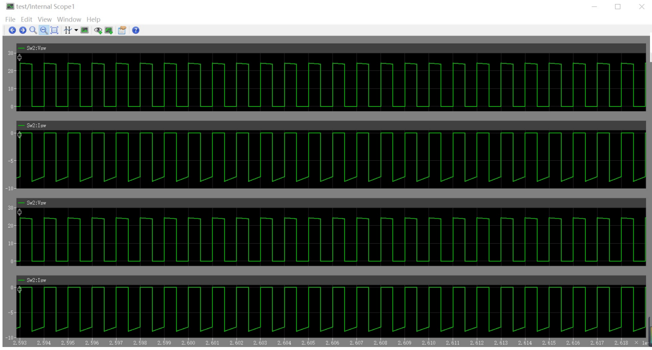
3. i_L ripple $\langle i_L \rangle = \frac{P_{out}}{V_{out}} = \frac{100}{12} \approx 8.34$ (ideal) & real: $\underline{\langle i_L \rangle = 8.3219}$

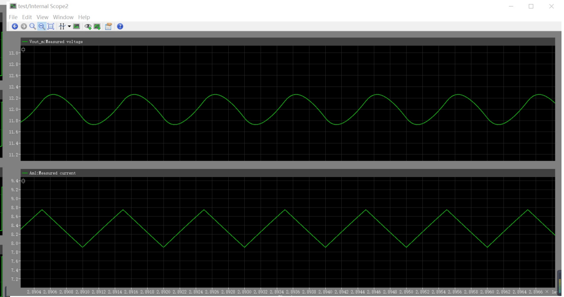
$$\text{ripple} = \frac{8.75 - 7.9}{8.3219} \approx 10.21\%.$$ $= 0.85A$



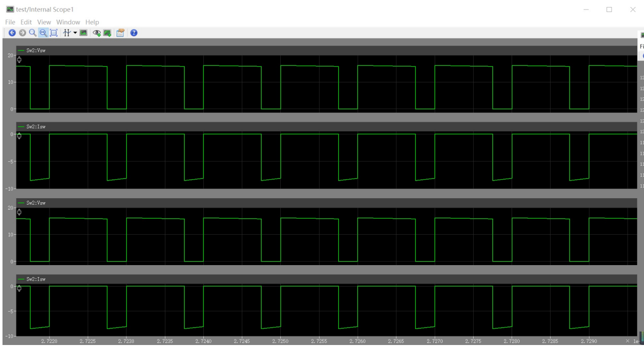
All of the ripples on switches:

$P = 100W,\ V_{in} = 24V$:

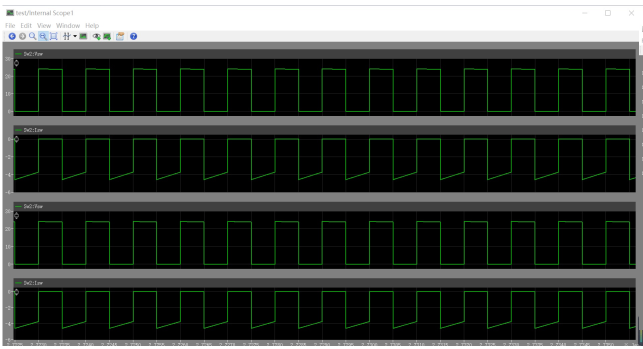


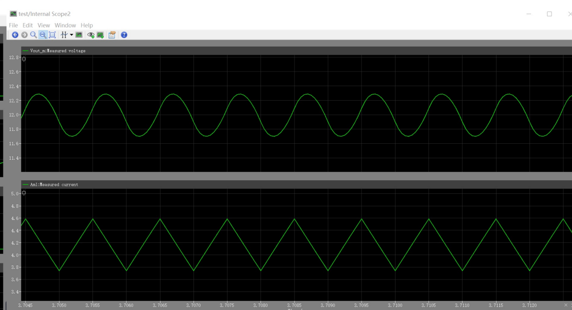


$V_{in} = 16V,\ P = 100W$

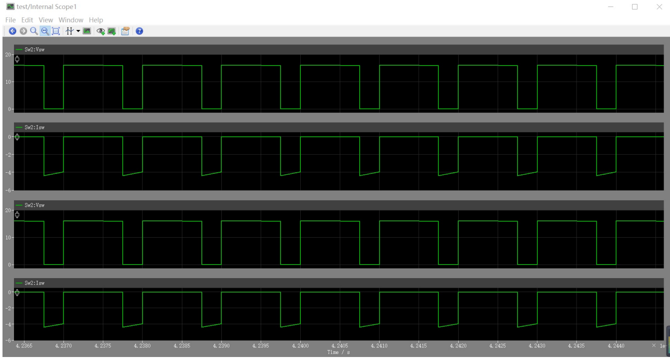


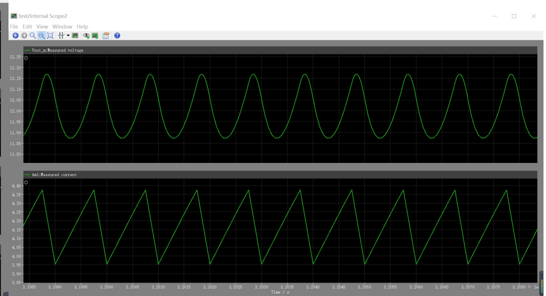
$V_{in} = 24V,\ P = 50W$



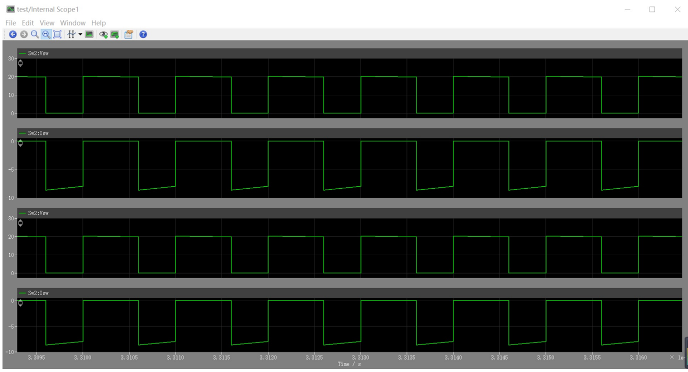


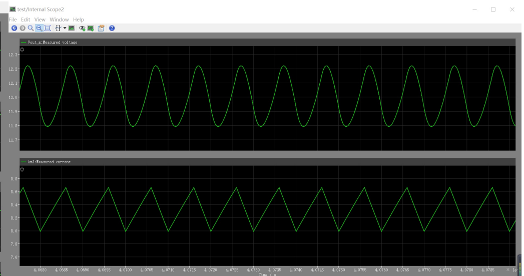
Vin=16V, P=50W





Vin=20V. P=100W norminal situation





Solver | Options | Diagnostics | Initialization

circuit ↓

System state

Initialize from: (•) Block parameters

( ) Stored system state

Store current state...

Model initialization commands

```
P = 50
Vout = 12
R = Vout^2/P
Vin = 24
Iin = P/Vin
L = 7.2e-5
Cin = 4.17e-5
Cout = 3.47e-6 / 2
fsw = 1e5
D = Vout/Vin
tr = 150*1e-9
tf = 80*1e-9
```

OK | Cancel | Apply | Help

Switch (mask) (link)

ideal, real switch models

Configuration

switches- parameter.

Non-ideal Sw

Parameters | Assertions

On-State Resistance [Ohms]: 0.01

Body Diode Forward Voltage [V]: 1.3

Body Diode On-State Resistance [Ohms]: 0.0065

Sw Output Capacitance [F]: 870e-12

Sw Output Capacitance ESR [Ohms]: 10e-6

OK | Cancel | Apply | Help

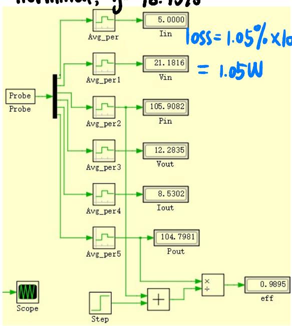
= parameters given

Simulation with parasitics:

1. The efficiency of your power converter.

2. The maximum voltage and current stresses on each of your switches, considering the entire operating range.

normal, $\eta = 98.95\%$



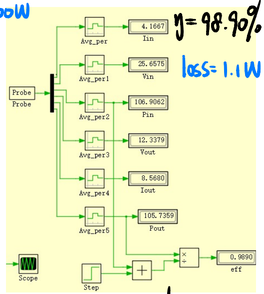
loss $= 1.05\% \times 100W$

$= 1.05W$

$V_{in,max} = 24V$, $P_{max} = 100W$

$\eta = 98.90\%$

loss $= 1.1W$

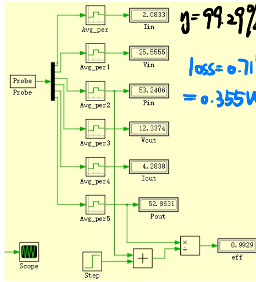


$V_{in,max} = 24V$, $P_{min} = 50W$

$\eta = 99.29\%$

loss $= 0.71\% \times 50$

$= 0.355W$

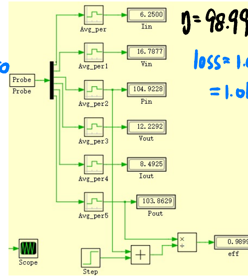


$V_{in,min} = 16V$, $P_{max} = 100W$

$\eta = 98.99\%$

loss $= 1.01\% \times 100$

$= 1.01W$

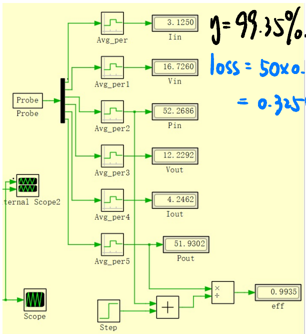


cond

0 V

Coss

$V_{in,min} = 16V$, $P_{min} = 50W$

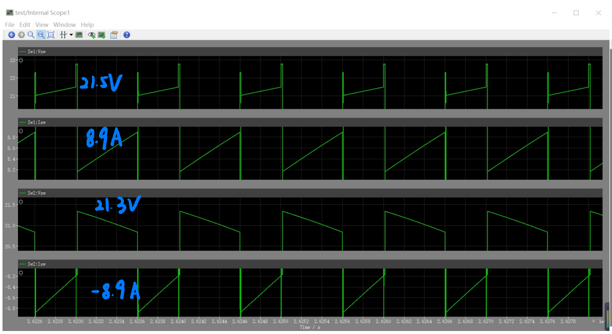


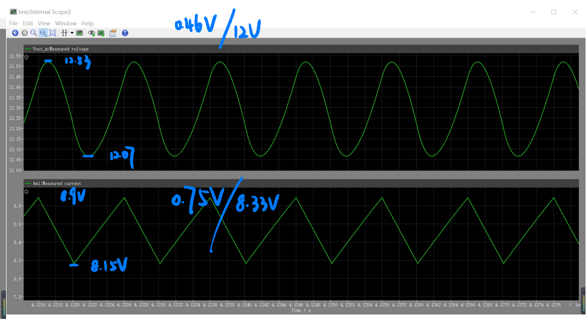
$\eta = 99.35\%$

loss $= 50 \times 0.65\%$

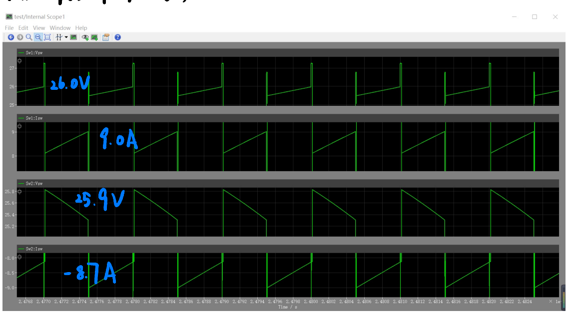
$= 0.325W$

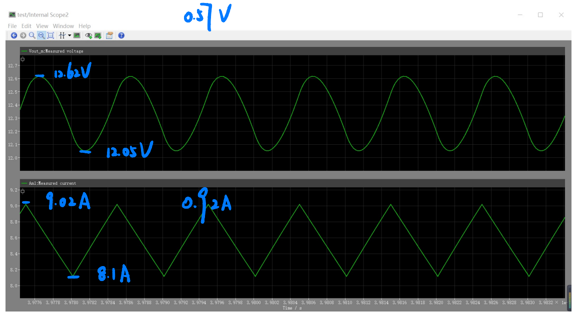
normal: $V_{in} = 20V$, $P = 100W$. stresses.



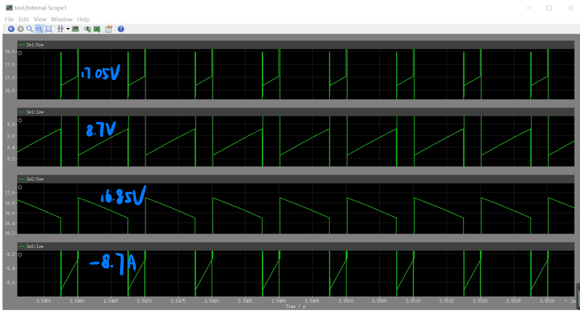


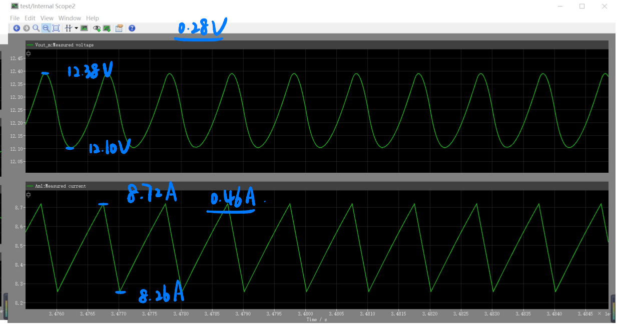
$V_{in} = 24V$, $P = 100W$,



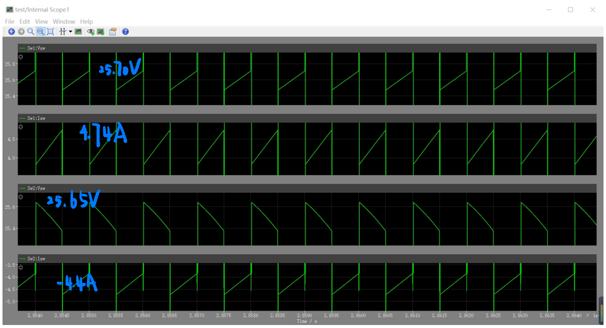


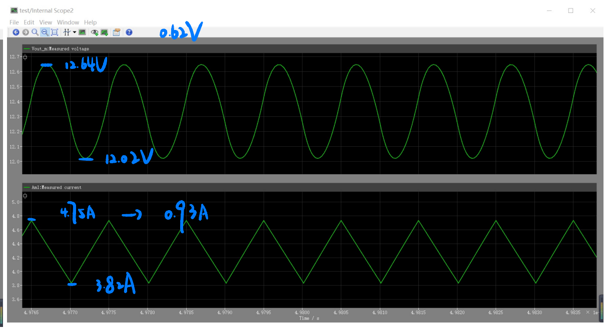
Vin=16V, P=100W



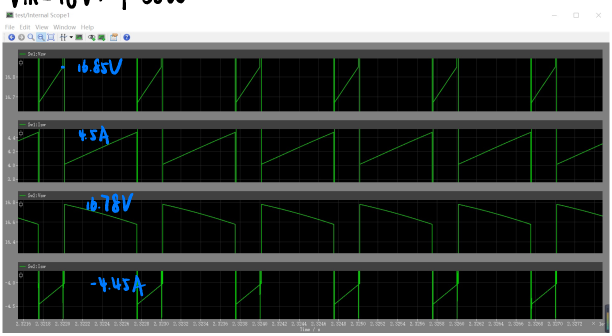


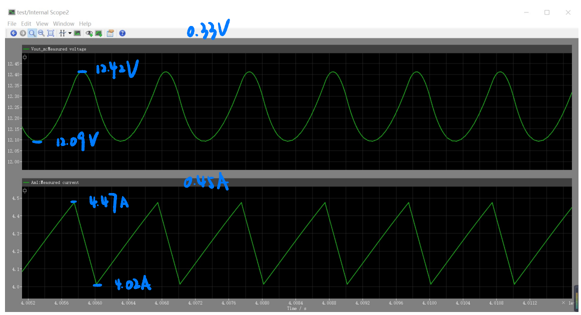
Vin=24V, P=50W.





Vin=16V. P=50W





1. Total converter losses, based on measured efficiency. → seen before.
2. RMS current for each switch.

> **PLECS Tip:** Use probe and RMS blocks. What sampling time makes sense to get a good rms estimate? Because we are not modeling all circuit parasitics, there will be very large voltage/current spikes on the switches. For the conduction loss estimate, you can ignore the large spikes in switch current, so try different sampling times until you get a 'reasonable' rms measurement.

3. Conduction losses for each switch.
4. Switching losses (as the remaining losses).

$V_{out} = 12V$

nominal

(2). $I_{rms,1} = \sqrt{D} \cdot I_L$

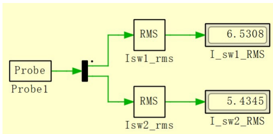
$I_{rms,2} = \sqrt{D'} \cdot I_L$

① $V_{in} = 20V$. $P = 100W$

$D = 0.6$

$I_{rms,1} = \sqrt{0.6} \times \frac{100}{12} = 6.46 A_{rms}$

$I_{rms,2} = \sqrt{0.4} \times \frac{100}{12} = 5.27 A_{rms}$.

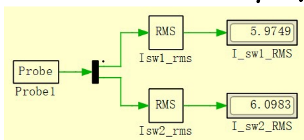


② $V_{in} = 24V$. $P = 100W$

$D = 0.5$

$I_{rms,1} = \sqrt{0.5} \times \frac{100}{12} = 5.89 A_{rms}$

$I_{rms,2} = \sqrt{0.5} \times \frac{100}{12} = 5.89 A_{rms}$

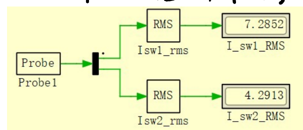


③ $V_{in} = 16V$, $P = 100W$

$D = 0.75$

$I_{rms,1} = \sqrt{0.75} \times \frac{100}{12} = 7.22 A_{rms}$

$I_{rms,2} = \sqrt{0.25} \times \frac{100}{12} = 4.17 A_{rms}$

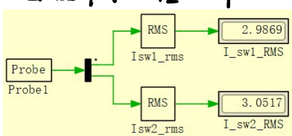


④ $V_{in} = 24V$, $P = 50W$

$D = 0.5$

$I_{rms,1} = \sqrt{0.5} \times \frac{50}{12} = 2.95 A_{rms}$

$I_{rms,2} = \sqrt{0.5} \times \frac{50}{12} = 2.95 A_{rms}$

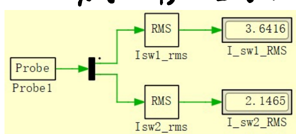


⑤ $V_{in} = 16V$, $P = 50W$

$D = 0.75$

$I_{rms,1} = \sqrt{0.75} \times \frac{50}{12} = 3.61 A_{rms}$

$I_{rms,2} = \sqrt{0.25} \times \frac{50}{12} = 2.08 A_{rms}$



(3). $P_{cond.loss} = I_{rms}^2 \cdot R_{ds,on}$.

$P_{sw.loss} = (P_{ov} + P_{coss})$

$= P_{total} - P_{cond.loss}$

Real Situation:

```
% norminal Vin=20V P=100W [real situation]
P_loss_total = 1.05*1e-2 * 100
I_rms_1 = 6.5308;
I_rms_2 = 5.4345;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1
P_sw_2 = P_loss_total - P_cond_2
```

```
P_loss_total = 1.0500

P_cond_1 = 0.4265
P_cond_2 = 0.2953

P_sw_1 = 0.6235
P_sw_2 = 0.7547
```

```
% Vin=16V P=100W [real situation]
P_loss_total = 1.01
I_rms_1 = 7.2852;
I_rms_2 = 4.2913;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1
P_sw_2 = P_loss_total - P_cond_2
```

```
P_loss_total = 1.0100

P_cond_1 = 0.5307
P_cond_2 = 0.1842

P_sw_1 = 0.4793
P_sw_2 = 0.8258
```

```
% Vin=24V P=100W [real situation]
P_loss_total = 1.1
I_rms_1 = 5.9749;
I_rms_2 = 6.0983;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1
P_sw_2 = P_loss_total - P_cond_2
```

```
P_loss_total = 1.1000

P_cond_1 = 0.3570
P_cond_2 = 0.3719

P_sw_1 = 0.7430
P_sw_2 = 0.7281
```

```
% Vin=16V P=50W [real situation]
P_loss_total = 0.325
I_rms_1 = 3.6416;
I_rms_2 = 2.1465;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1
P_sw_2 = P_loss_total - P_cond_2
```

```
P_loss_total = 0.3250

P_cond_1 = 0.1326
P_cond_2 = 0.0461

P_sw_1 = 0.1924
P_sw_2 = 0.2789
```

```
% Vin=24V P=50W [real situation]
P_loss_total = 0.355
I_rms_1 = 2.9869;
I_rms_2 = 3.0517;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1
P_sw_2 = P_loss_total - P_cond_2
```

```
P_loss_total = 0.3550

P_cond_1 = 0.0892
P_cond_2 = 0.0931

P_sw_1 = 0.2658
P_sw_2 = 0.2619
```

conduction and switching loss.

```
% norminal Vin=20V P=100W [real situation]
P_loss_total = 1.05*1e-2 * 100
I_rms_1 = 6.5308;
I_rms_2 = 5.4345;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1
P_sw_2 = P_loss_total - P_cond_2
```

```
P_loss_total = 1.0500

P_cond_1 = 0.4265
P_cond_2 = 0.2953

P_sw_1 = 0.6235
P_sw_2 = 0.7547
```

```
P_loss_cond1 = D*IL^2*Rds
P_loss_cond2 = Dbar*IL^2*Rds

P_loss1 = P_loss_cond1 + P_loss_ov + P_loss_coss
P_loss2 = P_loss_cond2

P_sw1 = P_loss1 - P_loss_cond1
P_sw2 = P_loss2 - P_loss_cond2
```

```
P_loss_cond1 = 0.4167
P_loss_cond2 = 0.2778

P_loss1 = 0.8920
P_loss2 = 0.2778

P_sw1 = 0.4754
P_sw2 = 0
```

```
% Vin=24V P=100W [real situation]
P_loss_total = 1.1
I_rms_1 = 5.9749;
I_rms_2 = 6.0983;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1
P_sw_2 = P_loss_total - P_cond_2
```

```
P_loss_total = 1.1000

P_cond_1 = 0.3570
P_cond_2 = 0.3719

P_sw_1 = 0.7430
P_sw_2 = 0.7281
```

```
P_loss_cond1 = D*IL^2*Rds
P_loss_cond2 = Dbar*IL^2*Rds

P_loss1 = P_loss_cond1 + P_loss_ov + P_loss_coss
P_loss2 = P_loss_cond2

P_sw1 = P_loss1 - P_loss_cond1
P_sw2 = P_loss2 - P_loss_cond2
```

```
P_loss_cond1 = 0.3472
P_loss_cond2 = 0.3472

P_loss1 = 0.9338
P_loss2 = 0.3472

P_sw1 = 0.5865
P_sw2 = 0
```

```
% Vin=24V P=50W [real situation]
P_loss_total = 0.355
I_rms_1 = 2.9869;
I_rms_2 = 3.0517;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1
P_sw_2 = P_loss_total - P_cond_2
```

```
P_loss_total = 0.3550

P_cond_1 = 0.0892
P_cond_2 = 0.0931

P_sw_1 = 0.2658
P_sw_2 = 0.2619
```

```
P_loss_cond2 = Dbar*IL^2*Rds

P_loss1 = P_loss_cond1 + P_loss_ov + P_loss_coss
P_loss2 = P_loss_cond2

P_sw1 = P_loss1 - P_loss_cond1
P_sw2 = P_loss2 - P_loss_cond2
```

```
P_loss_cond1 = 0.0868
P_loss_cond2 = 0.0868
P_loss1 = 0.4283
P_loss2 = 0.0868
P_sw1 = 0.3415
P_sw2 = 0
```

```
% Vin=16V P=100W [real situation]
P_loss_total = 1.01
I_rms_1 = 7.2852;
I_rms_2 = 4.2913;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1
P_sw_2 = P_loss_total - P_cond_2
```

```
P_loss_total = 1.0100

P_cond_1 = 0.5307
P_cond_2 = 0.1842

P_sw_1 = 0.4793
P_sw_2 = 0.8258
```

```
P_loss_cond1 = D*IL^2*Rds
P_loss_cond2 = Dbar*IL^2*Rds

P_loss1 = P_loss_cond1 + P_loss_ov + P_loss_coss
P_loss2 = P_loss_cond2

P_sw1 = P_loss1 - P_loss_cond1
P_sw2 = P_loss2 - P_loss_cond2
```

```
P_loss_cond1 = 0.5208
P_loss_cond2 = 0.1736

P_loss1 = 0.8904
P_loss2 = 0.1736

P_sw1 = 0.3696
P_sw2 = 0
```

```
% Vin=16V P=50W [real situation]
P_loss_total = 0.325
I_rms_1 = 3.6416;
I_rms_2 = 2.1465;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1
P_sw_2 = P_loss_total - P_cond_2
```

```
P_loss_total = 0.3250

P_cond_1 = 0.1326
P_cond_2 = 0.0461

P_sw_1 = 0.1924
P_sw_2 = 0.2789
```

```
P_sw1 = P_loss1 - P_loss_cond1
P_sw2 = P_loss2 - P_loss_cond2

% junction Temperature
Tj1_nosink = Tamb + P_loss1*R_th_JA;
Tj2_nosink = Tamb + P_loss2*R_th_JA;
```

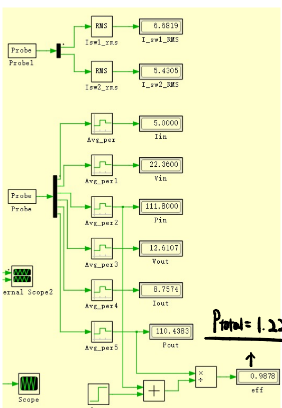
```
P_loss_cond1 = 0.1302
P_loss_cond2 = 0.0434
P_loss1 = 0.3364
P_loss2 = 0.0434
P_sw1 = 0.2062
P_sw2 = 0
```

converter design tradeoff.

1. Simulate your converter for the same operating point as above but with twice the switching frequency. In PLECS, estimate your conduction losses and switching losses, and compare these to the losses of the previous section. Estimate the ripple on the inductor current, and compare this to the previous ripple. Are these differences predictable using calculations?

f_s: 100kHz → 200kHz

Norminal Situation: V_{in} = 20V, P_{out} = 100W



P_{total} = 1.22

2fs:

```
% Vin=20V P=100W [real situation]
P_loss_total = 1.22
I_rms_1 = 6.6819;
I_rms_2 = 5.4305;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1 - P_cond_2
P_sw_2 = 0 % It's negelected
```

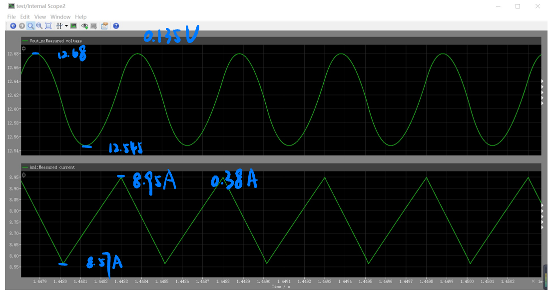
```
P_loss_total = 1.2200

P_cond_1 = 0.4465
P_cond_2 = 0.2949

P_sw_1 = 0.4786
P_sw_2 = 0
```

fs

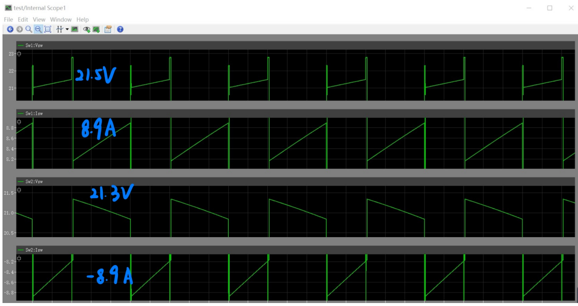
```
% Vin=20V P=100W [real situation]
P_loss_total = 1.05
I_rms_1 = 6.5308;
I_rms_2 = 5.4345;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1 - P_cond_2
P_sw_2 = 0 % It's negelected
```

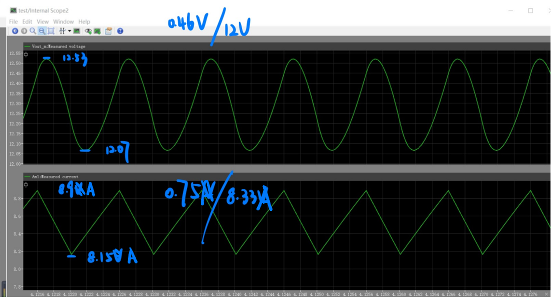
```
P_loss_total = 1.0500

P_cond_1 = 0.4265
P_cond_2 = 0.2953

P_sw_1 = 0.3281
P_sw_2 = 0
```

Smaller ripples

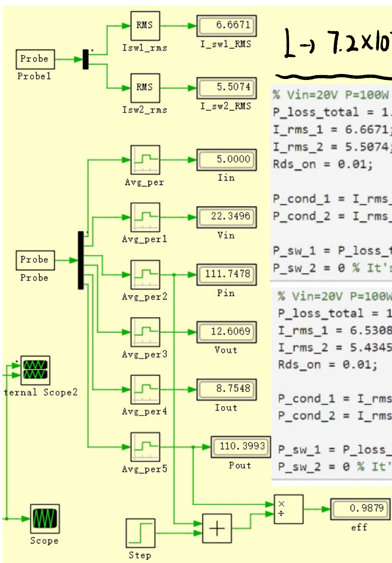


normirnal: $V_{in} = 20V$, $P = 100W$. Stresses.





2. Simulate your converter for the same operating point as above but with 1/8 the inductor size. In PLECS, estimate your conduction losses and switching losses, and compare these to the losses of the previous section. Are these differences predictable using calculations?



$L \to 7.2\times10^{-5}H / 8$

$L_x = \frac{1}{8}$

```
% Vin=20V P=100W [real situation]
P_loss_total = 1.21
I_rms_1 = 6.6671;
I_rms_2 = 5.5074;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1 - P_cond_2
P_sw_2 = 0 % It's negelected
```

ripple ↑, spikes ↑, s.t. Irms would be ↑ Pcond ↑

sw ↑

```
P_loss_total = 1.2100

P_cond_1 = 0.4445
P_cond_2 = 0.3033

P_sw_1 = 0.4622
P_sw_2 = 0
```

```
% Vin=20V P=100W [real situation]
P_loss_total = 1.05
I_rms_1 = 6.5308;
I_rms_2 = 5.4345;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1 - P_cond_2
P_sw_2 = 0 % It's negelected
```

```
P_loss_total = 1.0500
```

fs, L same. ⇓ P_cond should be the same.

```
P_cond_1 = 0.4265
P_cond_2 = 0.2953

P_sw_1 = 0.3281
P_sw_2 = 0
```

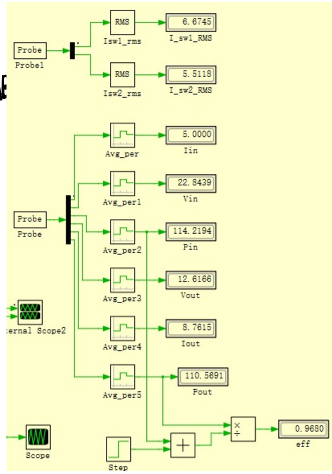
3. The $R_{ds,on}$ and C_{oss} of a switch are closely related to its die size. Select a different switch with the same voltage rating but a significantly $\boxed{\text{larger die size}}$ (~~i.e.~~, higher current rating), and use it to simulate your converter. In PLECS, estimate your conduction losses and switching losses, and compare these to the losses of the previous section. How does the switch's $R_{ds,on}$ and C_{oss} compare to the switch you chose?

??

Use IRZ34NPbF. but smaller die size $\boxed{29A}$

$R_{ds} = 0.04\Omega$. $C_{eq,E} = 4.3254\times10^{-10}$ F (From MATLA

$C_{oss} = 240pF$



original

```
% Vin=20V P=100W [real situation]
P_loss_total = 1.05
I_rms_1 = 6.5308;
I_rms_2 = 5.4345;
Rds_on = 0.01;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1 - P_cond_2
P_sw_2 = 0 % It's negelected
```

```
P_loss_total = 1.0500

P_cond_1 = 0.4265
P_cond_2 = 0.2953

P_sw_1 = 0.3281
P_sw_2 = 0
```

smaller die size.

```
% Vin=20V P=100W [real situation]
P_loss_total = 3.2
I_rms_1 = 6.6745;
I_rms_2 = 5.5118;
Rds_on = 0.04;

P_cond_1 = I_rms_1^2 * Rds_on
P_cond_2 = I_rms_2^2 * Rds_on

P_sw_1 = P_loss_total - P_cond_1 - P_cond_2
P_sw_2 = 0 % It's negelected
```

```
P_loss_total = 3.2000

P_cond_1 = 1.7820
P_cond_2 = 1.2152

P_sw_1 = 0.2028
P_sw_2 = 0
```

comparison on Coss and Rds.on.

Switch (mask) (link)
ideal, real switch models
Configuration
Non-ideal Sw
Parameters | Assertions
On-State Resistance [Ohms]:
0.01
Body Diode Forward Voltage [V]:
1.3
Body Diode On-State Resistance [Ohms]:
0.0065
Sw Output Capacitance [F]:
870e-12
Sw Output Capacitance ESR [Ohms]:
10e-6
OK | Cancel | Apply | Help

Block Parameters: test/Sw1
Switch (mask) (link)
ideal, real switch models
Configuration
Non-ideal Sw
Parameters | Assertions
On-State Resistance [Ohms]:
0.04
Body Diode Forward Voltage [V]:
1.6
Body Diode On-State Resistance [Ohms]:
0.0065
Sw Output Capacitance [F]:
240e-12
Sw Output Capacitance ESR [Ohms]:
10e-6
OK | Cancel | Apply | Help