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** **NCP1380 Inductor and Losses calculation for adapter** **

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** Rev: 2.0 12/22/2011

** Modifications: Version for WEB release

Corrected BO resistors calculation and OPP

Corrected Fsw calculation for Pout_limit

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HOW TO USE THE SPREADSHEET

This spreadsheet will calculate for you every parameter needed to design a power supply using the NCP1380 or the NCP1379.
The zones underlined in pink need data from the user.
The zones underlined in yellow are calculation results.

INPUT DATA

Minimum AC input voltage: $VIN_{min} := 85$ Maximum AC input voltage: $VIN_{max} := 265$

Maximum output power: $Pout := 60$ Output voltage: $Vout := 19$

Estimated efficiency: $\eta := 0.85$ Output diode forward voltage: $Vf := 0.8$

Switching frequency at maximum output power, low line: $F_{sw} := 45000$

Mosfet Coss: $C_{OSS} := 250 \cdot 10^{-12}$

MOSFET Rdson at Tj = 110 °C: $R_{dson110} := 0.77$

Bulk voltage ripple: $V_{BulkRipple} := 20$

$VIN_{minDC} := VIN_{min} \cdot \sqrt{2}$

$VCSmax := 0.8$

$VIN_{maxDC} := VIN_{max} \cdot \sqrt{2}$ $Iout := \frac{Pout}{Vout}$

Minimum DC voltage including bulk ripple (for transformer calculation):

$V_{min} := VIN_{minDC} - V_{BulkRipple}$ $V_{min} = 100.208$

Total Propagation delay time: $t_{prop} := 150 \cdot 10^{-9}$

Primary to secondary turn ratio calculation (Nps=Ns/Np)

MOSFET breakdown voltage: $BVdss := 650$

Derating factor for the MOSFET breakdown voltage: $\alpha := 0.85$

Leakage inductance ratio ($k_{leak} = L_{leak} / L_p$) $k_{leak1} := 0.005$ $k_{leak2} := 0.008$

$k_{leak3} := 0.01$

Clamping diode recovery time overshoot: $V_{os} := 20$

$V_{DSmax} := BVdss \cdot \alpha$

$V_{DSmax} = 552.5$

$$P_{cond}(k_c) := \frac{4}{3} \cdot R_{dson110} \cdot \frac{Pout^2}{\eta^2 \cdot V_{min}} \cdot \left[\frac{1}{V_{min}} + \frac{k_c}{(V_{DSmax} - VIN_{maxDC} - V_{os})} \right]$$

$$P_{cond2}(k_c) := \frac{4}{3} \cdot 1.2 \cdot \frac{Pout^2}{\eta^2 \cdot V_{min}} \cdot \left[\frac{1}{V_{min}} + \frac{k_c}{(V_{DSmax} - VIN_{maxDC} - V_{os})} \right]$$

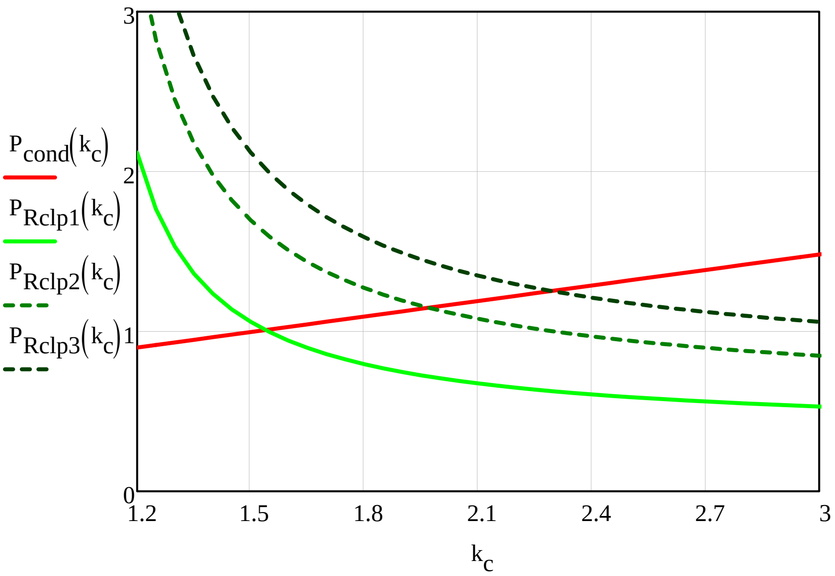
$$P_{Rclp1}(k_c) := k_{leak1} \cdot \frac{Pout}{\eta} \cdot \frac{k_c}{k_c - 1}$$

$$P_{Rclp2}(k_c) := k_{leak2} \cdot \frac{Pout}{\eta} \cdot \frac{k_c}{k_c - 1}$$

$$P_{Rclp3}(k_c) := k_{leak3} \cdot \frac{Pout}{\eta} \cdot \frac{k_c}{k_c - 1}$$

$k_c := 1.2, 1.25 .. 4$

The losses caused by the clamping resistor are plotted below for different value of kleak.



From above graph, enter the value for the clamping coefficient:

Clamping coefficient ($k_c = V_{clamp} / V_{reflect}$): $k_c := 2$

$$Nps := \frac{k_c \cdot (Vout + Vf)}{(BVdss \cdot \alpha - V_{os} - VIN_{maxDC})}$$ $Nps = 0.251$

Enter your value for Nps: $Nps := 0.25$

Ipk and Lp calculation including the dead-time

$$I_{pk} := \frac{2 \cdot Pout}{\eta} \cdot \left(\frac{1}{V_{min}} + \frac{Nps}{Vout + Vf} \right) + \pi \sqrt{\frac{2 \cdot Pout \cdot C_{OSS} \cdot F_{sw}}{\eta}}$$ $I_{pk} = 3.317$

$$L_p := \frac{2 \cdot Pout}{I_{pk}^2 \cdot \eta \cdot F_{sw}}$$ $L_p = 2.852 \times 10^{-4}$

Enter your value for Lp: $L_p := 285 \cdot 10^{-6}$

$$Rsense_1 := \frac{VCSmax}{I_{pk}}$$ $Rsense_1 = 0.241$

Enter the normalized value for Rsense: $Rsense := 0.23$

Primary and secondary rms current calculation

$$Ton_{max} := \frac{I_{pk} \cdot L_p}{V_{min}}$$ $Ton_{max} = 9.433 \times 10^{-6}$

$$D_{max} := Ton_{max} \cdot F_{sw}$$ $D_{max} = 0.424$

$$Ip_{RMS} := I_{pk} \cdot \sqrt{\frac{1 \cdot D_{max}}{3}}$$ $Ip_{RMS} = 1.248$

$$Ip_s := \frac{I_{pk}}{Nps}$$ $Ip_s = 13.266$

$$Is_{RMS} := Ip_s \cdot \sqrt{\frac{1}{3} \cdot (1 - D_{max})}$$ $Is_{RMS} = 5.811$

$$I_{priDC} := I_{pk} \cdot \frac{D_{max}}{2}$$ $I_{priDC} = 0.704$

$$I_{priAC} := \sqrt{Ip_{RMS}^2 - I_{priDC}^2}$$ $I_{priAC} = 1.03$

Auxiliary winding turn ratio

Desired value for VCC: $V_{CC} := 14$

$$N_{aux} := \frac{Nps \cdot (V_{CC} + Vf)}{Vout + Vf}$$ $N_{aux} = 0.187$

Output capacitor calculation

Desired Output voltage ripple: $Vripple := 0.4$

$$R_{ESR} := \frac{Vripple}{Ip_S} \qquad R_{ESR} = 0.03$$

$$I_{CoutRMS} := \sqrt{Is_{RMS}^2 - Iout^2} \qquad I_{CoutRMS} = 4.878$$

Enter your choice of output capacitor:

Panasonic serie FM: Two 680 uF cap (3.29 A, 16m, 35 V)

$C_{out} := 1360 \cdot 10^{-6}$ $\qquad R_{ESR} := 8 \cdot 10^{-3}$

Timing capacitor calculation

$I_{Ct} := 20 \cdot 10^{-6}$

$V_{FB1} := 0.8 \qquad V_{FB2} := 1.4$

$$T_{sw\_4th} := \left[\left(\frac{V_{FB1}}{4Rsense} + VIN_{maxDC} \cdot \frac{t_{prop}}{L_p}\right) \cdot L_p \cdot \left(\frac{1}{VIN_{maxDC}} + \frac{Nps}{Vout + Vf}\right)\right] + 7\pi \cdot \sqrt{L_p \cdot C_{OSS}}$$

$T_{sw\_4th} = 1.052 \times 10^{-5}$

$$V_{Ct} := 6.5 - \left(\frac{10}{3}\right) \cdot V_{FB2} \qquad V_{Ct} = 1.833$$

$$Ct := \frac{I_{Ct} \cdot \left(T_{sw\_4th} + 10 \cdot 10^{-6}\right)}{V_{Ct}} \qquad Ct = 2.239 \times 10^{-10}$$

Designer value for Ct: $Ct := 200 \cdot 10^{-12}$

Switching frequency versus output power at a given input voltage

* The function named "Chrono" below allows to calculate the peak current and the switching frequency for a defined output power and for a defined valley.
INPUTS: - Pout: the output power
- k: the operating valley (1st valley: k=0, 2nd valley: k=1, 3rd valley: k=2, 4th valley: k=3
- VIN: the input voltage in DC

OUPUT: a two line vector containing the peak current (1st line) and the switching frequency (2nd line)

$t_x := \pi \cdot \sqrt{L_p \cdot C_{OSS}}$

$$\text{chrono}(Pout, k, VIN) := \begin{array}{|l} n \leftarrow k \\ a \leftarrow \dfrac{L_p \cdot \eta}{2 \cdot Pout} \\ b \leftarrow -1 \cdot \left[\dfrac{L_p}{VIN} + \dfrac{Nps \cdot L_p}{(Vout + Vf)} \right] \\ c \leftarrow -(1 + 2 \cdot n) \cdot t_x \\ delta \leftarrow b^2 - 4 \cdot a \cdot c \\ Ip \leftarrow \dfrac{-b + \sqrt{delta}}{2 \cdot a} \\ Fsw \leftarrow \dfrac{1}{Ip \cdot \left[\dfrac{L_p}{VIN} + \dfrac{Nps \cdot L_p}{(Vout + Vf)} \right] + (1 + 2 \cdot n) \cdot t_x} \\ t_{demag} \leftarrow \dfrac{Ip \cdot L_p \cdot Nps}{Vout + Vf} \\ t_{on} \leftarrow \dfrac{Ip \cdot L_p}{VIN} \\ I_{priRMS} \leftarrow Ip \cdot \sqrt{\dfrac{t_{on} \cdot Fsw}{3}} \\ \begin{pmatrix} Ip \\ Fsw \\ t_{demag} \\ I_{priRMS} \end{pmatrix} \end{array}$$

$$\text{chrono}(20.1, 3, 100) = \begin{pmatrix} 1.658 \\ 6.039 \times 10^{4} \\ 5.965 \times 10^{-6} \\ 0.511 \end{pmatrix}$$

* The function below calculate the switching frequency and the corresponding valley for a decreasing output power.
Indeed, as there is hysteresis for the valley lockout, for a given ouput power, we can have two different couple of (Ipk,Fsw) delivering the same ouput power.

INPUTS: - Pmax: the starting output power
- Rsense: sense resistor
- VIN: the DC input voltage
- t_{prop}: the total propagation delay (curent sense + MOSFET) (For this design: 300 ns). At low line, it can be neglected: put $t_{prop} = 0$
- decr: decrementing calculation step for the output power

OUTPUT: a matrix containing the switching frequency, the peak current and the operating valley at different output powers.
Line 0: output power
Line 1: peak current
Line 2 : switching frequency
Line 3: valley number

$$Z_D(Pmax, Rsense, VIN, t_{prop}, decr) :=$$

$$j \leftarrow 0$$
$$V_{fb} \leftarrow 3.2$$
$$Pout \leftarrow Pmax$$
$$\text{while } (V_{fb} \geq 1.4)$$
$$\quad n \leftarrow 0$$
$$\quad v \leftarrow chrono(Pout, n, VIN)$$
$$\quad V_{fb} \leftarrow \left(v_0 \cdot Rsense - \frac{VIN \cdot t_{prop}}{L_p} \cdot Rsense\right) \cdot 4$$
$$\quad (\text{break}) \text{ if } V_{fb} < 1.4$$
$$\quad m_{0,j} \leftarrow Pout$$
$$\quad m_{1,j} \leftarrow v_0$$
$$\quad m_{2,j} \leftarrow v_1$$
$$\quad m_{3,j} \leftarrow n + 1$$
$$\quad m_{4,j} \leftarrow v_2$$
$$\quad m_{5,j} \leftarrow R_{dson110} \cdot (v_3)^2$$
$$\quad m_{6,j} \leftarrow \frac{1}{2} \cdot C_{OSS} \cdot \left(VIN - \frac{Vout + Vf}{Nps}\right)^2 \cdot v_1$$
$$\quad j \leftarrow j + 1$$
$$\quad Pout \leftarrow Pout - decr$$
$$\text{while } (1.2 \leq V_{fb} < 2.0)$$
$$\quad n \leftarrow 1$$
$$\quad v \leftarrow chrono(Pout, n, VIN)$$
$$\quad V_{fb} \leftarrow \left(v_0 \cdot Rsense - \frac{VIN \cdot t_{prop}}{L_p} \cdot Rsense\right) \cdot 4$$
$$\quad (\text{break}) \text{ if } (V_{fb} < 1.2) \vee (V_{fb} > 2.0)$$
$$\quad m_{0,j} \leftarrow Pout$$
$$\quad m_{1,j} \leftarrow v_0$$
$$\quad m_{2,j} \leftarrow v_1$$
$$\quad m_{3,j} \leftarrow n + 1$$
$$\quad m_{4,j} \leftarrow v_2$$
$$\quad m_{5,j} \leftarrow R_{dson110} \cdot (v_3)^2$$
$$\quad m_{6,j} \leftarrow \frac{1}{2} \cdot C_{OSS} \cdot \left(VIN - \frac{Vout + Vf}{Nps}\right)^2 \cdot v_1$$
$$\quad j \leftarrow j + 1$$
$$\quad Pout \leftarrow Pout - decr$$
$$\text{while } (0.9 \leq V_{fb} < 1.8)$$
$$\quad n \leftarrow 2$$

$n \leftarrow 2$

$v \leftarrow \text{chrono}(Pout, n, VIN)$

$V_{fb} \leftarrow \left(v_0 \cdot Rsense - \frac{VIN \cdot t_{prop}}{L_p} \cdot Rsense\right) \cdot 4$

$(\text{break}) \;\; \text{if} \;\; (V_{fb} < 0.9) \vee (V_{fb} > 1.8)$

$m_{0,j} \leftarrow Pout$

$m_{1,j} \leftarrow v_0$

$m_{2,j} \leftarrow v_1$

$m_{3,j} \leftarrow n + 1$

$m_{4,j} \leftarrow v_2$

$m_{5,j} \leftarrow R_{dson110} \cdot (v_3)^2$

$m_{6,j} \leftarrow \frac{1}{2} \cdot C_{OSS} \cdot \left(VIN - \frac{Vout + Vf}{Nps}\right)^2 \cdot v_1$

$j \leftarrow j + 1$

$Pout \leftarrow Pout - decr$

$\text{while} \;\; (0.8 \le V_{fb} < 1.6)$

$n \leftarrow 3$

$v \leftarrow \text{chrono}(Pout, n, VIN)$

$V_{fb} \leftarrow \left(v_0 \cdot Rsense - \frac{VIN \cdot t_{prop}}{L_p} \cdot Rsense\right) \cdot 4$

$(\text{break}) \;\; \text{if} \;\; (V_{fb} < 0.8) \vee (V_{fb} > 1.6)$

$m_{0,j} \leftarrow Pout$

$m_{1,j} \leftarrow v_0$

$m_{2,j} \leftarrow v_1$

$m_{3,j} \leftarrow n + 1$

$m_{4,j} \leftarrow v_2$

$m_{5,j} \leftarrow R_{dson110} \cdot (v_3)^2$

$m_{6,j} \leftarrow \frac{1}{2} \cdot C_{OSS} \cdot \left(VIN - \frac{Vout + Vf}{Nps}\right)^2 \cdot v_1$

$j \leftarrow j + 1$

$Pout \leftarrow Pout - decr$

$V_{fb} \leftarrow 1.38$

$\text{while} \;\; (0.3 \le V_{fb} < 1.4) \wedge (Pout > 0)$

$v \leftarrow \text{VCO1}(V_{fb}, VIN, t_{prop})$

$Pout_2 \leftarrow v_0$

$(\text{break}) \;\; \text{if} \;\; Pout_2 < 0.1$

$V_{fb} \leftarrow V_{fb} - 0.02$

$$
\begin{array}{l}
(\text{continue}) \quad \text{if } Pout_2 > Pout \\
m_{0,j} \leftarrow Pout_2 \\
m_{1,j} \leftarrow v_1 \\
m_{2,j} \leftarrow v_2 \\
m_{3,j} \leftarrow 1351 \\
m_{4,j} \leftarrow v_3 \\
j \leftarrow j + 1 \\
Pout \leftarrow Pout_2 \\
m
\end{array}
$$

Predicting the evolution of the switching frequency

Enter below the input voltage (rms) at which you want to see the frequency evolution (these voltage will also be used for the losses calculation)

$VIN_{low} := 115$ $VIN_{high} := 230$

$$decr_P := \frac{Pout}{60}$$

$$PatVINminD := Z_D\left(Pout, Rsense, VIN_{low} \cdot \sqrt{2}, t_{prop}, decr_P\right)$$

PatVINminD =

	0	1	2	3	4
0	60	59	58	57	56
1	2.799	2.755	2.71	2.666	2.622
2	$6.323 \cdot 10^{4}$	$6.419 \cdot 10^{4}$	$6.518 \cdot 10^{4}$	$6.621 \cdot 10^{4}$	$6.726 \cdot 10^{4}$
3	1	1	1	1	1
4	$1.007 \cdot 10^{-5}$	$9.913 \cdot 10^{-6}$	$9.753 \cdot 10^{-6}$	$9.594 \cdot 10^{-6}$	$9.434 \cdot 10^{-6}$
5	0.624	0.604	0.584	0.564	0.545
6	0.055	0.056	0.057	0.058	0.059

PatVINmaxD =

	0	1	2	3	4
0	60	59	58	57	56
1	2.39	2.353	2.316	2.279	2.242
2	$8.67 \cdot 10^{4}$	$8.796 \cdot 10^{4}$	$8.927 \cdot 10^{4}$	$9.061 \cdot 10^{4}$	$9.2 \cdot 10^{4}$
3	1	1	1	1	1
4	$8.602 \cdot 10^{-6}$	$8.468 \cdot 10^{-6}$	$8.334 \cdot 10^{-6}$	$8.201 \cdot 10^{-6}$	$8.067 \cdot 10^{-6}$
5	0.266	0.258	0.249	0.241	0.233
6	0.656	0.666	0.676	0.686	0.696

$$PatVINminI := Z_I\left(Rsense, VIN_{low} \cdot \sqrt{2}, t_{prop}, decr_P\right)$$

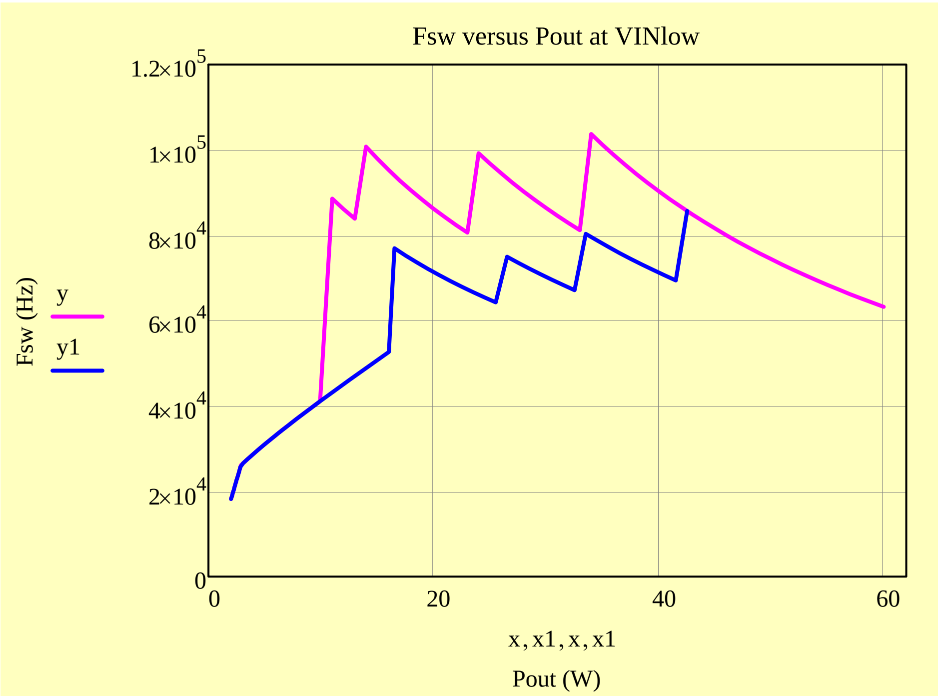
	0	1	2	3	4

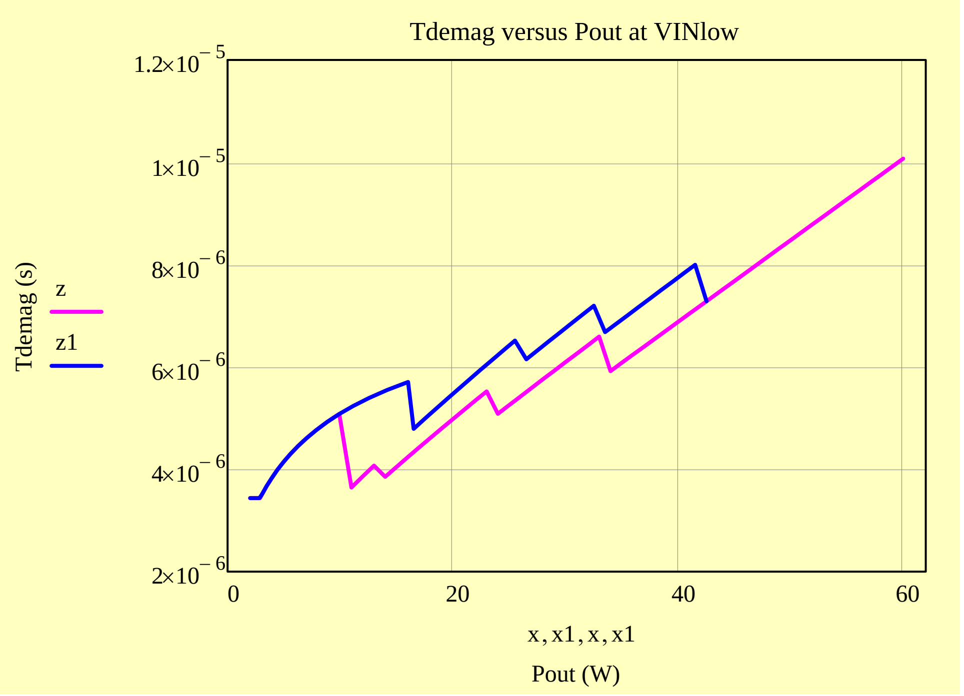
PatVINminI =

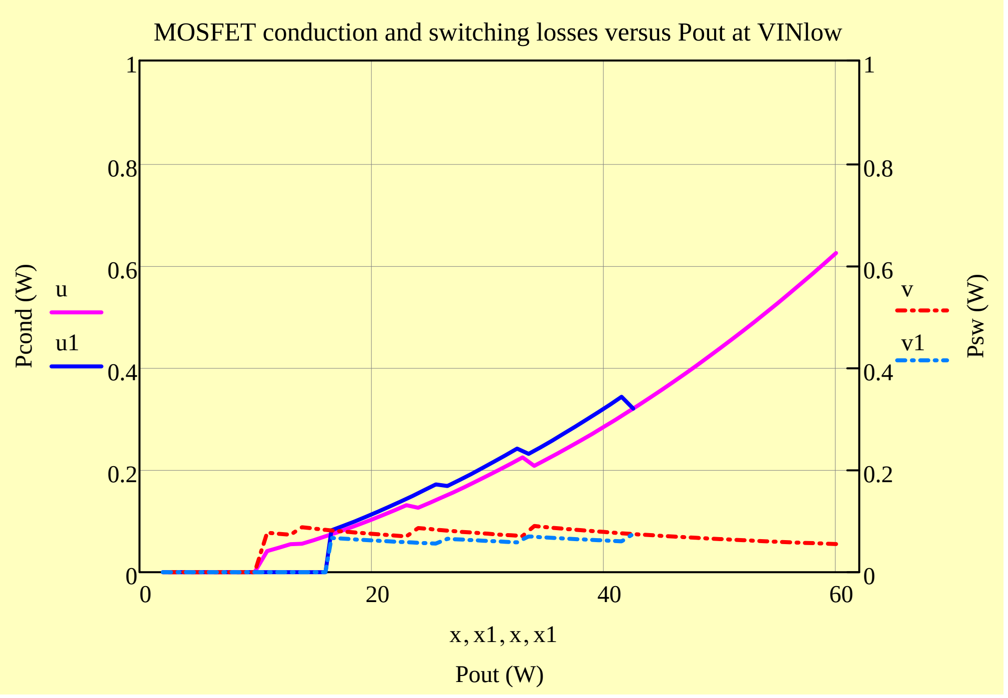
	0	1	2	3	4
0	2.009	2.059	2.112	2.167	2.225
1	0.955	0.955	0.955	0.955	0.955
2	$1.818 \cdot 10^{4}$	$1.863 \cdot 10^{4}$	$1.911 \cdot 10^{4}$	$1.961 \cdot 10^{4}$	$2.013 \cdot 10^{4}$
3	$1.351 \cdot 10^{3}$	$1.351 \cdot 10^{3}$	$1.351 \cdot 10^{3}$	$1.351 \cdot 10^{3}$	$1.351 \cdot 10^{3}$
4	$3.437 \cdot 10^{-6}$	$3.437 \cdot 10^{-6}$	$3.437 \cdot 10^{-6}$	$3.437 \cdot 10^{-6}$	$3.437 \cdot 10^{-6}$
5	0	0	0	0	0

PatVINmaxI =

	0	1	2	3	4
0	2.385	2.445	2.507	2.573	2.64[illegible]
1	1.041	1.041	1.041	1.041	1.04[illegible]
2	$1.818 \cdot 10^{4}$	$1.863 \cdot 10^{4}$	$1.911 \cdot 10^{4}$	$1.961 \cdot 10^{4}$	$2.013 \cdot 10^{4}$
3	$1.351 \cdot 10^{3}$	$1.351 \cdot 10^{3}$	$1.351 \cdot 10^{3}$	$1.351 \cdot 10^{3}$	$1.351 \cdot 10^{3}$
4	$3.745 \cdot 10^{-6}$	$3.745 \cdot 10^{-6}$	$3.745 \cdot 10^{-6}$	$3.745 \cdot 10^{-6}$	$3.745 \cdot 10^{-6}$
5	0	0	0	0	0
6	0	0	0	0	0







Note:
The MOSFET losses (conduction and switching) are calculated only for the quasi-resonant mode from the 1st valley to the 4th valley.
The losses are not calculated in VCO mode and that's why the curves shows a zero value at low output power.

OPP Calculation

Total propagation delay: $t_{prop\_OPP} := 600 \cdot 10^{-9}$

Output power capability at high line:

$$I_{pk\_max} := \frac{VCSmax}{Rsense} + \frac{VIN_{maxDC} \cdot t_{prop\_OPP}}{L_p}$$ $I_{pk\_max} = 4.267$

$$T_{sw\_max} := I_{pk\_max} \cdot L_p \cdot \left(\frac{1}{VIN_{maxDC}} + \frac{Nps}{Vout + Vf}\right) + \pi \cdot \sqrt{L_p \cdot C_{OSS}}$$

$T_{sw\_max} = 1.944 \times 10^{-5}$

$$P_{out\_max} := \frac{1}{2} \cdot L_p \cdot I_{pk\_max}^{\,2} \cdot \frac{1}{T_{sw\_max}} \cdot \eta$$ $P_{out\_max} = 113.461$

Ouput power limit wanted by the power supply designer: $P_{out\_limit} := 80$

$$a_{limit} := \frac{L_p \cdot \eta}{2 \cdot P_{out\_limit}}$$

$$b_{limit} := -L_p \cdot \left(\frac{1}{VIN_{maxDC}} + \frac{Nps}{Vout + Vf}\right)$$

$$c_{limit} := -\pi \sqrt{L_p \cdot C_{OSS}}$$

The corresponding peak current is:

$$I_{pk\_limit} := \frac{-b_{limit} + \sqrt{b_{limit}^{\,2} - 4 \cdot a_{limit} \cdot c_{limit}}}{2 \cdot a_{limit}}$$ $I_{pk\_limit} = 3.06$

The corresponding switching frequency is:

$$F_{sw\_limit} := \frac{2 \cdot P_{out\_limit}}{L_p \cdot I_{pk\_limit}^{\,2} \cdot \eta}$$ $F_{sw\_limit} = 7.054 \times 10^{4}$

OPP peak current reduction :

$$OPP := 100 \cdot \left(1 - \frac{I_{pk\_limit}}{I_{pk\_max}}\right)$$ $OPP = 28.291$ %

Primary to Auxiliary winding (Naux/Np) turn ratio: $Naux := 0.18$

OPP lower resistor: $R_{lowerOPP} := 1000$

$$VOPP := -VCSmax \cdot \frac{OPP}{100}$$ $VOPP = -0.226$

Note to the power supply designer:
The maximum OPP voltage that can be applied to the NCP1380 is -0.3 V.
Applying OPP voltage lower than -0.3 V can lead to an erratic behavior of the OPP.
If the OPP voltage calculated is below this limit, the output power limit must be increased.

$$Ratio := \frac{-Naux \cdot VIN_{maxDC} - VOPP}{VOPP}$$ $Ratio = 297.05$

$R_{upperOPP} := R_{lowerOPP} \cdot Ratio$ $\qquad R_{upperOPP} = 2.971 \times 10^{5}$

RCD clamp calculation

$V_{clamp} := \left(BVdss \cdot \alpha - V_{os} - VIN_{maxDC}\right)$ $\qquad V_{clamp} = 157.733$

We consider the leakage inductance equal to 1% of primary inductance.

$L_{leak} := 0.01 \cdot L_p$

$$R_{clp} := \frac{2 \cdot V_{clamp} \cdot \left[V_{clamp} - \frac{(Vout + Vf)}{Nps}\right]}{I_{pk}^{2} \cdot L_{leak} \cdot F_{sw}} \qquad R_{clp} = 1.756 \times 10^{4}$$

We consider a 20% ripple on V_{clamp} to calculate C_{clp}:

$$C_{clp} := \frac{V_{clamp}}{R_{clp} \cdot F_{sw} \cdot 0.2 \cdot V_{clamp}} \qquad C_{clp} = 6.327 \times 10^{-9}$$

$$PIV_{Dclp} := \frac{(Vout + Vf)}{Nps} + V_{os} \qquad PIV_{Dclp} = 99.2$$

Startup resistor calculation

$I_{CC1} := 20 \cdot 10^{-6}$

$I_{CC2} := 2 \cdot 10^{-3}$ $\qquad Q_g := 17 \cdot 10^{-9}$ $\qquad t_{reg} := 10 \cdot 10^{-3}$

$V_{CCon} := 17$ $\qquad V_{CCoff} := 9$ $\qquad T_{startup} := 3$

$VCC := 11$

$$Cvcc_1 := \frac{\left(I_{CC2} + Q_g \cdot F_{sw}\right) \cdot t_{reg}}{V_{CCon} - V_{CCoff}} \qquad Cvcc_1 = 3.456 \times 10^{-6}$$

Chosen value for Cvcc1: $Cvcc_1 := 4.7 \cdot 10^{-6}$

$$I_{Cvcc1} := V_{CCon} \cdot \frac{Cvcc_1}{T_{startup}} \qquad I_{Cvcc1} = 2.663 \times 10^{-5}$$

$$Rstart := \frac{VIN_{min} \cdot \sqrt{2}}{I_{Cvcc1} + I_{CC1}} \qquad Rstart = 2.578 \times 10^{6}$$

$$P_{Rstart} := \frac{\left(VIN_{max} \cdot \sqrt{2} - VCC\right)^{2}}{Rstart} \qquad P_{Rstart} = 0.051$$

*Half wave connexion

$$Rstart2 := \frac{\frac{VIN_{min} \cdot \sqrt{2}}{\pi}}{I_{Cvcc1} + I_{CC1}}$$ $Rstart2 = 8.205 \times 10^{5}$

$$P_{Rstart2} := \frac{\left(\frac{VIN_{max} \cdot \sqrt{2}}{\pi} - VCC\right)^{2}}{Rstart2}$$ $P_{Rstart2} = 0.014$

Brown-Out Resitors Calculation

dc voltage at which the controller should **start** switching: $V_{bulkON} := 110$

dc voltage at which the controller should **stop** switching: $V_{bulkOFF} := 70$

$IBO := 10 \cdot 10^{-6}$ $VBO := 0.8$

BO bridge lower resistor calculation:

$$R_{BOL} := \frac{VBO \cdot \left(V_{bulkON} - V_{bulkOFF}\right)}{IBO \cdot \left(V_{bulkON} - VBO\right)}$$ $R_{BOL} = 2.93 \times 10^{4}$

BO bridge lower resistor calculation:

$$R_{BOU} := \frac{R_{BOL} \cdot \left(V_{bulkON} - VBO\right)}{VBO}$$ $R_{BOU} = 4 \times 10^{6}$

* **MOSFET Heatsink Calculation**

MOSFET C_{OSS} at Vds = V_0 = 25 V: $C_{OSS} = 2.5 \times 10^{-10}$

Power loss at minimum input voltage

$$P_{condMOS} := R_{dson110} \cdot Ip_{RMS}^{2}$$ $P_{condMOS} = 1.198$

Junction temperature for MOS die : $Tj_{max} := 110$

Ambient temperature : $T_A := 50$

Heatsink calculation :

Junction to case coefficient (°C/W): $R_{\theta JC} := 2.5$

Case to heatsink coefficient (°C/W): $R_{\theta CS} := 1.6$

$$R_{\theta SA} := \frac{Tj_{max} - T_A}{P_{condMOS}} - R_{\theta CS} - R_{\theta JC}$$ $R_{\theta SA} = 45.968$

* **Output diode heatsink calculation**

Diode forward voltage at low current: $Vf_{d0} := 0.62$

Diode dynamic resistance: $R_d := 0.02$

$$Pdiode := Vf_{d0} \cdot Iout + R_d \cdot Is_{RMS}^2$$ $$Pdiode = 2.633$$

Junction temperature for diode die : $Tj_{max} := 120$

Ambient temperature : $T_A := 50$

Heatsink calculation :

$R_{\theta JC} := 2$ $R_{\theta CS} := 1.6$

$$R_{\theta SAd} := \frac{Tj_{max} - T_A}{Pdiode} - R_{\theta CS} - R_{\theta JC}$$ $$R_{\theta SAd} = 22.984$$

Losses calculation

$$I_{pk\_low} := Z_D\left(Pout, Rsense, VIN_{low} \cdot \sqrt{2}, t_{prop}, decr_P\right)_{1,0}$$ $$I_{pk\_low} = 2.799$$

$$F_{sw\_low} := Z_D\left(Pout, Rsense, VIN_{low} \cdot \sqrt{2}, t_{prop}, decr_P\right)_{2,0}$$

$$d_{low} := \frac{I_{pk\_low} \cdot L_p}{VIN_{low} \cdot \sqrt{2}} \cdot F_{sw\_low}$$ $$d_{low} = 0.31$$

$$Ip_{RMS\_low} := I_{pk\_low} \cdot \sqrt{\frac{d_{low}}{3}}$$ $$Ip_{RMS\_low} = 0.9$$

$$Is_{RMS\_low} := \frac{I_{pk\_low}}{Nps} \cdot \sqrt{\frac{1}{3} \cdot \left(1 - d_{low}\right)}$$ $$Is_{RMS\_low} = 5.369$$

$$I_{CoutRMS\_low} := \sqrt{Is_{RMS\_low}^2 - Iout^2}$$ $$I_{CoutRMS\_low} = 4.342$$

* Power loss in RCD clamp

$$P_{Clp} := \frac{V_{clamp}^2}{R_{clp}}$$ $$P_{Clp} = 1.417$$

* Power loss in sense resistor:

$$Psense := Rsense \cdot Ip_{RMS\_low}^2$$ $$Psense = 0.186$$

* Power loss in Cout

$$P_{Cout} := R_{ESR} \cdot I_{CoutRMS\_low}^2$$ $$P_{Cout} = 0.151$$

* **Power loss in MOSFET**

MOSFET C_{OSS} at Vds = V_0 = 25 V: $C_{OSS} = 2.5 \times 10^{-10}$

Power loss at minimum input voltage

$$P_{cond1} := R_{dson110} \cdot Ip_{RMS\_low}^{2}$$ $$P_{cond1} = 0.624$$

* **Switching losses**

$$P_{SW1} := \frac{2}{3} \cdot \left(VIN_{low} \cdot \sqrt{2} + \frac{Vout + Vf}{Nps} \cdot \cos(\pi) \right)^{\frac{3}{2}} \cdot C_{OSS} \cdot \sqrt{25} \cdot F_{sw}$$

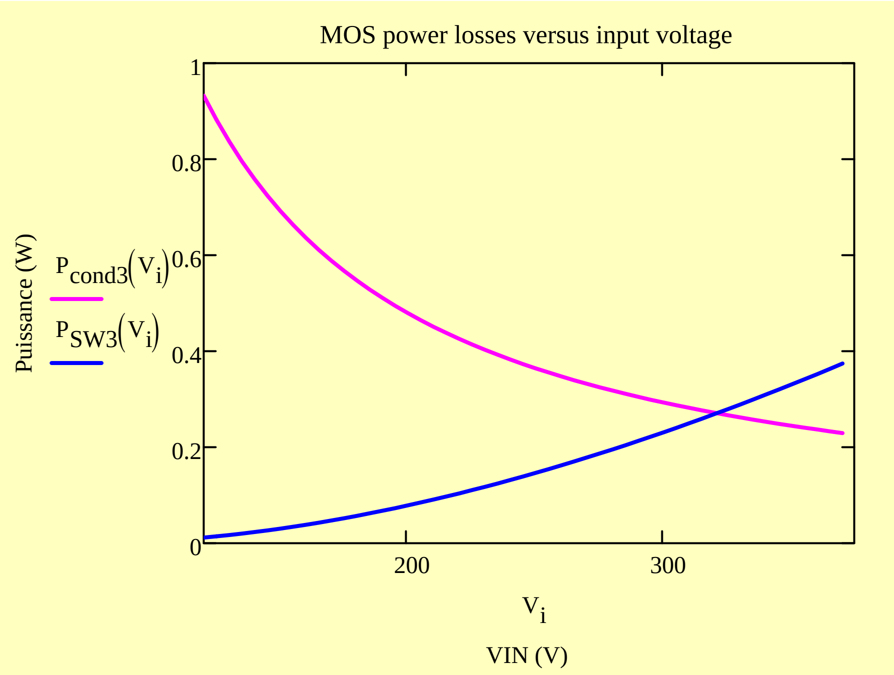
$$P_{SW1} = 0.029$$

$$P_{MOS1} := P_{cond1} + P_{SW1}$$ $$P_{MOS1} = 0.652$$

$$V_i := VIN_{minDC}, VIN_{minDC} + 5 .. VIN_{maxDC}$$

$$P_{SW3}(V_i) := \frac{2}{3} \cdot \left(V_i + \frac{Vout + Vf}{Nps} \cdot \cos(\pi) \right)^{\frac{3}{2}} \cdot C_{OSS} \cdot \sqrt{25} \cdot \left(Z_D(Pout, Rsense, V_i, t_{prop}, decr_P)_{2,}\right.$$

$$P_{cond3}(V_i) := R_{dson110} \cdot \frac{\left(Z_D(Pout, Rsense, V_i, t_{prop}, decr_P)_{1,0} \right)^{3} \cdot L_p \cdot \left(Z_D(Pout, Rsense, V_i, t_p \right.}{3 \cdot V_i}$$



* **Power loss in output diode**

Diode forward voltage at low current: $Vf_{d0} := 0.62$

Diode dynamic resistance: $R_d := 0.02$

$Pdiode := Vf_{d0} \cdot Iout + R_d \cdot Is_{RMS\_low}^2$ $Pdiode = 2.534$

Junction temperature for diode die : $Tj_{max} := 120$

Ambient temperature : $T_A := 50$

Heatsink calculation :

$R_{\theta JC} := 2$ $R_{\theta CS} := 1.6$

$$R_{\theta SAd} := \frac{Tj_{max} - T_A}{Pdiode} - R_{\theta CS} - R_{\theta JC}$$ $R_{\theta SAd} = 24.02$

Peak inverse voltage :

$PIV_{diode} := VIN_{maxDC} \cdot Nps + Vout + Vf$ $PIV_{diode} = 113.492$

* **Power loss in diode bridge and in bulk capacitor**

Bulk cap: $C_{bulk2} := 100 \cdot 10^{-6}$ $ESR_{bulk} := 0.360$

Minimum bulk voltage (including ripple): $Vmin2 := VIN_{low} \cdot \sqrt{2} - V_{BulkRipple}$

Threshold voltage of one diode of the diode bridge: $V_{f0} := 0.74$

Dymanic resistance of one diode of the diode bridge: $R_{d2} := 0.07$

(The diode bridge used is a KBU4K)

Line frequency: $F_{line} := 50$

$$Iin_{moy} := \frac{I_{pk\_low} \cdot d_{low}}{2}$$ $Iin_{moy} = 0.434$

Diode conduction time:

$$t_c := \frac{1}{4 \cdot F_{line}} - \frac{\operatorname{asin}\left(\frac{Vmin2}{VIN_{low} \cdot \sqrt{2}}\right)}{2 \cdot \pi \cdot F_{line}}$$ $t_c = 1.595 \times 10^{-3}$

$$I_{bulkRMS} := Iin_{moy} \cdot \sqrt{\frac{2}{3 \cdot F_{line} \cdot t_c} - 1}$$ $I_{bulkRMS} = 1.177$

$$P_{ESRbulk} := ESR_{bulk} \cdot I_{bulkRMS}^2$$ $P_{ESRbulk} = 0.499$

$$I_{diodeRMS} := \frac{Iin_{moy}}{\sqrt{3 \cdot F_{line} \cdot t_c}}$$ $I_{diodeRMS} = 0.887$

$$Idiode_{moy} := \frac{Iin_{moy}}{2}$$ $Idiode_{moy} = 0.217$

$$P_{diodeIN} := \left(\frac{Iin_{moy}}{2} \cdot V_{f0} + R_{d2} \cdot I_{diodeRMS}^{\;2}\right) \cdot 4$$ $P_{diodeIN} = 0.863$

$$Iin_{RMS} := \frac{\sqrt{2} \cdot Iin_{moy}}{\sqrt{3 \cdot F_{line} \cdot t_c}}$$ $Iin_{RMS} = 1.255$

* **Transfo losses**

Secondary winding DC resistance: $R_{secDC} := 0.008 \cdot \Omega$

Secondary winding AC resistance: $R_{secAC} := 0.03 \cdot \Omega$

Secondary winding DC resistance: $R_{priDC} := 0.1 \cdot \Omega$

Secondary winding AC resistance: $R_{priAC} := 0.18 \cdot \Omega$

Core loss: $P_{core} := 0.2 \cdot W$

$$P_{sec} := R_{secAC} \cdot I_{CoutRMS\_low}^{\;2} + R_{secDC} \cdot Iout^2$$ $P_{sec} = 0.645\ \Omega$

$$P_{pri} := R_{priAC} \cdot \left(Ip_{RMS\_low}^{\;2} - Iin_{moy}^{\;2}\right) + R_{priDC} \cdot Iin_{moy}^{\;2}$$ $P_{pri} = 0.131\ \Omega$

$$P_{transfo} := P_{sec} + P_{pri} + P_{core}$$ $P_{transfo} = ▮$

* Total losses at max input power

$$P_{loss} := P_{transfo} + P_{ESRbulk} + P_{diodeIN} + Pdiode + P_{MOS2} + P_{Clp} + Psense + P_{Cout}$$

$P_{loss} = ▮$

Estimated efficiency at low line: $$effi := \frac{Pout}{Pout + P_{loss}} \cdot 100$$ $effi = ▮$

<u>* Synchronous rectification calculation</u>

Mosfet : 1 MOS IRFS4321PBF BV = 150 V D²PAK

RdsON @ Tj = 110°C : $R_{dsON2} := 30 \cdot 10^{-3}$ $C_{OSS2} := 390 \cdot 10^{-12}$

Body diode voltage drop: $V_{f2} := 0.5$

NCP4302 delay time: $t_{delay} := 70 \cdot 10^{-9}$

At minimum input voltage:

$P_{ON3} := Is_{RMS}^{2} \cdot R_{dsON2}$ $P_{ON3} = 1.013$

$P_{d3} := V_{f2} \cdot Iout \cdot F_{sw} \cdot t_{delay}$ $P_{d3} = 4.974 \times 10^{-3}$

$P_{SyncR} := P_{ON3} + P_{d3}$ $P_{SyncR} = 1.018$

Total power loss with synchronous rectification

$P_{loss2} := P_{transfo} + P_{ESRbulk} + P_{diodeIN} + P_{SyncR} + P_{MOS2} + P_{Clp} + Psense + P_{Cout}$

$P_{loss2} = ▮$

Estimated efficiency with SR: $effi2 := \frac{Pout}{Pout + P_{loss2}} \cdot 100$ $effi2 = ▮$

*** Compensating the power supply**

FB pullup resistor inside NCP1380: $R_{pullup} := 18 \cdot 10^{3}$

Current in the TL431 bridge: $I_{bridge} := 250 \cdot 10^{-6}$

Optocoupler transfer ratio: $CTR := 0.6$

Optocoupler parasitic capacitance: $C_{opto} := 2.5 \cdot 10^{-9}$

Desired Cross over frequency: $f_c := 800$

Desired phase margin: $PM := 60$

$R_{lower} := \frac{2.5}{I_{bridge}}$ $R_{lower} = 1 \times 10^{4}$

$R_{upper} := \frac{Vout - 2.5}{I_{bridge}}$ $R_{upper} = 6.6 \times 10^{4}$

$R_{load} := \frac{Vout}{Iout}$

$R_{eq} := R_{load} \cdot \frac{Vout + Nps \cdot VIN_{minDC}}{2 \cdot Vout + Nps \cdot VIN_{minDC}}$ $R_{eq} = 4.337$

$G_0 := \frac{\eta \cdot VIN_{minDC} \cdot R_{load}}{8 \cdot Rsense \cdot (2 \cdot Vout + Nps \cdot VIN_{minDC})}$ $G_0 = 4.91$

$V_c := \frac{2 \cdot Pout \cdot 4 \cdot Rsense \cdot (Vout + Nps \cdot VIN_{minDC})}{Vout \cdot VIN_{minDC} \cdot \eta}$

$$G_x(f) := G_0 \cdot \frac{(1 + R_{ESR} \cdot C_{out} \cdot 2 \cdot \pi \cdot f \cdot i) \cdot \left[1 - \frac{L_p \cdot V_c}{8 \cdot Rsense \cdot VIN_{minDC}} \cdot (2 \cdot \pi \cdot f \cdot i)\right]}{(1 + R_{eq} \cdot C_{out} \cdot 2 \cdot \pi \cdot f \cdot i) \cdot (1 + R_{pullup} \cdot C_{opto} \cdot 2 \cdot \pi \cdot f \cdot i)}$$

$PS := \arg(G_x(f_c)) \cdot \frac{180}{\pi}$ $PS = -98.718$

Needed phase boost:

$$Boost := PM - PS - 90 \qquad Boost = 68.718$$

$$k := \tan\left[\left(\frac{Boost}{2} + 45\right)\cdot\frac{\pi}{180}\right] \qquad k = 5.322$$

$$f_{pc} := k\cdot f_c \qquad f_{pc} = 4.258\times 10^{3}$$

$$f_{zc} := \frac{f_c}{k} \qquad f_{zc} = 150.306$$

$$C_{zero} := \frac{1}{2\cdot\pi\cdot R_{upper}\cdot f_{zc}} \qquad C_{zero} = 1.604\times 10^{-8}$$

$$C_{pole} := \frac{1}{2\cdot\pi\cdot R_{pullup}\cdot f_{pc}} \qquad C_{pole} = 2.077\times 10^{-9}$$

$$G_s := 20\cdot\log\left(\left|G_x\left(f_c\right)\right|\right) \qquad G_s = -15.826$$

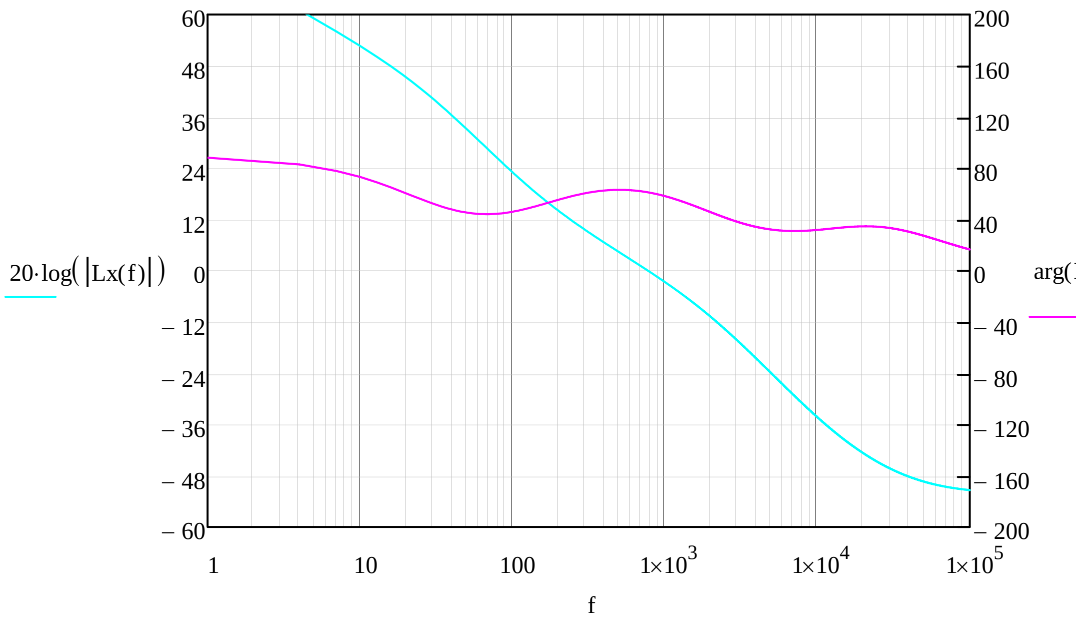
$$R_{led} := \frac{R_{pullup}\cdot CTR}{10^{\frac{-G_s}{20}}} \qquad R_{led} = 1.746\times 10^{3}$$

$$H_0 := R_{pullup}\cdot\frac{CTR}{R_{led}}$$

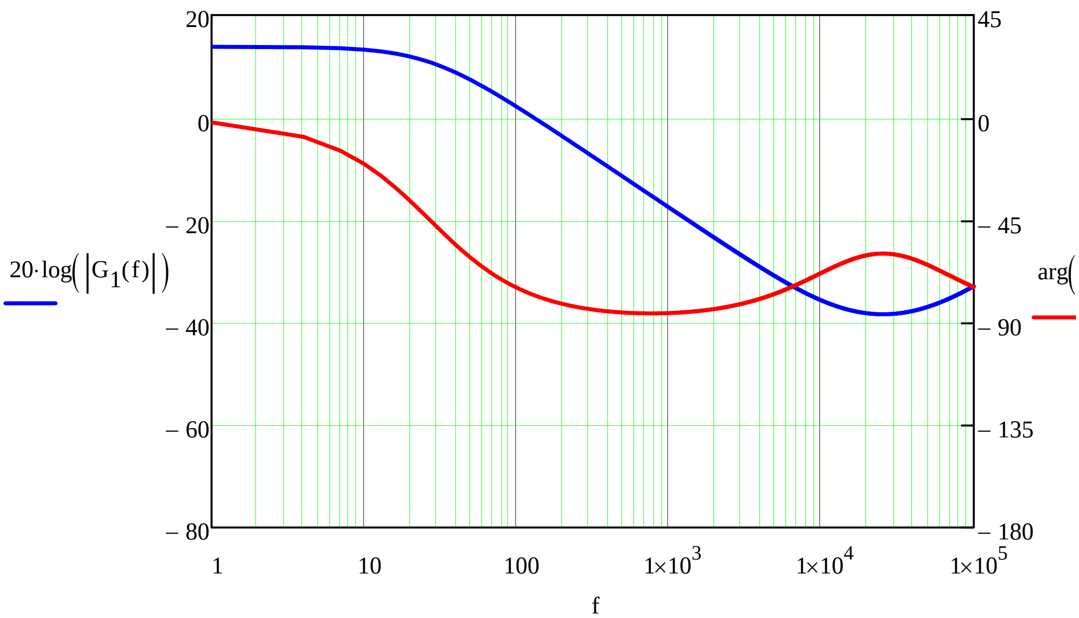
$$f := 1, 4 .. 100000$$

$$G_1(f) := G_0\cdot\frac{\left(1 + R_{ESR}\cdot C_{out}\cdot 2\cdot\pi\cdot f\cdot i\right)\cdot\left[1 - \frac{L_p\cdot V_c}{8\cdot Rsense\cdot VIN_{minDC}}\cdot(2\cdot\pi\cdot f\cdot i)\right]}{\left(1 + R_{eq}\cdot C_{out}\cdot 2\cdot\pi\cdot f\cdot i\right)}$$

$$Lx(f) := -G_0\cdot H_0\cdot\frac{\left(1 + R_{upper}\cdot C_{zero}\cdot 2\cdot\pi\cdot f\cdot i\right)\cdot\left(1 + R_{ESR}\cdot C_{out}\cdot 2\cdot\pi\cdot f\cdot i\right)\cdot\left[1 - \frac{L_p\cdot V_c}{8\cdot Rsense\cdot VIN_{minI}}\right.}{\left[1 + R_{pullup}\cdot\left(C_{pole} + C_{opto}\right)\cdot 2\cdot\pi\cdot f\cdot i\right]\cdot\left(R_{upper}\cdot C_{zero}\cdot 2\cdot\pi\cdot f\cdot i\right)\cdot\left(1 + R_{eq}\cdot C_{(}\right.}$$



60
48
36
24
12
0
– 12
– 24
– 36
– 48
– 60
200
160
120
80
40
0
– 40
– 80
– 120
– 160
– 200
20·log(|Lx(f)|)
arg(
1
10
100
1×10^3
1×10^4
1×10^5
f



20
0
– 20
– 40
– 60
– 80
45
0
– 45
– 90
– 135
– 180
20·log(|G1(f)|)
arg(
1
10
100
1×10^3
1×10^4
1×10^5
f

$$VCO1(V_{fb}, VIN, t_{prop}) := \left| \begin{array}{l} Fsw \leftarrow \dfrac{I_{Ct}}{Ct \cdot \left(6.5 - \dfrac{10}{3} \cdot V_{fb}\right)} \\ Ip \leftarrow \left(\dfrac{V_{fb}}{4 \cdot Rsense} + VIN \cdot \dfrac{t_{prop}}{L_p}\right) \text{ if } V_{fb} > 0.8 \\ Ip \leftarrow \left(\dfrac{0.8}{4 \cdot Rsense} + VIN \cdot \dfrac{t_{prop}}{L_p}\right) \text{ if } V_{fb} \le 0.8 \\ Pout \leftarrow \dfrac{1}{2} \cdot L_p \cdot Ip^2 \cdot Fsw \cdot \eta \\ t_{demag} \leftarrow \dfrac{Ip \cdot L_p \cdot Nps}{Vout + Vf} \\ \begin{pmatrix} Pout \\ Ip \\ Fsw \\ t_{demag} \end{pmatrix} \end{array} \right.$$

$$VCO1(0.8, 100, 0) = \begin{pmatrix} 2.389 \\ 0.87 \\ 2.609 \times 10^{4} \\ 3.129 \times 10^{-6} \end{pmatrix}$$

* The function below calculate the switching frequency and the corresponding valley for an increasing output power.
Indeed, as there is hysteresis for the valley lockout, for a given ouput power, we can have two different couple of (Ipk,Fsw) delivering the same ouput power.

INPUTS: - Pmin: the lowest starting output power
- Rsense: sense resistor
- VIN: the DC input voltage
- t_{prop}: the total propagation delay (current sense +MOSFET).
At low line, it can be neglected: put $t_{prop} = 0$
- inc: incrementing calculation step for the output power

OUTPUT: a matrix containing the switching frequency, the peak current and the operating valley at different output powers.
Line 0: output power
Line 1: peak current
Line 2: valley number

$$Z_I(Rsense, VIN, t_{prop}, inc) :=$$

$$j \leftarrow 0$$
$$V_{fb} \leftarrow 0.3$$
$$\text{while } (0.3 \le V_{fb} < 1.4)$$
$$\quad v \leftarrow VCO1(V_{fb}, VIN, t_{prop})$$
$$\quad Pout \leftarrow v_0$$
$$\quad (\text{break}) \text{ if } (V_{fb} \ge 1.4)$$
$$\quad m_{0,j} \leftarrow Pout$$
$$\quad m_{1,j} \leftarrow v_1$$
$$\quad m_{2,j} \leftarrow v_2$$
$$\quad m_{3,j} \leftarrow 1351$$
$$\quad m_{4,j} \leftarrow v_3$$
$$\quad j \leftarrow j + 1$$
$$\quad V_{fb} \leftarrow V_{fb} + 0.04$$
$$V_{fb} \leftarrow 0.82$$
$$Pout \leftarrow Pout + 0.5$$
$$\text{while } (0.8 < V_{fb} < 1.6)$$
$$\quad n \leftarrow 3$$
$$\quad v \leftarrow chrono(Pout, n, VIN)$$
$$\quad V_{fb} \leftarrow \left(v_0 \cdot Rsense - \frac{VIN \cdot t_{prop}}{L_p} \cdot Rsense\right) \cdot 4$$
$$\quad (\text{break}) \text{ if } (V_{fb} < 0.8) \vee (V_{fb} > 1.6)$$
$$\quad m_{0,j} \leftarrow Pout$$
$$\quad m_{1,j} \leftarrow v_0$$
$$\quad m_{2,j} \leftarrow v_1$$
$$\quad m_{3,j} \leftarrow n + 1$$
$$\quad m_{4,j} \leftarrow v_2$$
$$\quad m_{5,j} \leftarrow R_{dson110} \cdot (v_3)^2$$
$$\quad m_{6,j} \leftarrow \frac{1}{2} \cdot C_{OSS} \cdot \left(VIN - \frac{Vout + Vf}{Nps}\right)^2 \cdot v_1$$
$$\quad j \leftarrow j + 1$$
$$\quad Pout \leftarrow Pout + inc$$
$$\text{while } (0.9 \le V_{fb} < 1.8)$$
$$\quad n \leftarrow 2$$
$$\quad v \leftarrow chrono(Pout, n, VIN)$$
$$\quad V_{fb} \leftarrow \left(v_0 \cdot Rsense - \frac{VIN \cdot t_{prop}}{L_p} \cdot Rsense\right) \cdot 4$$

$$(\text{break}) \ \text{if} \ (V_{fb} < 0.9) \vee (V_{fb} > 1.8)$$
$$m_{0,j} \leftarrow Pout$$
$$m_{1,j} \leftarrow v_0$$
$$m_{2,j} \leftarrow v_1$$
$$m_{3,j} \leftarrow n + 1$$
$$m_{4,j} \leftarrow v_2$$
$$m_{5,j} \leftarrow R_{dson110} \cdot (v_3)^2$$
$$m_{6,j} \leftarrow \frac{1}{2} \cdot C_{OSS} \cdot \left(VIN - \frac{Vout + Vf}{Nps}\right)^2 \cdot v_1$$
$$j \leftarrow j + 1$$
$$Pout \leftarrow Pout + inc$$

$$\text{while} \ (1.2 \le V_{fb} < 2.0)$$
$$n \leftarrow 1$$
$$v \leftarrow chrono(Pout, n, VIN)$$
$$V_{fb} \leftarrow \left(v_0 \cdot Rsense - \frac{VIN \cdot t_{prop}}{L_p} \cdot Rsense\right) \cdot 4$$
$$(\text{break}) \ \text{if} \ (V_{fb} < 1.2) \vee (V_{fb} > 2.0)$$
$$m_{0,j} \leftarrow Pout$$
$$m_{1,j} \leftarrow v_0$$
$$m_{2,j} \leftarrow v_1$$
$$m_{3,j} \leftarrow n + 1$$
$$m_{4,j} \leftarrow v_2$$
$$m_{5,j} \leftarrow R_{dson110} \cdot (v_3)^2$$
$$m_{6,j} \leftarrow \frac{1}{2} \cdot C_{OSS} \cdot \left(VIN - \frac{Vout + Vf}{Nps}\right)^2 \cdot v_1$$
$$j \leftarrow j + 1$$
$$Pout \leftarrow Pout + inc$$

$$\text{while} \ (2.0 \le V_{fb} < 3.2)$$
$$n \leftarrow 0$$
$$v \leftarrow chrono(Pout, n, VIN)$$
$$V_{fb} \leftarrow \left(v_0 \cdot Rsense - \frac{VIN \cdot t_{prop}}{L_p} \cdot Rsense\right) \cdot 4$$
$$(\text{break}) \ \text{if} \ (V_{fb} \ge 3.2)$$
$$m_{0,j} \leftarrow Pout$$
$$m_{1,j} \leftarrow v_0$$
$$m_{2,j} \leftarrow v_1$$

$$
\left|\begin{array}{l}
\left|\begin{array}{l}
m_{3,j} \leftarrow n + 1 \\
m_{4,j} \leftarrow v_2 \\
m_{5,j} \leftarrow R_{dson110} \cdot \left(v_3\right)^2 \\
m_{6,j} \leftarrow \frac{1}{2} \cdot C_{OSS} \cdot \left(VIN - \frac{Vout + Vf}{Nps}\right)^2 \cdot v_1 \\
j \leftarrow j + 1 \\
Pout \leftarrow Pout + inc
\end{array}\right. \\
m
\end{array}\right.
$$

$$PatVINmaxD := Z_D\left(Pout, Rsense, VIN_{high} \cdot \sqrt{2}, t_{prop}, decr_P\right)$$

5	6	7	8	9	10
55	54	53	52	51	50
2.577	2.533	2.489	2.444	2.4	2.356
$6.835 \cdot 10^4$	$6.948 \cdot 10^4$	$7.064 \cdot 10^4$	$7.185 \cdot 10^4$	$7.309 \cdot 10^4$	$7.438 \cdot 10^4$
1	1	1	1	1	1
$9.275 \cdot 10^{-6}$	$9.115 \cdot 10^{-6}$	$8.956 \cdot 10^{-6}$	$8.796 \cdot 10^{-6}$	$8.637 \cdot 10^{-6}$	$8.477 \cdot 10^{-6}$
0.526	0.508	0.49	0.472	0.455	0.437
0.059	0.06	0.061	0.063	0.064	...

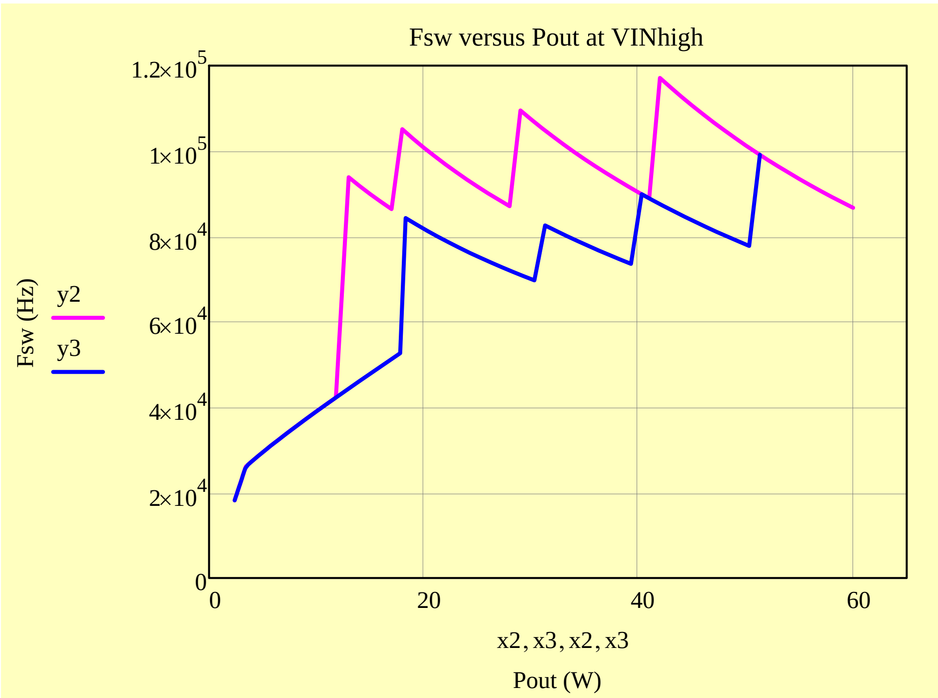
5	6	7	8	9	10
55	54	53	52	51	50
2.205	2.167	2.13	2.093	2.056	2.019
$9.343 \cdot 10^4$	$9.49 \cdot 10^4$	$9.643 \cdot 10^4$	$9.8 \cdot 10^4$	$9.962 \cdot 10^4$	$1.013 \cdot 10^5$
1	1	1	1	1	1
$7.933 \cdot 10^{-6}$	$7.799 \cdot 10^{-6}$	$7.666 \cdot 10^{-6}$	$7.532 \cdot 10^{-6}$	$7.398 \cdot 10^{-6}$	$7.264 \cdot 10^{-6}$
0.225	0.217	0.21	0.202	0.195	0.187
0.707	0.718	0.73	0.742	0.754	...

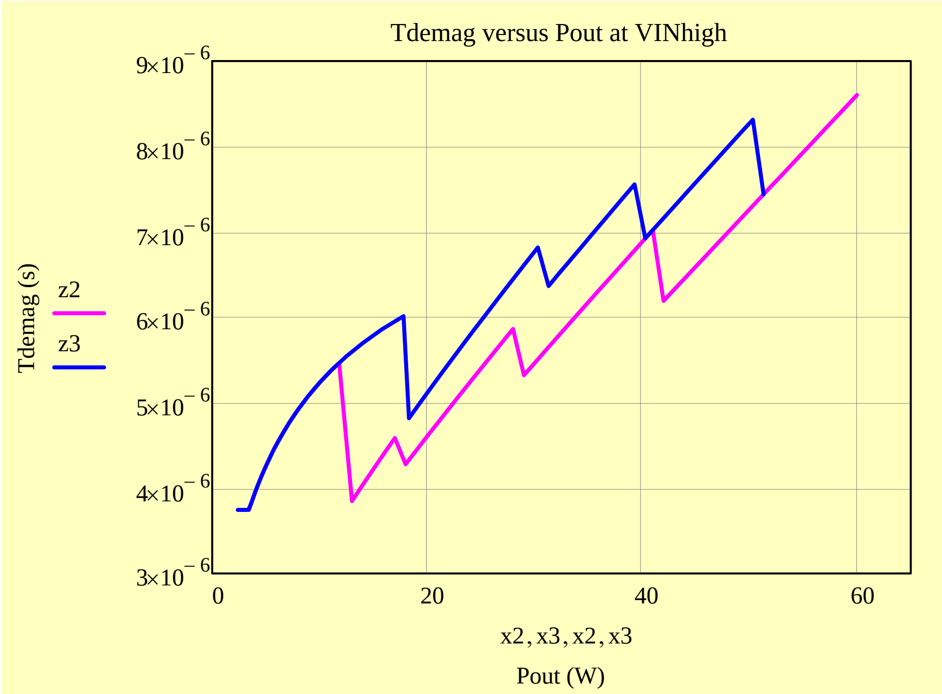
$$PatVINmaxI := Z_I\left(Rsense, VIN_{high} \cdot \sqrt{2}, t_{prop}, decr_P\right)$$

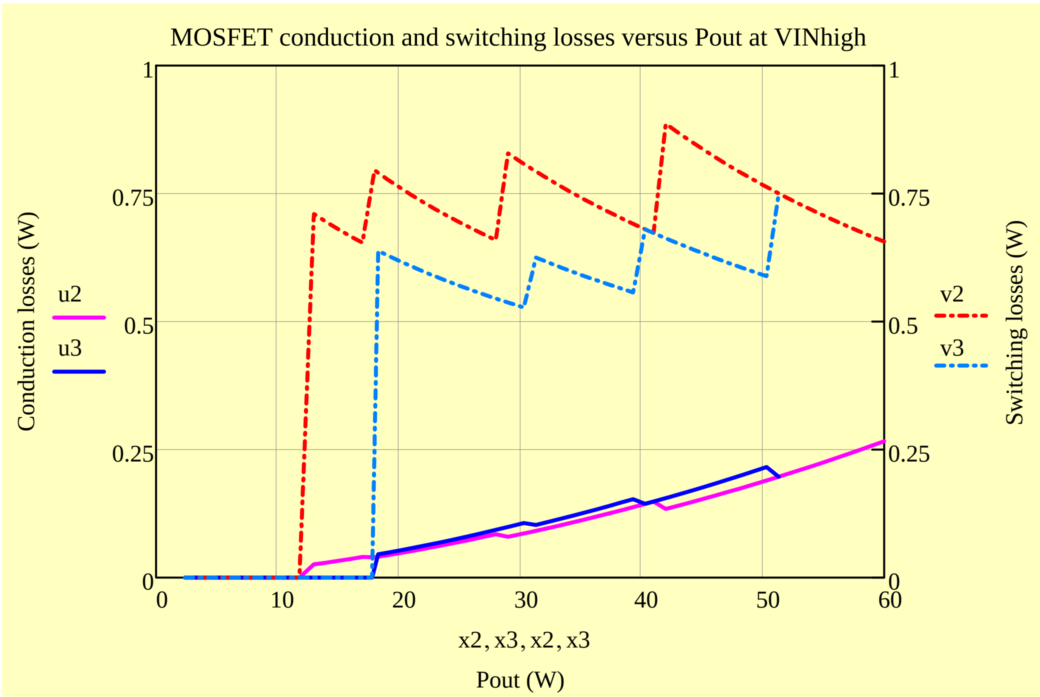
5	6	7	8	9	10

	5	6	7	8	9	10
5	2.286	2.351	2.42	2.493	2.57	2.652
5	0.955	0.955	0.955	0.955	0.955	0.955
4	$2.069\cdot10^{4}$	$2.128\cdot10^{4}$	$2.19\cdot10^{4}$	$2.256\cdot10^{4}$	$2.326\cdot10^{4}$	$2.4\cdot10^{4}$
3	$1.351\cdot10^{3}$	$1.351\cdot10^{3}$	$1.351\cdot10^{3}$	$1.351\cdot10^{3}$	$1.351\cdot10^{3}$	$1.351\cdot10^{3}$
6	$3.437\cdot10^{-6}$	$3.437\cdot10^{-6}$	$3.437\cdot10^{-6}$	$3.437\cdot10^{-6}$	$3.437\cdot10^{-6}$	$3.437\cdot10^{-6}$
0	0	0	0	0	0	...

	5	6	7	8	9
2	2.714	2.791	2.873	2.959	3.051
1	1.041	1.041	1.041	1.041	1.041
4	$2.069\cdot10^{4}$	$2.128\cdot10^{4}$	$2.19\cdot10^{4}$	$2.256\cdot10^{4}$	$2.326\cdot10^{4}$
3	$1.351\cdot10^{3}$	$1.351\cdot10^{3}$	$1.351\cdot10^{3}$	$1.351\cdot10^{3}$	$1.351\cdot10^{3}$
6	$3.745\cdot10^{-6}$	$3.745\cdot10^{-6}$	$3.745\cdot10^{-6}$	$3.745\cdot10^{-6}$	$3.745\cdot10^{-6}$
0	0	0	0	0	0
0	0	0	0	0	...




Tdemag versus Pout at VINhigh
Tdemag (s)
z2
z3
9×10⁻⁶
8×10⁻⁶
7×10⁻⁶
6×10⁻⁶
5×10⁻⁶
4×10⁻⁶
3×10⁻⁶
0
20
40
60
x2, x3, x2, x3
Pout (W)


MOSFET conduction and switching losses versus Pout at VINhigh
Conduction losses (W)
Switching losses (W)
u2
u3
v2
v3
1
0.75
0.5
0.25
0
0
10
20
30
40
50
60
x2, x3, x2, x3
Pout (W)

$_{0})$

$\text{rop}, \text{decr}_{\mathrm{P}})_{2,0})$

$$\frac{\overline{\;\;\;\;}\cdot(2\cdot\pi\cdot f\cdot i)\Big]}{DC}$$

$$\overline{\text{out}\cdot 2\cdot\pi\cdot f\cdot i)}$$

$$Lx(f))\cdot\frac{180}{\pi}$$

$$G_1(f)\Big)\cdot\frac{180}{\pi}$$