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** **NCP/NCV1362 Inductor and Losses calculation for adapter**

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** Rev: 0.0 10/07/2017

** Modifications: Initial Version

** Rev 0.0: - Initial Release for NCP/NCV1362

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HOW TO USE THE SPREADSHEET

This spreadsheet will calculate for you every parameters needed
to design a power supply using the NCP1362

Comment:

The zones underlined in pink need data from the user.

The zones underlined in yellow are calculation results

The zones underlined in red are controllers internal parameters and must not be changed !

INPUT DATA

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

Maximum output power: $P_{out} := 12W$ Output voltage: $V_{out} := 12V$

Estimated efficiency: $\eta := 85\%$ Output diode forward voltage: $V_f := 0.6V$

Bulk voltage ripple: $V_{BulkRipple} := 45V$

Switching frequency at maximum output power, low line: $F_{sw} := 50kHz$

External Capacitor between Drain & Source: $C_{DS} := 0.100pF$ External Cap for valley adjust

MOSFET part number: FCU600N65S3R0

MOSFET breakdown voltage: $BVdss := 650V$

Mosfet Coss @ $V_{DS} = V_o$: $C_{OSS} := 10pF$

Mosfet $V_{DS} = V_o$ @ which is measured $V_o := 400V$

Mosfet Qg: $Q_g := 11nC$

MOSFET Rdson at Tj = 110 °C: $R_{dson110} := 1.0\Omega$ (0.6 Ω max @ 25°C)

Output diode forward part number: ON Semiconductor NRVTSS5100E

Output diode forward voltage @ Tj = 125 °C: $V_{f0} := 0.2V$

Controller Parameters:

Swiching Frequency Clamp: $F_{sw\_max} := 500kHz$

Note: For no clamp option please enters Fsw_max >> to the max freq of your design, otherwise enters 80 kHz, 110 kHz or 140 kHz value

Maximum peak current: $V_{CSmax} := 0.8V$

Frozen peak current in VCO mode: $V_{CSmin} := 250mV$

Frozen peak current in VCO mode: $V_{CSmin2} := 65mV$

Constant Current Voltage ref: $V_{ref\_CC} := 1.0V$

Internal min dead time in VCO: $DT\_min := 650ns$

$K_{compCV} := K_{compCC} = 4$

Minimal Fsw in VCO mode $F_{min} := 1kHz$ Option 200 Hz or 1 kHz

Internal Comp Offset level $V_{CompOffset} := 1.1V$

Min Comp pin level at which the peak current is frozen: $V_{CompIPKmin} := V_{CSmin} \cdot K_{compCV} + V_{CompOffset} = 2.1\,V$

Min Comp pin level: $V_{Compmin} := 0.2V$

Max Comp pin level: $V_{Compmax} := V_{CSmax} \cdot K_{compCV} + V_{CompOffset} = 4.3\,V$

Total Propagation delay time: $t_{prop} := 150 \cdot ns$

Internal Voltage reference $V_{ref\_CV1} := 2.5V$

$V_{ref\_OVP} := V_{ref\_CV1} \cdot 126\% = 3.15\,V$

$V_{ref\_UVP} := 1.5V$

Transconductance gain: $g_m := 200 \frac{\mu A}{V}$

Preliminary calculations:

$I_{out} := \frac{P_{out}}{V_{out}}$ $I_{out} = 1\,A$

$VIN_{minDC} := VIN_{min} \cdot \sqrt{2}$ $VIN_{minDC} = 120.208\,V$

$VIN_{maxDC} := VIN_{max} \cdot \sqrt{2}$ $VIN_{maxDC} = 374.767\,V$

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

$V_{min} := VIN_{minDC} - V_{BulkRipple}$ $V_{min} = 75.208\,V$

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

MOSFET breakdown voltage: $BVdss = 650\,V$

Derating factor for the MOSFET breakdown voltage: $\alpha := 90\%$

Leakage inductance ratio ($k_{leak} = L_{leak} / L_p$) $k_{leak1} := 1.8\%$ $k_{leak2} := 2.0\%$ $k_{leak3} := 2.2\%$

Clamping diode recovery time overshoot: $V_{os} := 10V$

$V_{DSmax} := BVdss \cdot \alpha$ $V_{DSmax} = 585\ V$

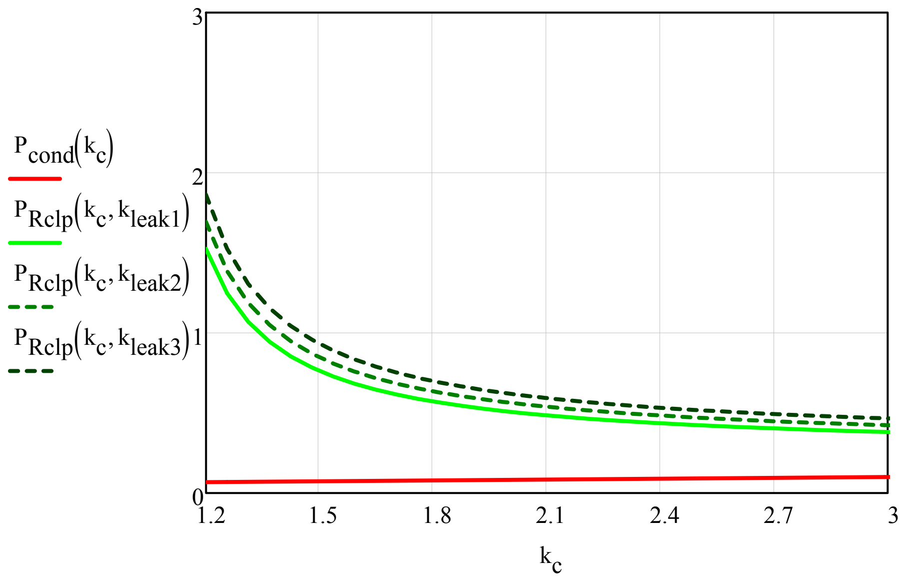
$$P_{cond}(k_c) := \frac{4}{3} \cdot R_{dson110} \cdot \frac{P_{out}^2}{\eta^2 \cdot V_{min}} \cdot \left[\frac{1}{V_{min}} + \frac{k_c}{(V_{DSmax} - VIN_{maxDC} - V_{os})}\right]$$

$$P_{Rclp}(k_c, k_{leak}) := k_{leak} \cdot \frac{P_{out}}{\eta} \cdot \frac{k_c}{k_c - 1}$$

$k_{c\_min} := 1.2$ $k_{c\_max} := 4$ $nb\_step := 50$

$$k_c := k_{c\_min}, k_{c\_min} + \frac{(k_{c\_max} - k_{c\_min})}{nb\_step} .. k_{c\_max}$$

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



Clamping coefficient ($k_c = V_{clamp} / V_{reflect}$): $k_c := 1.9$

$$Nps_{min} := \frac{k_c \cdot (V_{out} + V_f)}{(V_{DSmax} - V_{os} - VIN_{maxDC})}$$ $Nps_{min} = 0.12$

Enter your value for Nps: $Nps := 0.124$

New k_c based on the turn ratio selection if different from the theoritical calulation:

$$k_c := Nps \cdot \frac{(V_{DSmax} - V_{os} - VIN_{maxDC})}{(V_{out} + V_f)}$$ $k_c = 1.971$

New V_{DS} of the Power MOS based on the Nps turn ratio selection:

$$V_{DS} := \frac{(V_{out} + V_f)}{Nps} \cdot k_c + V_{os} + VIN_{maxDC}$$ $V_{DS} = 585\ V$ must be < $V_{DSmax} = 585\ V$

$$V_{clamp} := \frac{(V_{out} + V_f)}{Nps} \cdot k_c$$ $V_{clamp} = 200.233\ V$

Ipk and Lp calculation including the dead-time

$$I_{pk} := \frac{2 \cdot P_{out}}{\eta} \cdot \left(\frac{1}{V_{min}} + \frac{Nps}{V_{out} + V_f}\right) + \pi \sqrt{\frac{2 \cdot P_{out} \cdot (C_{OSS} + C_{DS}) \cdot F_{sw}}{\eta}}$$ $I_{pk} = 0.665\ A$

$$L_p := \frac{2 \cdot P_{out}}{I_{pk}^2 \cdot \eta \cdot F_{sw}}$$ $L_p = 1.276 \cdot mH$

Enter your value for Lp: $L_p := 1.2 \cdot mH$

Expected Leakage: $k_{leak} := 1.8\%$ $L_{leak} := L_p \cdot k_{leak}$ $L_{leak} = 21.6 \cdot \mu H$

New Ipk value based on Lp selection

$$I_{pk} := \sqrt{\frac{2 \cdot P_{out}}{L_p \cdot \eta \cdot F_{sw}}}$$ $I_{pk} = 0.686\ A$

$$R_{senseCV} := \frac{V_{CSmax}}{I_{pk}}$$ $R_{senseCV} = 1.166 \cdot \Omega$

$V_{CSmax} = 0.8\ V$

$$V_{ref\_CC\_max} := V_{CSmax} \cdot 2 \cdot K_{compCC} \cdot Nps \cdot \sqrt{\frac{L_p \cdot \eta \cdot F_{sw} \cdot I_{out}}{2 \cdot V_{out}}} = 1.157\ V$$

$K_{compCC} \equiv 4$ $V_{ref\_CC} := 1.0V$

$$I_{out\_min} := \frac{2 \cdot V_{out} \cdot V_{ref\_CC}^2}{(V_{CSmax} \cdot 2 \cdot K_{compCC} \cdot Nps)^2} \cdot \frac{1}{L_p \cdot \eta \cdot F_{sw}} = 0.747\ A$$

R_{sense} calculation for CC regulation:

Maximum output current: $I_{out\_CC} := I_{out} = 1\ A$

$I_{out\_CC} := I_{out} \cdot 1.10$ Iout + 10%

$$R_{sense\_theo} := \frac{V_{ref\_CC}}{2 \cdot K_{compCC} \cdot Nps \cdot I_{out\_CC}}$$ $R_{sense\_theo} = 0.916 \cdot \Omega$

Enter the normalized value for Rsense: $R_{sense} := R_{sense\_theo} \cdot 99\% = 0.907\,\Omega$

$R_{sense} := 0.907\Omega$

New Iout value based on the R_{sense} selection:

$$I_{out\_new} := \frac{V_{ref\_CC}}{2 \cdot K_{compCC} \cdot Nps \cdot R_{sense}}$$

$I_{out\_new} = 1.111\ A$

Auxiliary winding turn ratio

Desired value for VCC: $V_{CC} := 8V$

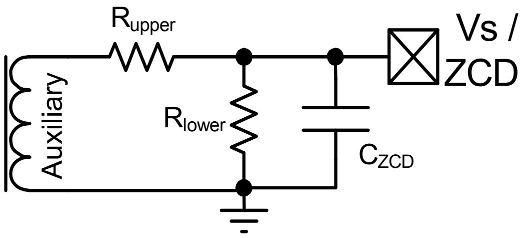
Forward Voltage of Aux diode $V_{f\_aux} := 0.8V$

$$N_{aux} := \frac{Nps \cdot (V_{CC} + V_{f\_aux})}{V_{out} + V_{f0}}$$

$N_{aux} = 0.089$

Enter N_{aux} value: $N_{aux} := 0.089$

ZCD resistor divider calculation:



Max voltage on Aux winding $V_{aux} := (V_{out} + V_{f0}) \cdot \frac{N_{aux}}{Nps}$

$V_{aux} = 8.756\ V$

Constant time selection, must be below 100 ns in order to keep a good accuracy on the CV regualtion: $\tau := 0.100\mu s$

Arbitrary Selection of Rupper on ZCD pin: $R_{upper} := 9.29k\Omega$

$$R_{lower} := R_{upper} \frac{V_{ref\_CV1}}{(V_{aux}) - V_{ref\_CV1}}$$

$R_{lower} = 3.712 \cdot k\Omega$

$$C_{ZCD} := \frac{R_{upper} + R_{lower}}{R_{upper} \cdot R_{lower}} \cdot \tau$$

$C_{ZCD} = 37.703 \cdot pF$

$$M := \frac{V_{ref\_CV1}}{V_{aux} - V_{ref\_CV1}} = 0.4$$

R_{lower} components values selection: $R_{lower} := 4.3k\Omega$

$$C_{ZCD} := \frac{R_{upper} + R_{lower}}{R_{upper} \cdot R_{lower}} \cdot \tau = 34.02 \cdot pF$$

C_{zcd} components values selection: $C_{ZCD} := 10pF$

Time constant verification

$$\tau := \frac{R_{upper} \cdot R_{lower}}{R_{upper} + R_{lower}} \cdot C_{ZCD}$$ $\tau = 0.029 \cdot \mu s$

Output votlage error based on the R_{lower} and R_{upper} selection:

$$M := \frac{R_{lower}}{R_{upper}} = 0.463$$

$$V_{out\_Error} := \frac{V_{ref\_CV1} - V_{aux} \cdot \frac{M}{1 + M}}{V_{ref\_CV1}}$$ $V_{out\_Error} = -10.825 \cdot \%$

V_{out} OVP & UVP protection level with resistor divider selection:

$$V_{out\_OVP} := \frac{Nps}{N_{aux}} \cdot \frac{(R_{upper} + R_{lower})}{R_{lower}} \cdot V_{ref\_OVP}$$ $V_{out\_OVP} = 13.871\ V$

$$V_{out\_UVP} := \frac{Nps}{N_{aux}} \cdot \frac{(R_{upper} + R_{lower})}{R_{lower}} \cdot V_{ref\_UVP}$$ $V_{out\_UVP} = 6.605\ V$

Primary and secondary rms current calculation

$$Ton_{max} := \frac{I_{pk} \cdot L_p}{V_{min}}$$ $Ton_{max} = 10.946 \cdot \mu s$

$$D_{max} := Ton_{max} \cdot F_{sw}$$ $D_{max} = 54.728 \cdot \%$

$$I_{pRMS} := I_{pk} \cdot \sqrt{\frac{1 \cdot D_{max}}{3}}$$ $I_{pRMS} = 0.293\ A$

$$I_{ps} := \frac{I_{pk}}{Nps}$$ $I_{ps} = 5.532\ A$

$$I_{sRMS} := I_{ps} \cdot \sqrt{\frac{1}{3} \cdot (1 - D_{max})}$$ $I_{sRMS} = 2.149\ A$

$$I_{priDC} := I_{pk} \cdot \frac{D_{max}}{2}$$ $I_{priDC} = 0.188\ A$

$$I_{priAC} := \sqrt{I_{pRMS}^2 - I_{priDC}^2}$$ $I_{priAC} = 0.225\ A$

Output capacitor calculation

$V_{ripple} := V_{out} \cdot 1.5\%$

$R_{ESR} := \frac{V_{ripple}}{I_{ps}}$ $\quad R_{ESR} = 0.033 \cdot \Omega$

$I_{CoutRMS} := \sqrt{I_{sRMS}^2 - I_{out}^2}$ $\quad I_{CoutRMS} = 1.902\ A$

Enter Output capacitor selection:

Nichicon LF PLF1C471MDO1, 16 V, 470 µF Resr = 9 mOhm, Irms = 5.0 A

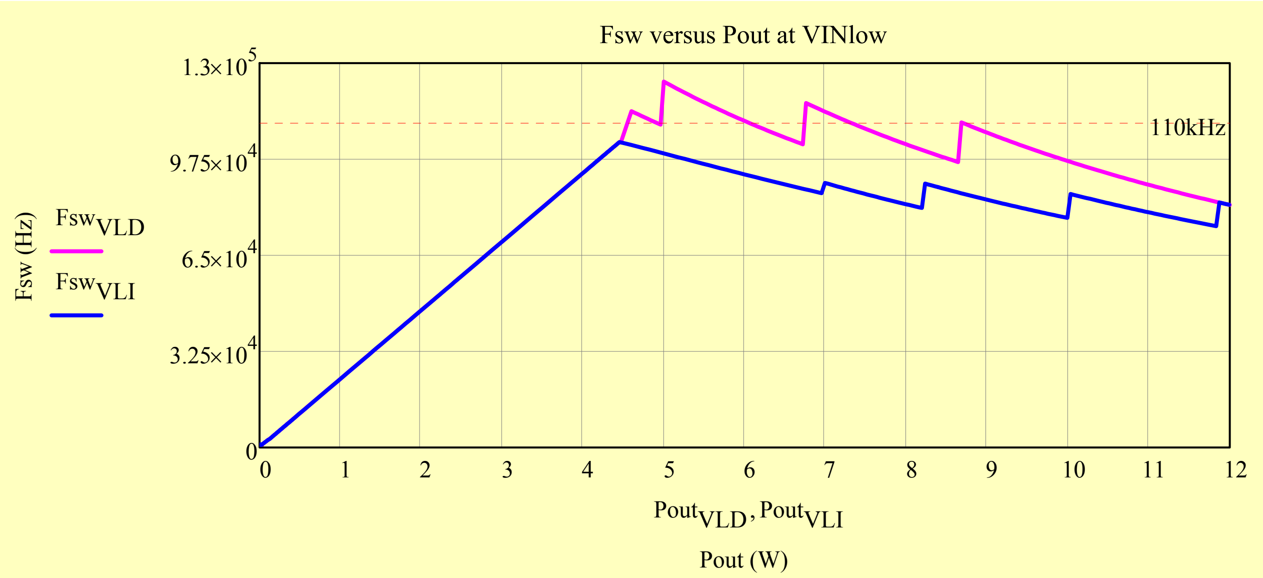
$nbr_{Cout} := 2$ $\quad I_{Cout} := nbr_{Cout} \cdot 5A = 10\ A$

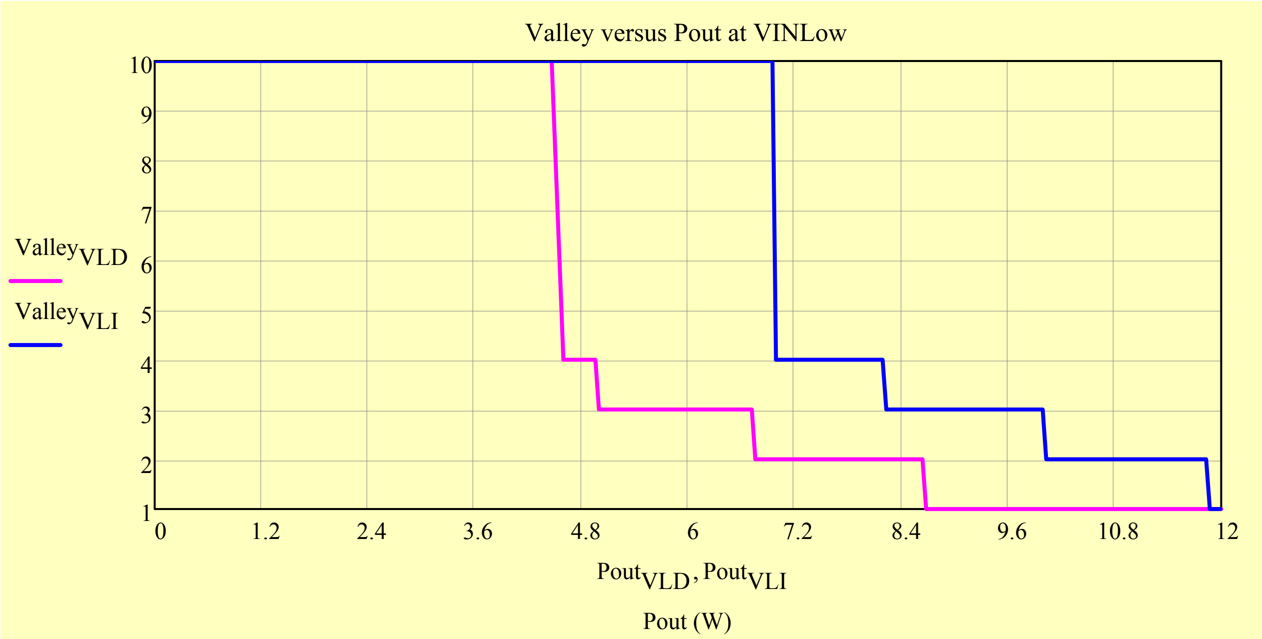
$C_{out} := nbr_{Cout} \cdot 470 \cdot \mu F = 940 \cdot \mu F$ $\quad R_{ESR} := \frac{5}{nbr_{Cout}} \cdot 10^{-3} \cdot \Omega = 2.5 \times 10^{-3}\ \Omega$

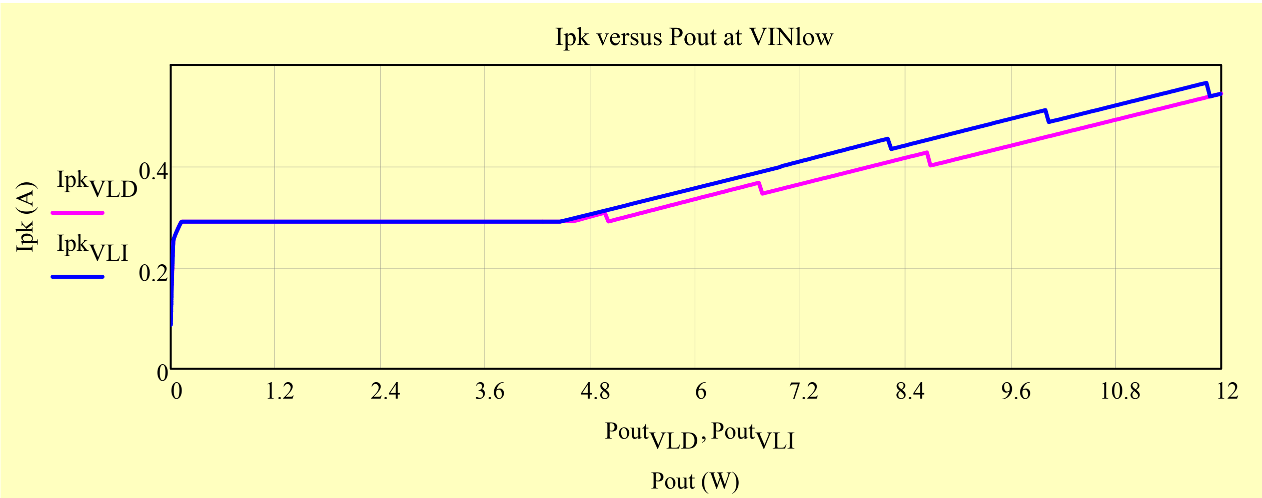
Predicting the evolution of the switching frequency

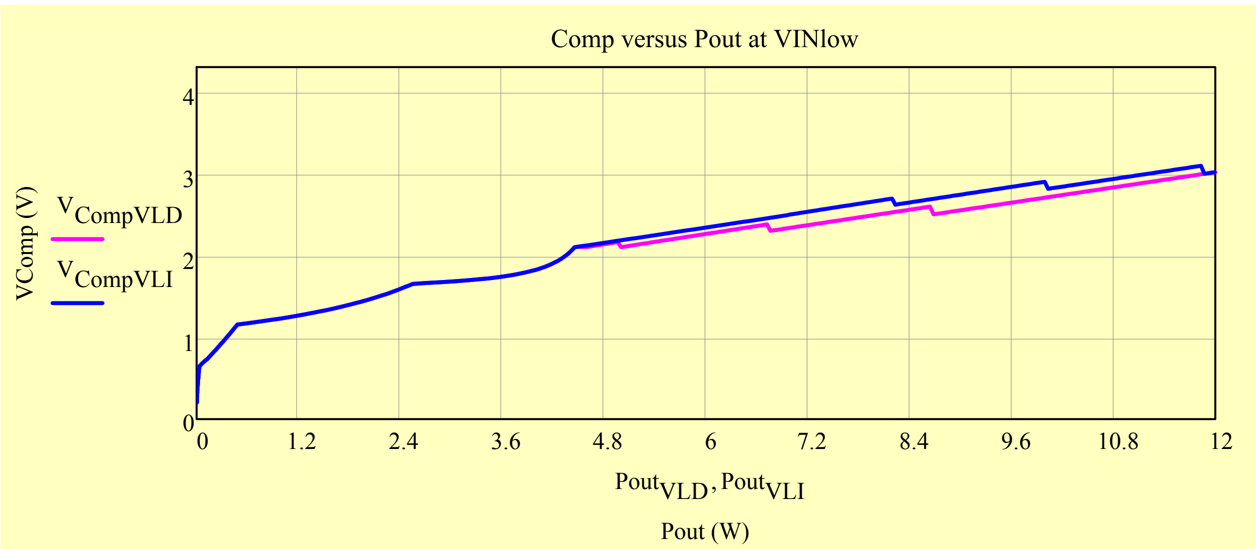
Enter below the AC input voltage (rms) at which you want to see the frequency evolution (these voltages will also be used for the losses calculations)

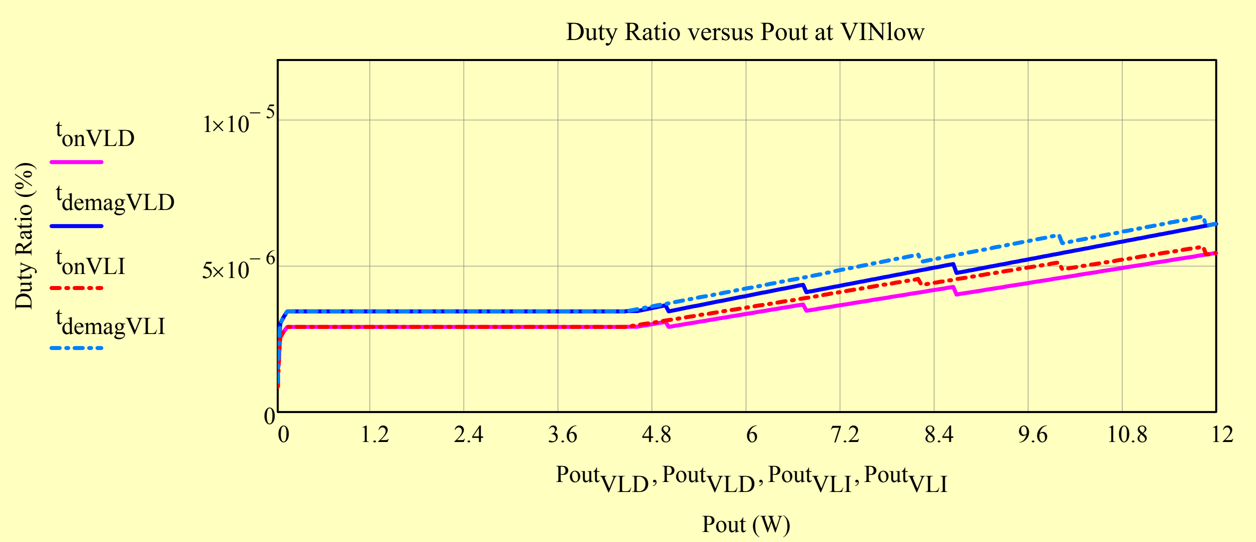
$VIN_{low} = 85\ V$ $\quad VIN_{high} = 265\ V$




Valley versus Pout at VINLow
Valley_VLD
Valley_VLI
10
9
8
7
6
5
4
3
2
1
0
1.2
2.4
3.6
4.8
6
7.2
8.4
9.6
10.8
12
Pout_VLD, Pout_VLI
Pout (W)


Ipk versus Pout at VINlow
Ipk (A)
Ipk_VLD
Ipk_VLI
0.4
0.2
0
0
1.2
2.4
3.6
4.8
6
7.2
8.4
9.6
10.8
12
Pout_VLD, Pout_VLI
Pout (W)


Comp versus Pout at VINlow
VComp (V)
V_CompVLD
V_CompVLI
4
3
2
1
0
0
1.2
2.4
3.6
4.8
6
7.2
8.4
9.6
10.8
12
Pout_VLD, Pout_VLI
Pout (W)



RCD clamp calculation

$V_{clamp} = 200.233\ V$

Leakage inductance considered for the RCD clamp calculation:

$k_{leak} = 1.8 \cdot \%$

$L_{leak} := L_p \cdot k_{leak}$ $\qquad L_{leak} = 21.6 \cdot \mu H$

$$R_{clp} := \frac{2 \cdot V_{clamp} \cdot \left[V_{clamp} - \frac{(V_{out} + V_f)}{Nps}\right]}{I_{pk}^{\ 2} \cdot L_{leak} \cdot F_{sw}} \qquad R_{clp} = 77.709 \cdot k\Omega$$

Enter R_{clp} selection: $\qquad R_{clp} := 136k\Omega$

Enter Voltage Ripple Percentage on Vclamp: $\qquad Clamp_{pkpk} := 50\%$

$$C_{clp} := \frac{V_{clamp}}{R_{clp} \cdot F_{sw} \cdot Clamp_{pkpk} \cdot V_{clamp}} \qquad C_{clp} = 0.294 \cdot nF$$

Peak Inverse Voltage of the clamp diode:

$$PIV_{Dclp} := \frac{(V_{out} + V_f)}{Nps} + V_{os} \qquad PIV_{Dclp} = 111.613\ V$$

RCD clamp losses:

$$P_{Clp} := \frac{V_{clamp}^{\ 2}}{R_{clp}} \qquad P_{Clp} = 0.295\ W$$

Losses calculation: @ Low line input Voltage

Extracted max peak current @ low line from the curves

$$I_{pk\_low} := \max\left(Ipk_{VLD}, Ipk_{VLI}\right)$$ $$I_{pk\_low} = 0.565\ A$$

Extracted swiching frequency @ the max peak current point from the curves:

$$F_{sw\_low} := \begin{cases} Fsw_{VLD_0} & \text{if } I_{pk\_low} = Ipk_{VLD_0} \\ Fsw_{VLI_{last(Fsw_{VLI})}} & \text{otherwise} \end{cases}$$ $$F_{sw\_low} = 82.092 \cdot kHz$$

Duty Ratio calculations:

$$DR_{low} := \frac{I_{pk\_low} \cdot L_p}{V_{min}} \cdot F_{sw\_low}$$ $$DR_{low} = 0.74$$

Transformer primary RMS current:

$$Ip_{RMS\_low} := I_{pk\_low} \cdot \sqrt{\frac{DR_{low}}{3}}$$ $$Ip_{RMS\_low} = 0.28\ A$$

Transformer secondary RMS current:

$$Is_{RMS\_low} := \frac{I_{pk\_low}}{Nps} \cdot \sqrt{\frac{1}{3} \cdot \left(1 - DR_{low}\right)}$$ $$Is_{RMS\_low} = 1.341\ A$$

Output Capacitor RMS current:

$$I_{CoutRMS\_low} := \sqrt{Is_{RMS\_low}^{\ 2} - I_{out}^{\ 2}}$$ $$I_{CoutRMS\_low} = 0.894\ A$$

Power loss in RCD clamp

$$P_{Clp} = 0.295\ W$$

Power loss in sense resistor:

$$P_{sense} := R_{sense} \cdot Ip_{RMS\_low}^{\ 2}$$ $$P_{sense} = 0.071\ W$$

Power loss in Cout

$$P_{Cout} := R_{ESR} \cdot I_{CoutRMS\_low}^{\ 2}$$ $$P_{Cout} = 1.999 \times 10^{-3}\ W$$

* **<u>Power loss in MOSFET</u>**

Drain source resistance at T_j = 110°C: $R_{dson110} = 1\ \Omega$

MOSFET C_{OSS} at Vds = V_0: $C_{OSS} = 10 \cdot pF$

<u>Condution losses:</u>

$$P_{COND}\left(Ip_{RMS}\right) := Ip_{RMS}^{\ 2} R_{dson110}$$

<u>Switching losses</u>

Switching losses due to the Power Mosfet only:

$$P_{SW1}(VIN_{DC}, F_{sw}) := \frac{2}{3} \cdot \left(VIN_{DC} - \frac{V_{out} + V_f}{Nps}\right)^{\frac{3}{2}} \cdot C_{OSS} \cdot \sqrt{V_o} \cdot F_{sw}$$

Switching losses due to the extra capacitor that it could be placed in parallel with the Power Mosfet:

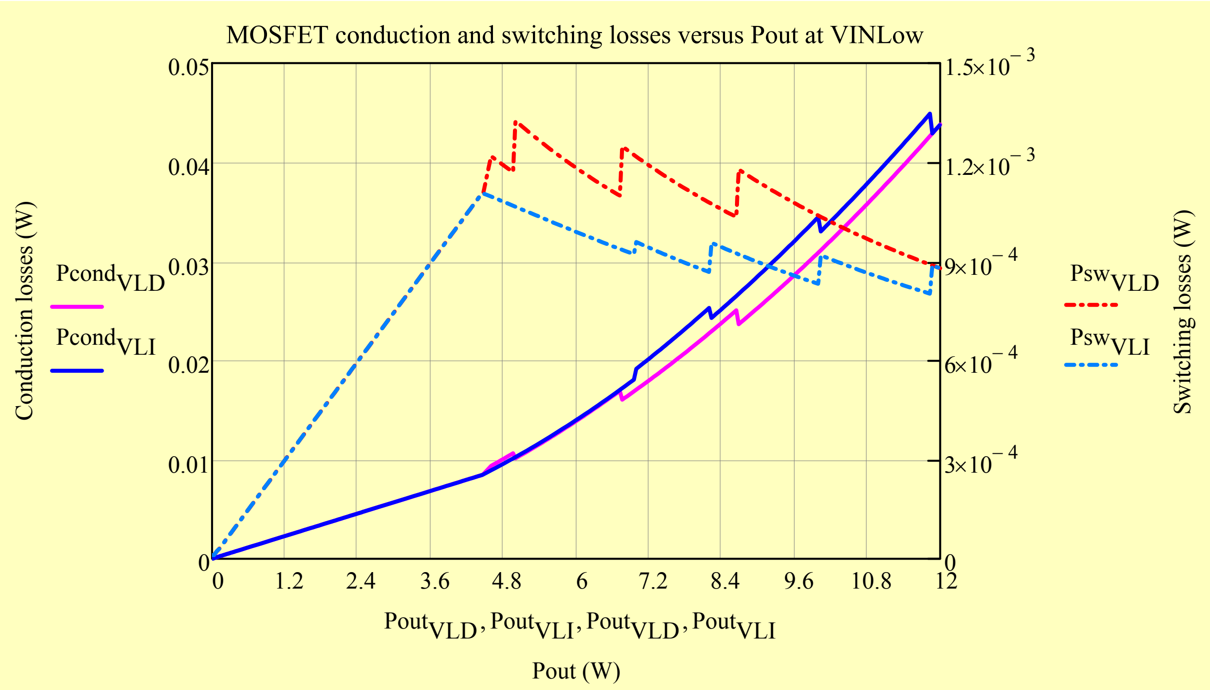
$$P_{SW2}(VIN_{DC}, F_{sw}) := \frac{1}{2} \cdot C_{DS} \cdot \left(VIN_{DC} - \frac{V_{out} + V_f}{Nps}\right)^{2} \cdot F_{sw}$$

Switching total losses is the sum:

$$P_{SW}(VIN_{DC}, F_{sw}) := P_{SW1}(VIN_{DC}, F_{sw}) + P_{SW2}(VIN_{DC}, F_{sw})$$

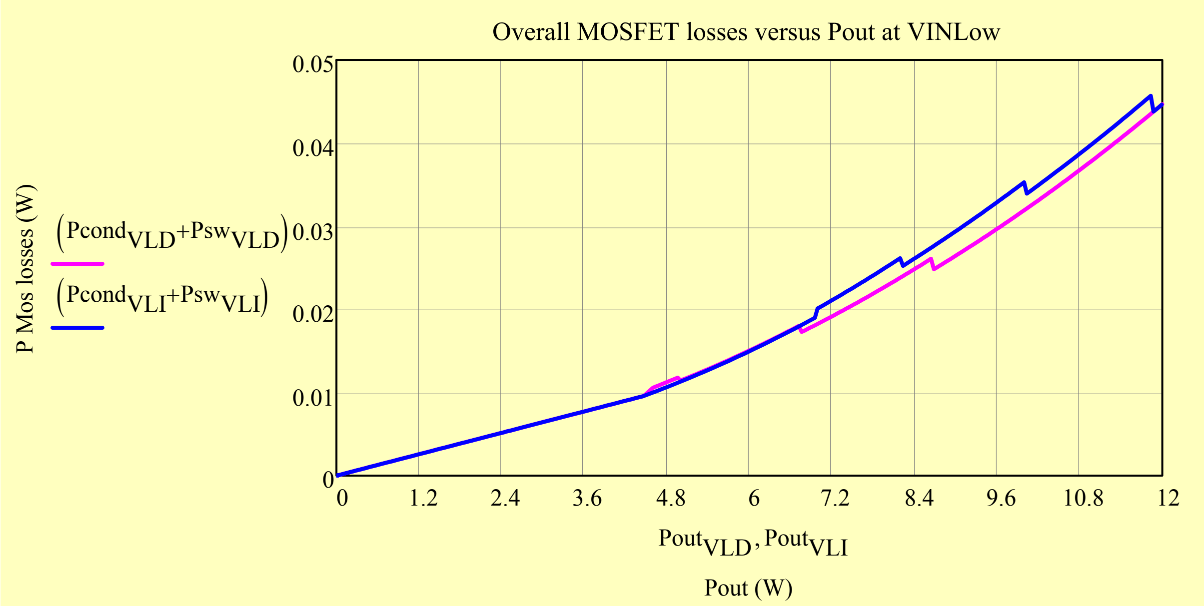
Due to the QR mode and thanks to the power mosfet losses graph it is possible to extract the worst case conditions losses:

$VIN_{low} = 85\ V$



The following graph illustrates the sum of the switching losses and conduction losses versus the output power and at different input voltages:

$VIN_{low} = 85\ V$



Thus worst case mosfet losses is extracted from the graphs above:

$VIN_{low} \equiv 85V$ $VIN_{high} \equiv 265V$ **<== Change the input voltage levels here**

$$P_{MOS} := \max(Pcond_{VLD} + Psw_{VLD}, Pcond_{VLI} + Psw_{VLI}, Pcond_{VHD} + Psw_{VHD}, Pcond_{VHI} + Psw_{VHI}$$

$P_{MOS} = 0.099\ W$

* **Power loss in output diode**

Peak inverse voltage :

$PIV_{diode} := VIN_{maxDC} \cdot Nps + V_{out} + V_f$ $PIV_{diode} = 59.071\ V$

Output diode : **NRVTSS5100E**

Diode forward voltage at low current: $V_{f0} = 0.2\ V$ @ 125°C

Diode dynamic resistance: $R_d := \frac{0.1V}{2A} = 0.05\ \Omega$

$P_{Diode} := V_{f0} \cdot I_{out} + R_d \cdot Is_{RMS\_low}^{2}$ $P_{Diode} = 0.29\ W$

* **Power loss in Synchronous Rectification MOSFET if it is used instead of Schottky diode**

Mosfet reference: NTMFS5C612NL from ONSEMI

Drain source resistance at T_j = 110°C: $R_{SRdson110} := 0.00345\Omega$

MOSFET C_{OSS} at Vds = V_{SR_o}: $C_{SR\_OSS} := 2953pF$

$V_{SR\_o} := 25V$

Maximum forward body diode: $V_{SR\_SD} := 0.66V$

Estimated maximum duration of the body diode conduction: $t_{BD\_on} := 100ns$

Condution losses:

$Ipk := Ipk_{VLD} \quad t_{demag} := t_{demagVLD} \quad F_{sw} := Fsw_{VLD}$

$$P_{SR\_condVLD} := \overrightarrow{\left[\left[\left[\frac{Ipk}{Nps}\cdot\sqrt{\frac{1}{3}\cdot\overrightarrow{\left(t_{demag}\cdot F_{sw}\right)}}\right]\right]^2 R_{SRdson110}\right]}$$

$Ipk := Ipk_{VLI} \quad t_{demag} := t_{demagVLI} \quad F_{sw} := Fsw_{VLI}$

$$P_{SR\_condVLI} := \overrightarrow{\left[\left[\frac{Ipk}{Nps}\cdot\sqrt{\frac{1}{3}\cdot\left[\overrightarrow{\left(t_{demag}\cdot F_{sw}\right)}\right]}\right]^2 R_{SRdson110}\right]}$$

$Ipk := Ipk_{VHD} \quad t_{demag} := t_{demagVHD} \quad F_{sw} := Fsw_{VHD}$

$$P_{SR\_condVHD} := \overrightarrow{\left[\left[\left[\frac{Ipk}{Nps}\cdot\sqrt{\frac{1}{3}\cdot\overrightarrow{\left(t_{demag}\cdot F_{sw}\right)}}\right]\right]^2 R_{SRdson110}\right]}$$

$Ipk := Ipk_{VHI} \quad t_{demag} := t_{demagVHI} \quad F_{sw} := Fsw_{VHI}$

$$P_{SR\_condVHI} := \overrightarrow{\left[\left[\frac{Ipk}{Nps}\cdot\sqrt{\frac{1}{3}\cdot\left[\overrightarrow{\left(t_{demag}\cdot F_{sw}\right)}\right]}\right]^2 R_{SRdson110}\right]}$$

Switching losses

Thanks to the body diode of the sync power mosfet, the SR mosfet is turned on at almost null voltage (Vf ~ 1.0 V) , thus the switching losses could be neglected.
However we could consider the losses due to the body diode conduction before the power mosfet is turned on.

Body diode losses :

$Ipk := Ipk_{VLD} \quad F_{sw} := Fsw_{VLD}$

$$P_{SR\_SDVLD} := \overrightarrow{\left(V_{SR\_SD}\cdot\frac{Ipk}{Nps}\cdot t_{BD\_on}\cdot F_{sw}\right)}$$

$Ipk := Ipk_{VLI} \quad F_{sw} := Fsw_{VLI}$

$$P_{SR\_SDVLI} := \overrightarrow{\left(V_{SR\_SD}\cdot\frac{Ipk}{Nps}\cdot t_{BD\_on}\cdot F_{sw}\right)}$$

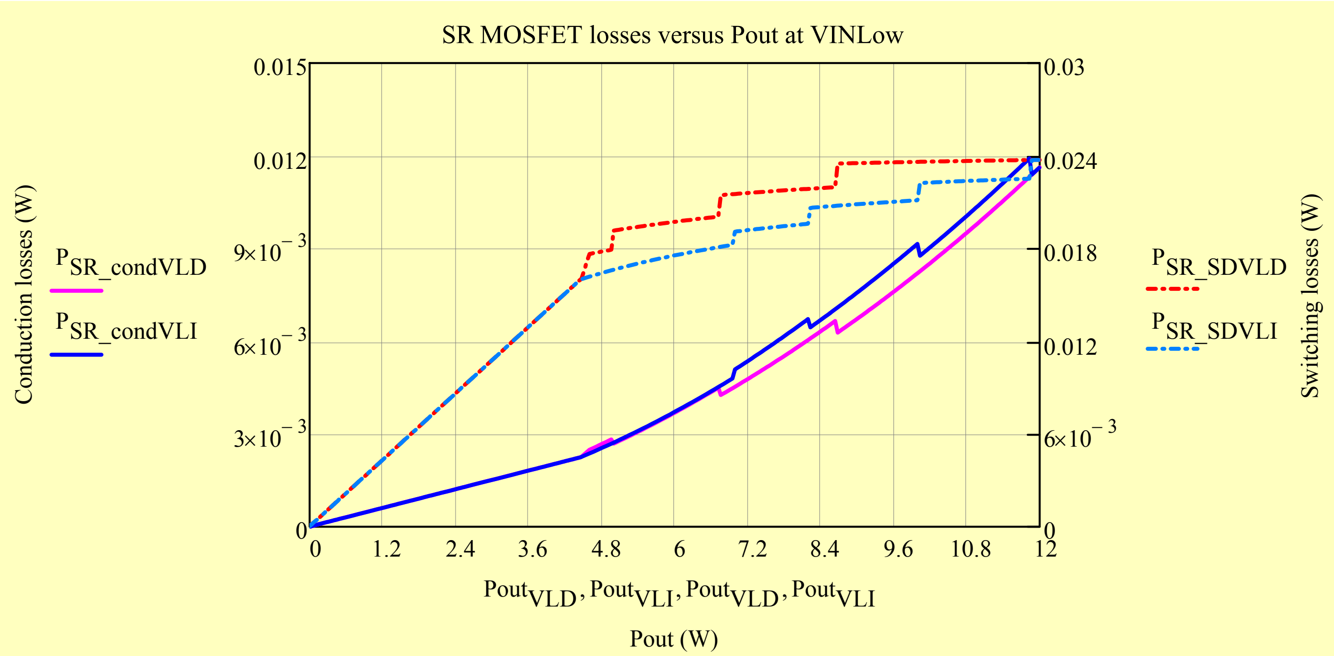
$Ipk := Ipk_{VHD} \quad F_{sw} := Fsw_{VHD}$

$$P_{SR\_SDVHD} := \overrightarrow{\left(V_{SR\_SD}\cdot\frac{Ipk}{Nps}\cdot t_{BD\_on}\cdot F_{sw}\right)}$$

$Ipk := Ipk_{VHI} \quad F_{sw} := Fsw_{VHI}$

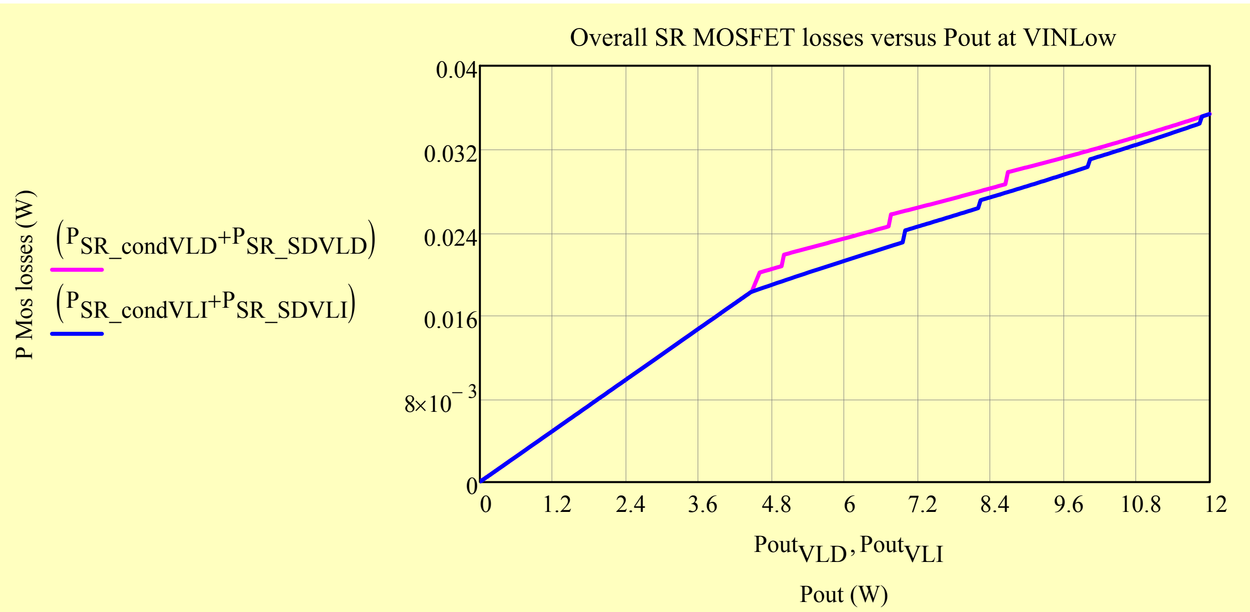
$$P_{SR\_SDVHI} := \overrightarrow{\left(V_{SR\_SD} \cdot \frac{Ipk}{Nps} \cdot t_{BD\_on} \cdot F_{sw}\right)}$$

$VIN_{low} = 85\,V$



The following graph illustrates the sum of the switching losses and conduction losses versus the output power and at different input voltages:

$VIN_{low} = 85\,V$



Thus worst case SR mosfet losses is extracted from the graphs above:

$$P_{SR\_MOS} := \max\left(P_{SR\_condVLD} + P_{SR\_SDVLD}, P_{SR\_condVLI} + P_{SR\_SDVLI}, P_{SR\_condVHD} + P_{SR\_SDVHD}, P_{SR\_co}\right.$$

$P_{SR\_MOS} = 0.042\,W$

*** Compensating the power supply**

$$R_{load} := \frac{V_{out}}{I_{out}}$$

$$H_0(VIN_{DC}) := \frac{R_{load}}{2 \cdot K_{compCV} \cdot Nps \cdot R_{sense} \cdot \left(2 \cdot \frac{V_{out}}{Nps \cdot VIN_{DC}} + 1\right)} \qquad H_0(120V) = 5.104$$

$$s_{z1} := \frac{1}{R_{ESR} \cdot C_{out}}$$

$$s_{z2}(VIN_{DC}) := \frac{R_{load}}{Nps^2 \cdot L_p} \cdot \frac{1}{\frac{V_{out}}{Nps \cdot VIN_{DC}} \cdot \left(1 + \frac{V_{out}}{Nps \cdot VIN_{DC}}\right)}$$

$$s_{p1}(VIN_{DC}) := \frac{1}{R_{load} \cdot C_{out}} \cdot \frac{2 \cdot \frac{V_{out}}{Nps \cdot VIN_{DC}} + 1}{\frac{V_{out}}{Nps \cdot VIN_{DC}} + 1}$$

Power stage without ZOH:

$$H_1(s, VIN_{DC}) := H_0(VIN_{DC}) \cdot \frac{\left(1 + \frac{s}{s_{z1}}\right) \cdot \left(1 - \frac{s}{s_{z2}(VIN_{DC})}\right)}{\left(1 + \frac{s}{s_{p1}(VIN_{DC})}\right)}$$

Transformer Gain:

$$K_{T0} := \frac{N_{aux}}{Nps} = 0.718 \qquad 20 \cdot \log(K_{T0}) = -2.881$$

Power stage on Aux winding without ZOH:

$$H_2(s, VIN_{DC}) := H_1(s, VIN_{DC}) \cdot K_{T0}$$

Power Stage with ZOH:

End of Demagnetization Transfer function:

$$K_{D0} := \frac{R_{lower}}{R_{lower} + R_{upper}} = 0.31641$$

$$\tau_1 := \frac{R_{lower} \cdot R_{upper}}{R_{lower} + R_{upper}} \cdot C_{ZCD} = 29.394 \cdot ns$$

$$K_D(s) := K_{D0} \cdot \frac{1}{1 + s \cdot 2 \cdot \pi \cdot \tau_1}$$

Internal Sample & Hold (ZOH):

ZOH Transfer function:

$$T_{ZOH}(s, T) := \frac{1 - e^{-s \cdot T}}{s \cdot T}$$

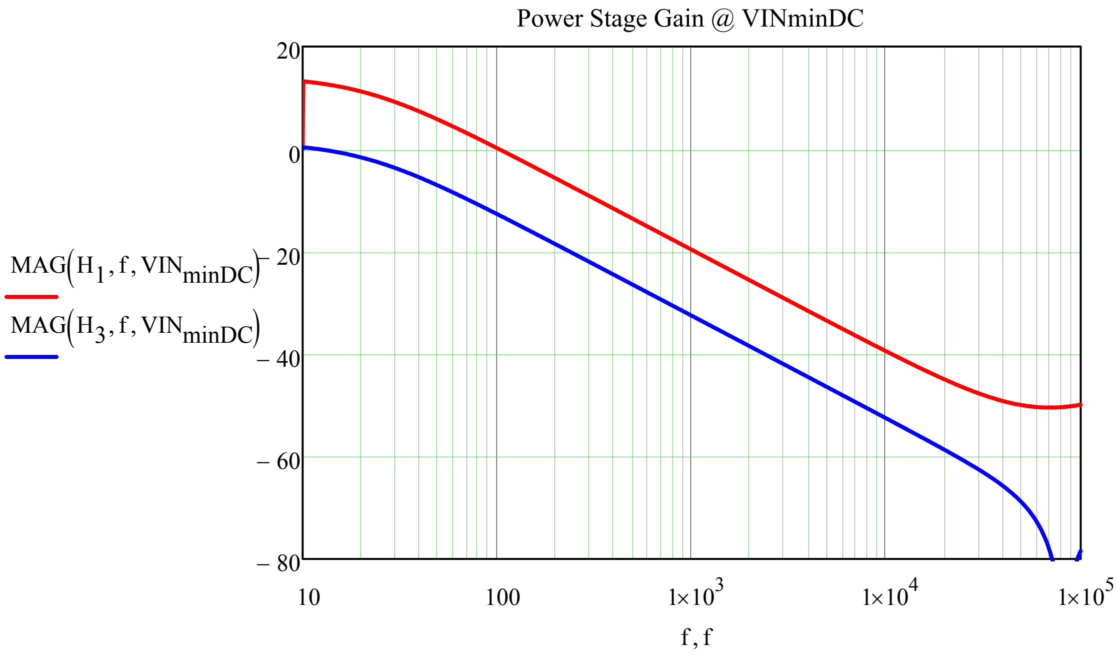
Switching frequency @ full load versus min and max input voltage:

$$T_{swZOH} := \begin{pmatrix} Fsw_{VLD_0} \\ Fsw_{VHD_0} \end{pmatrix} = \begin{pmatrix} 82.04 \\ 125.818 \end{pmatrix} \cdot kHz$$

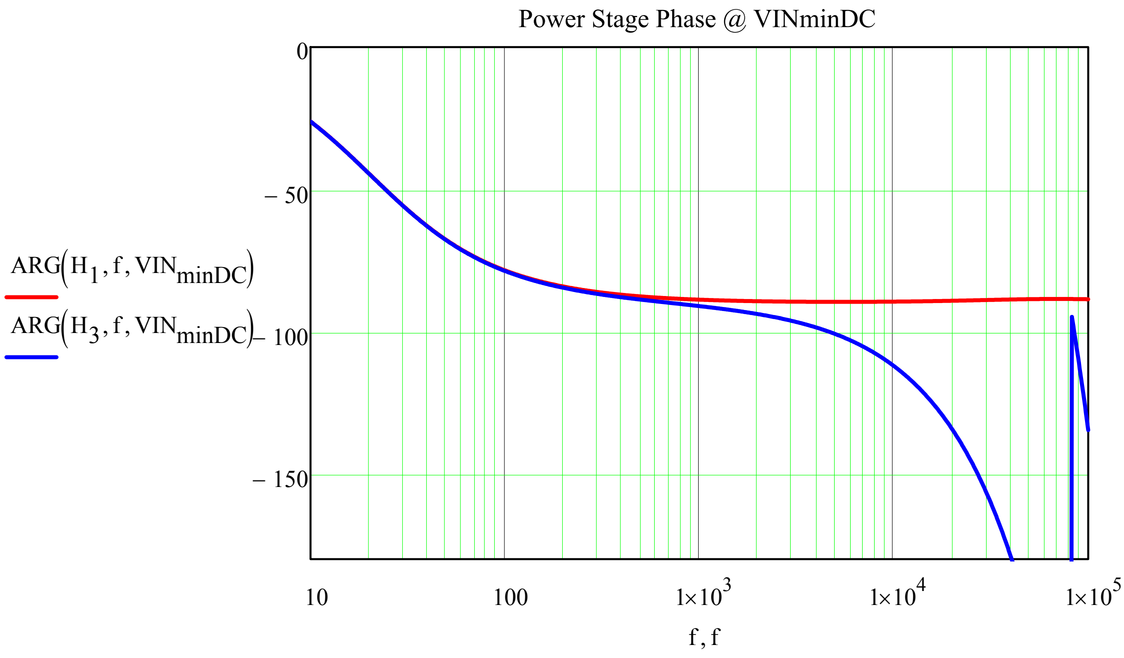
G3 Power Stage integrating internal transfer function (Demag detection & ZOH):

$$H_3(s, VIN_{DC}) := \left| \begin{array}{ll} T \leftarrow \frac{1}{T_{swZOH_0}} & \text{if } VIN_{DC} = VIN_{minDC} \\ T \leftarrow \frac{1}{T_{swZOH_1}} & \text{otherwise} \\ H_2(s, VIN_{DC}) \cdot K_D(s) \cdot T_{ZOH}(s, T) & \end{array} \right.$$

Tools for Bode Plot:



Power Stage Gain @ VINminDC
20
0
− 20
− 40
− 60
− 80
MAG(H1, f, VINminDC)
MAG(H3, f, VINminDC)
10
100
1×10^3
1×10^4
1×10^5
f, f



Power Stage Phase @ VINminDC
0
− 50
− 100
− 150
ARG(H1, f, VINminDC)
ARG(H3, f, VINminDC)
10
100
1×10^3
1×10^4
1×10^5
f, f

Type 2 OTA with automated calculations

$R_0 := \frac{1}{g_m} = 5 \cdot k\Omega$

Selected Crossover frequency (Fc) and the wanted Phase Margin (PM):

$F_c := 1kHz$ $\quad PM := 70°$

Power stage Gain and Phase at the selected crossover frequency (including end of demag detection and ZOH):

$G_{Fc} := 20 \cdot \log\left(\left|H_3\left(i \cdot 2 \cdot \pi \cdot F_c, VIN_{minDC}\right)\right|\right)$ $\qquad G_{Fc} = -32.516$

$P_{Fc} := \arg\left(H_3\left(i \cdot 2 \cdot \pi \cdot F_c, VIN_{minDC}\right)\right)$ $\qquad P_{Fc} = -91.05 \cdot °$

$Boost := PM - P_{Fc} - 90°$ $\qquad Boost = 71.05 \cdot °$

$G_0 := 10^{\left(\frac{-G_{Fc}}{20}\right)}$ $\qquad G_0 = 42.248$

$k_1 := \tan\left(\frac{Boost}{2} + 45°\right)$ $\qquad k_1 = 5.992$

$F_z := \frac{F_c}{k_1}$ $\qquad F_z = 166.893 \cdot Hz$

$F_p := k_1 \cdot F_c$ $\qquad F_p = 5.992 \cdot kHz$

$R_2 := \frac{G_0}{g_m}$ $\qquad R_2 = 211.24 \cdot k\Omega$

$C_2 := \frac{1}{2\pi R_2 F_z}$ $\qquad C_2 = 4.514 \cdot nF$

$C_1 := \frac{1}{2\pi R_2 F_p}$ $\qquad C_1 = 0.126 \cdot nF$

$G_0 := g_m \cdot \frac{R_2 \cdot C_2}{C_1 + C_2}$ $\qquad G_1(s) := -G_0 \cdot \frac{1 + \frac{2 \cdot \pi \cdot F_z}{s}}{1 + \frac{s}{2 \cdot \pi \cdot F_p}}$

$PM1 := \arg\left(G_1\left(i \cdot 2 \cdot \pi \cdot F_c\right)\right) + P_{Fc}$ $\qquad PM1 = 70 \cdot °$

$F_{p0}\left(R_0, C_1, C_2\right) := \frac{1}{2 \cdot \pi \cdot R_0 \cdot \left(C_1 + C_2\right)}$

$$F_{p1}(R_2, C_1, C_2) := \frac{1}{2 \cdot \pi \cdot R_2 \frac{C_1 \cdot C_2}{C_1 + C_2}}$$

$$F_z(R_2, C_2) := \frac{1}{2 \cdot \pi \cdot R_2 \cdot C_2}$$

$$F_c(R_2, C_1, C_2) := \sqrt{F_z(R_2, C_2) \cdot F_{p1}(R_2, C_1, C_2)}$$

Normalized value $R_2 := 220k\Omega$ $C_2 := 4.7nF$ $C_1 := 120pF$

$F_{p0}(R_0, C_1, C_2) = 6.604 \times 10^3 \cdot Hz$ $F_{p1}(R_2, C_1, C_2) = 6.183 \cdot kHz$

$F_z(R_2, C_2) = 153.922 \cdot Hz$ $F_c(R_2, C_1, C_2) = 975.512 \cdot Hz$

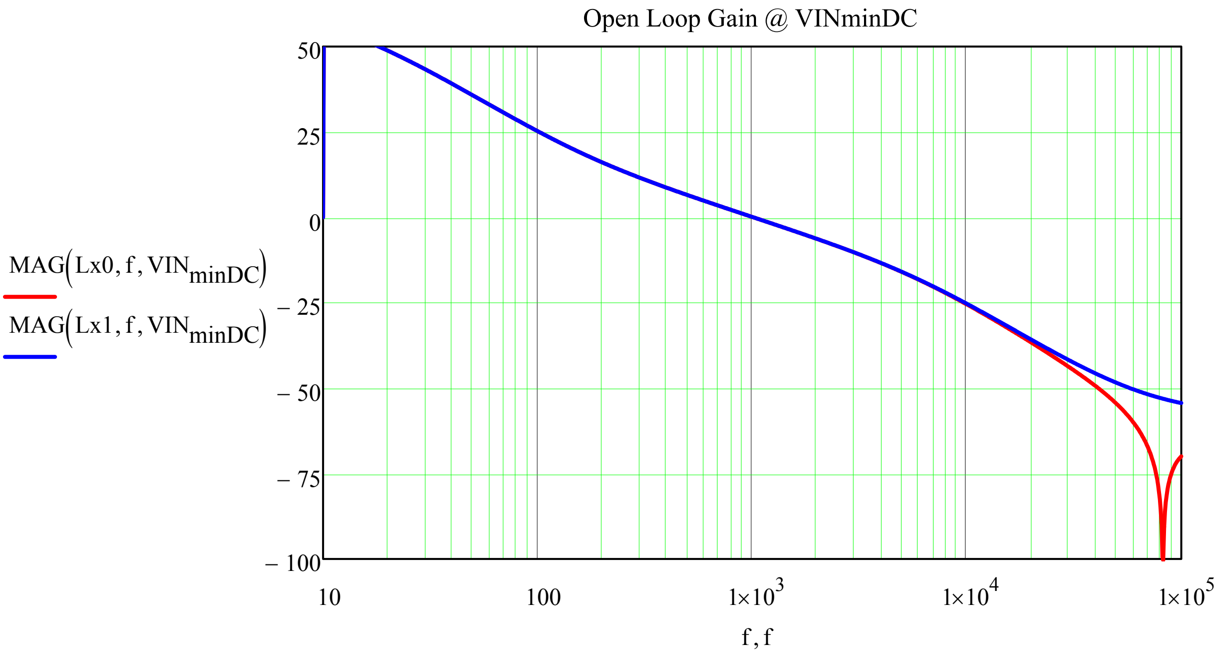
$$G_{01} := g_m \cdot \frac{R_2 \cdot C_2}{C_1 + C_2} \qquad G_{11}(s) := -G_{01} \cdot \frac{1 + \frac{2 \cdot \pi \cdot F_z(R_2, C_2)}{s}}{1 + \frac{s}{2 \cdot \pi \cdot F_{p1}(R_2, C_1, C_2)}}$$

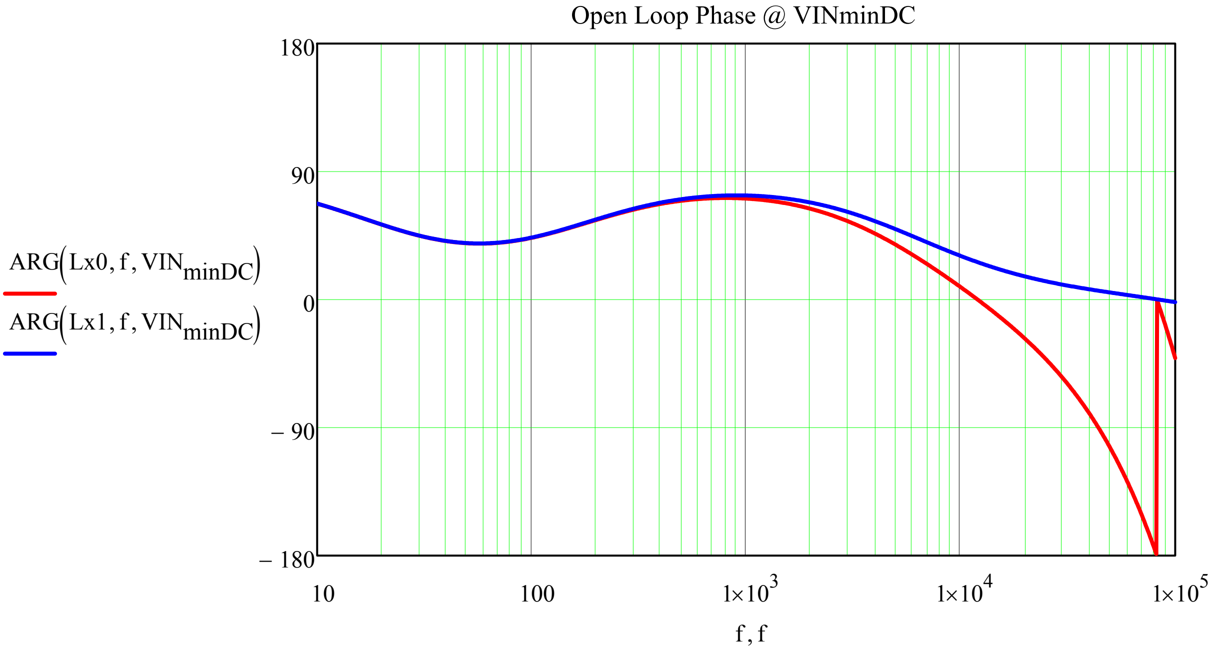
Open loop <u>with</u> ZOH:

$$Lx0(s, VIN_{DC}) := \left| \begin{array}{l} T \leftarrow \frac{1}{T_{swZOH_0}} \text{ if } VIN_{DC} = VIN_{minDC} \\ T \leftarrow \frac{1}{T_{swZOH_1}} \text{ otherwise} \\ H_2(s, VIN_{DC}) \cdot G_{11}(s) \cdot K_D(s) \cdot T_{ZOH}(s, T) \end{array} \right.$$

Open loop <u>without</u> ZOH:

$$Lx1(s, VIN_{DC}) := H_2(s, VIN_{DC}) \cdot G_{11}(s) \cdot K_D(s)$$





Stability Criteria:

crossover frequency:

$f_{c0} := f_c(Lx0, VIN_{minDC}) = 1.014 \cdot kHz$

Phase margin:

$PM_0 := PM(Lx0, VIN_{minDC}) = 70.958 \cdot °$

crossover frequency:

$f_{c1} := f_c(Lx1, VIN_{minDC}) = 1.014 \cdot kHz$

Phase margin:

$PM_1 := PM(Lx1, VIN_{minDC}) = 73.182 \cdot °$

Frequency @ Phase = 0°

$f_{g0} := f_g(Lx0, VIN_{minDC}) = 11.995 \cdot kHz$

Gain margin @ 180°:

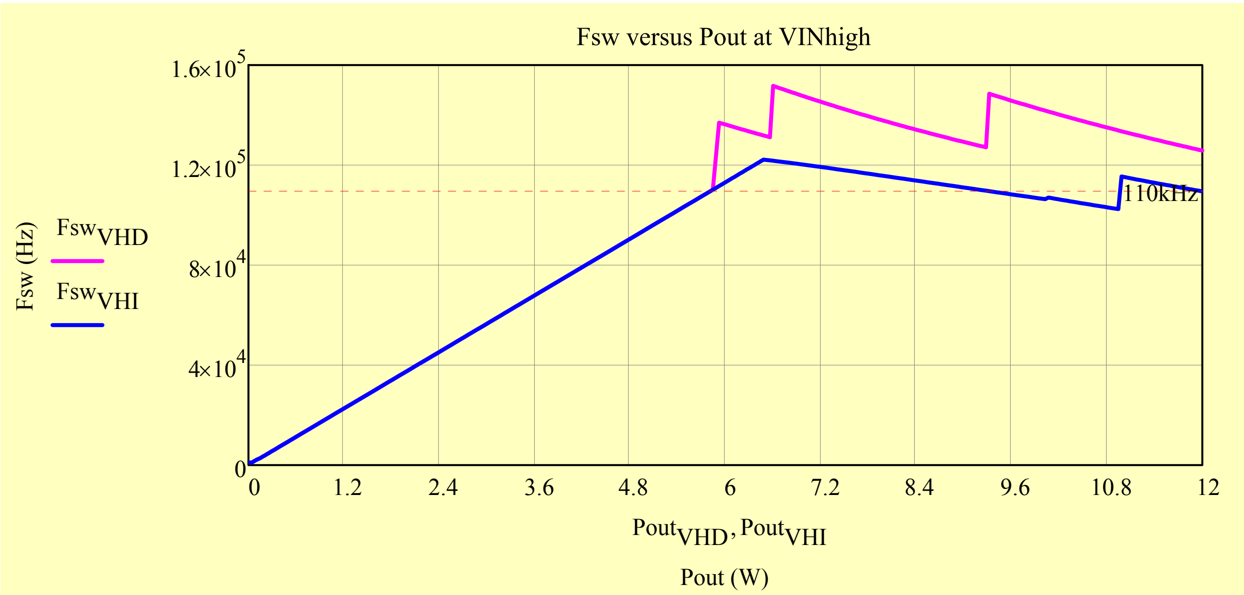
$GM_0 := GM(Lx0, VIN_{minDC}) = -28.276$

Frequency @ Phase = 0°

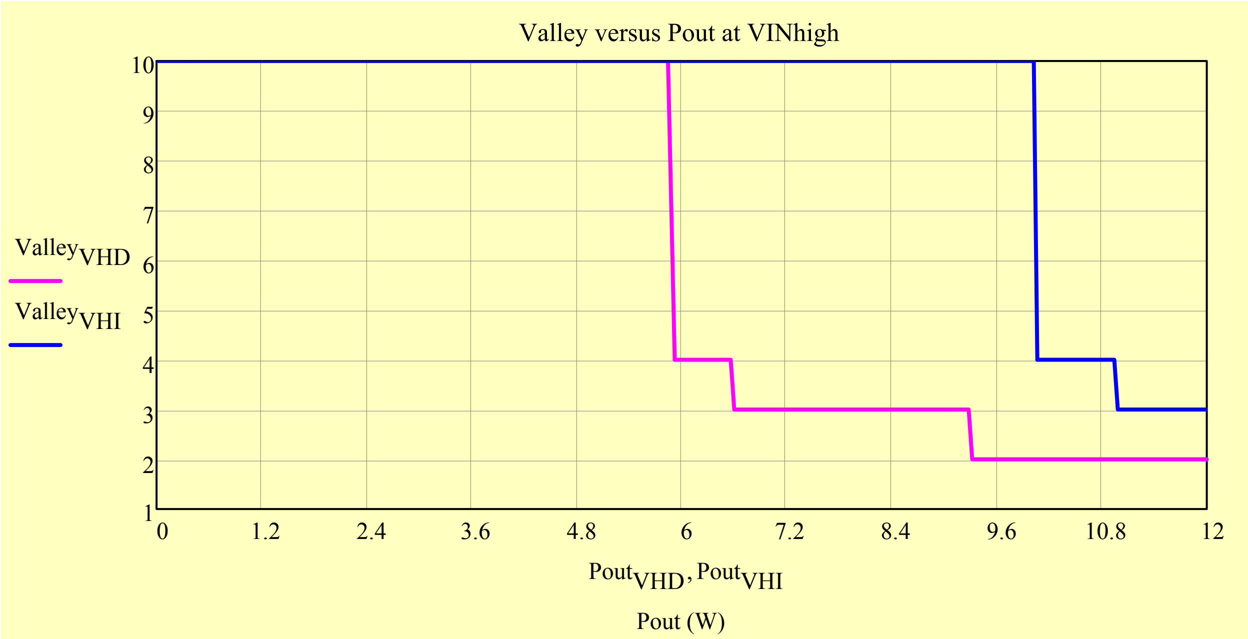
$f_{g1} := f_g(Lx1, VIN_{minDC}) = 83.748 \cdot kHz$

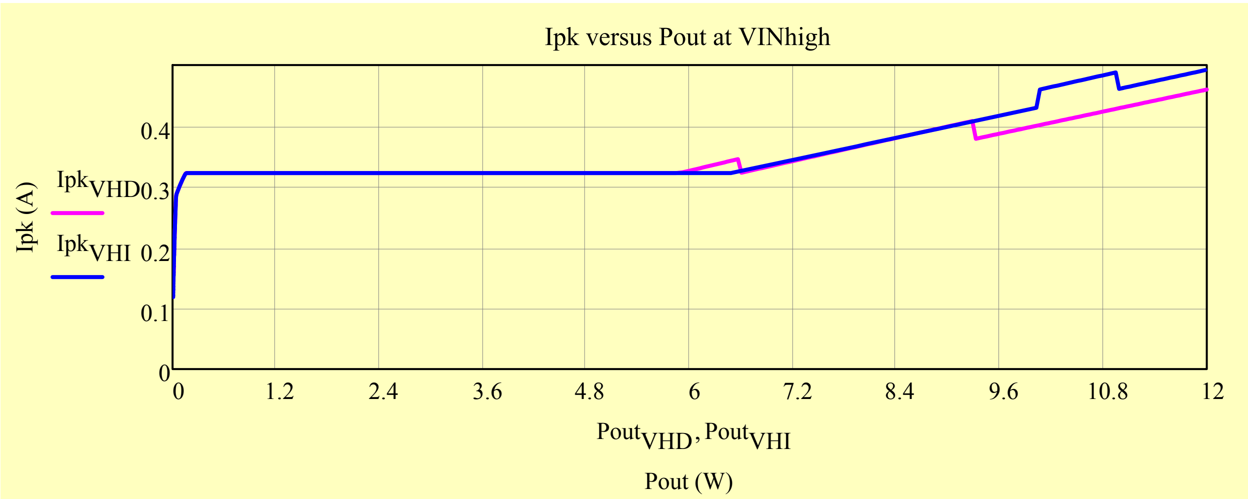
Gain margin @ 180°:

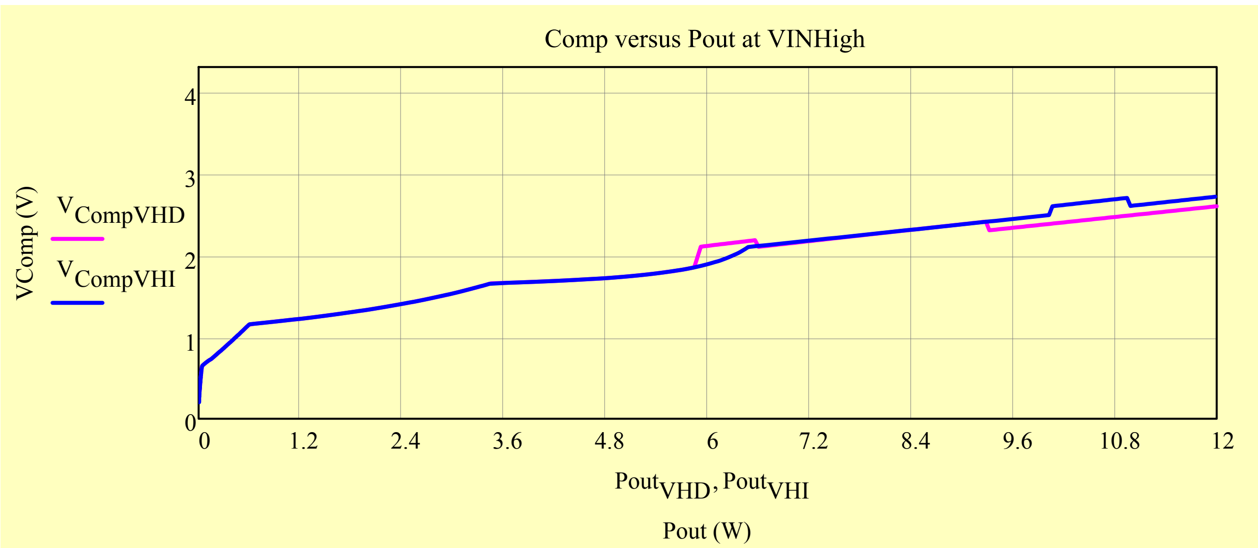
$GM_1 := GM(Lx1, VIN_{minDC}) = -53.224$

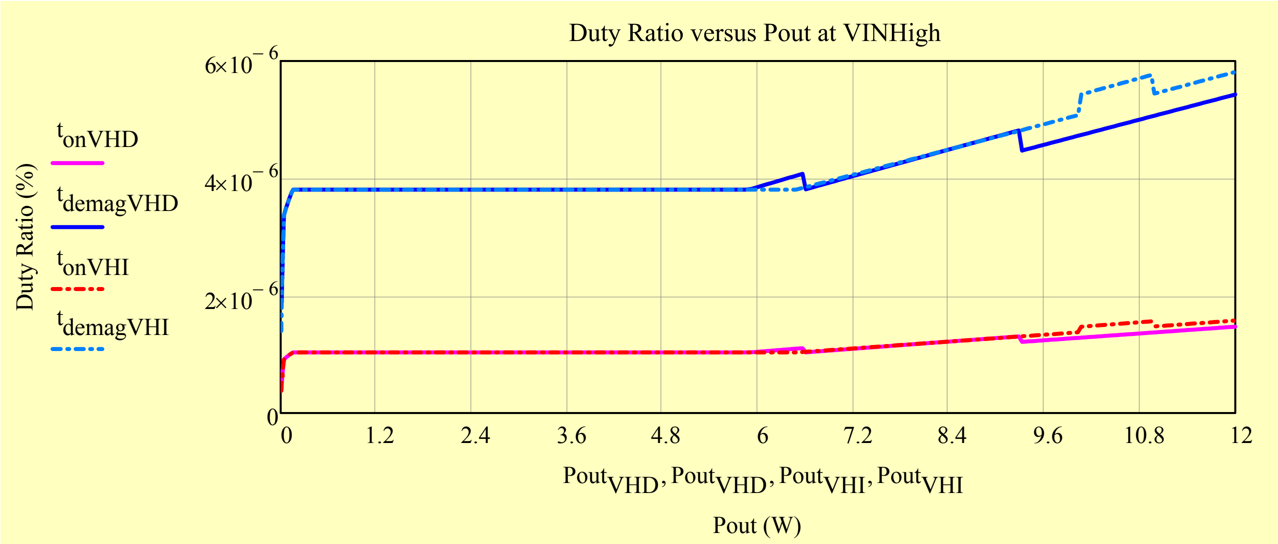


Fsw versus Pout at VINhigh
1.6×10^5
1.2×10^5
8×10^4
4×10^4
0
Fsw (Hz)
Fsw_VHD
Fsw_VHI
110kHz
0
1.2
2.4
3.6
4.8
6
7.2
8.4
9.6
10.8
12
Pout_VHD, Pout_VHI
Pout (W)


Valley versus Pout at VINhigh
Valley_VHD
Valley_VHI
10
9
8
7
6
5
4
3
2
1
0
1.2
2.4
3.6
4.8
6
7.2
8.4
9.6
10.8
12
Pout_VHD, Pout_VHI
Pout (W)

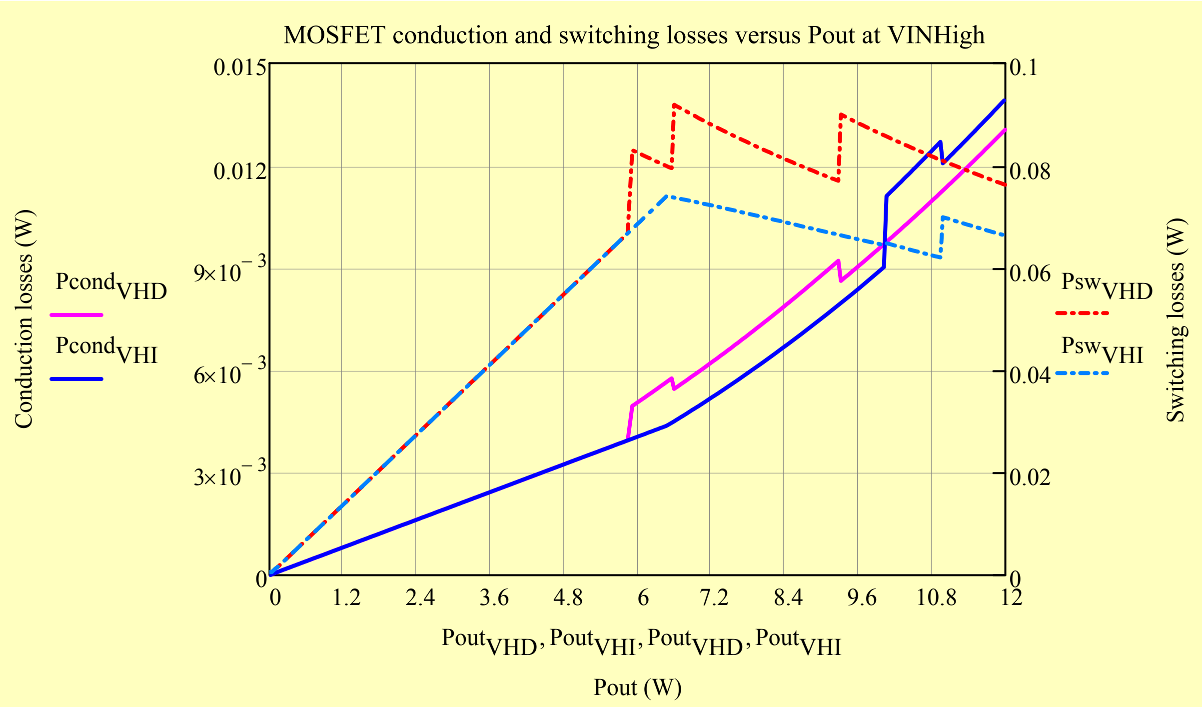

Ipk versus Pout at VINhigh
Ipk (A)
Ipk_VHD
Ipk_VHI
0.4
0.3
0.2
0.1
0
0
1.2
2.4
3.6
4.8
6
7.2
8.4
9.6
10.8
12
Pout_VHD, Pout_VHI
Pout (W)


Comp versus Pout at VINHigh
VComp (V)
V_CompVHD
V_CompVHI
4
3
2
1
0
0
1.2
2.4
3.6
4.8
6
7.2
8.4
9.6
10.8
12
Pout_VHD, Pout_VHI
Pout (W)

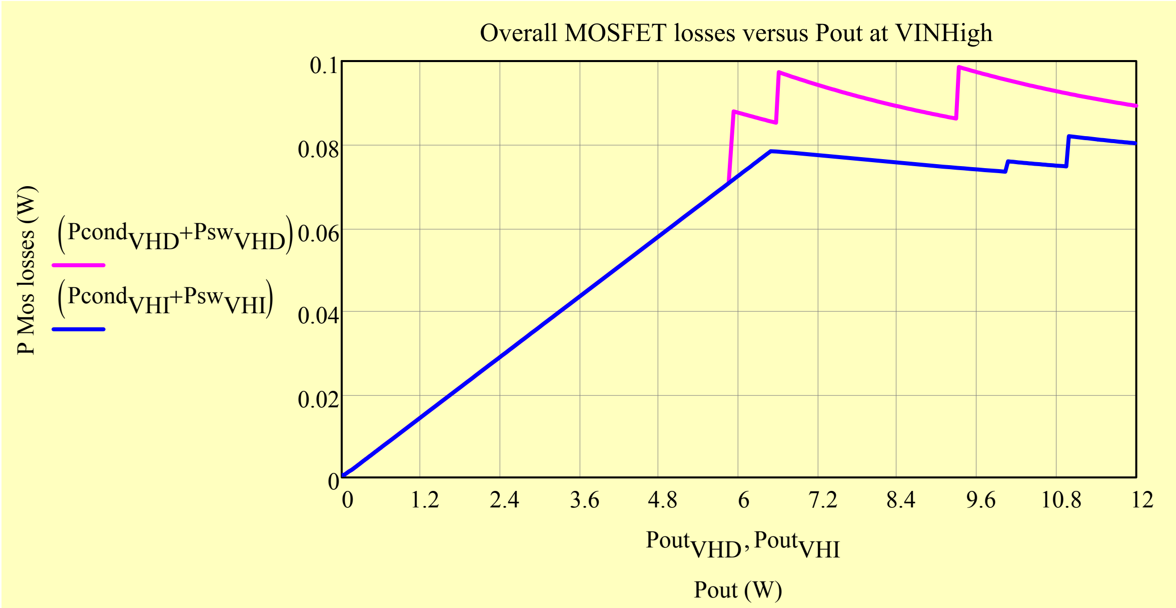


Duty Ratio versus Pout at VINHigh
t onVHD
t demagVHD
t onVHI
t demagVHI
Duty Ratio (%)
6×10⁻⁶
4×10⁻⁶
2×10⁻⁶
0
0
1.2
2.4
3.6
4.8
6
7.2
8.4
9.6
10.8
12
Pout VHD, Pout VHD, Pout VHI, Pout VHI
Pout (W)

$VIN_{high} = 265\ V$

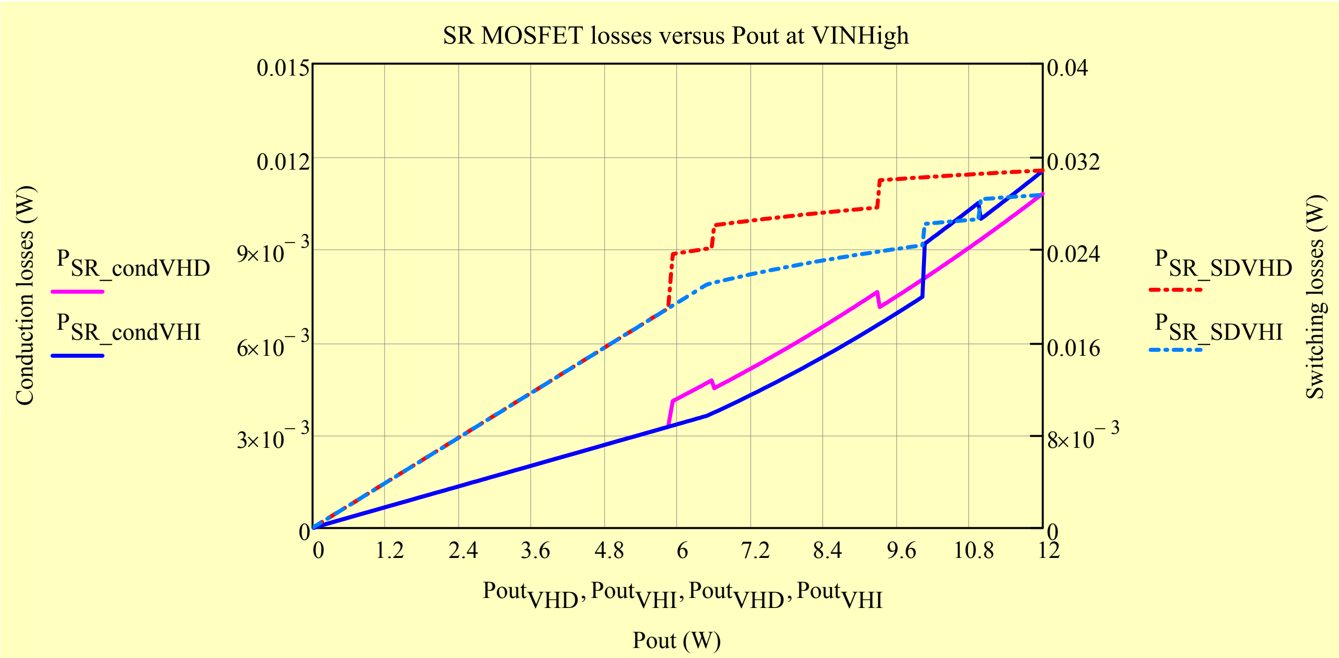


$VIN_{high} = 265\ V$

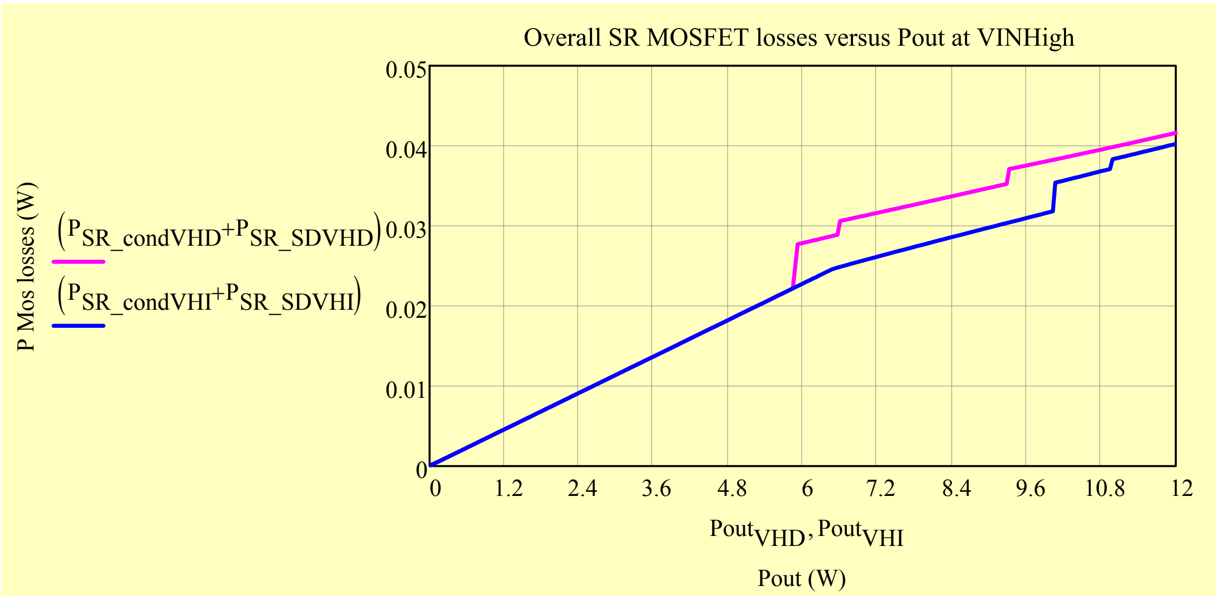

Overall MOSFET losses versus Pout at VINHigh
P Mos losses (W)
(Pcond_VHD+Psw_VHD)
(Pcond_VHI+Psw_VHI)
0.1
0.08
0.06
0.04
0.02
0
0
1.2
2.4
3.6
4.8
6
7.2
8.4
9.6
10.8
12
Pout_VHD, Pout_VHI
Pout (W)

)

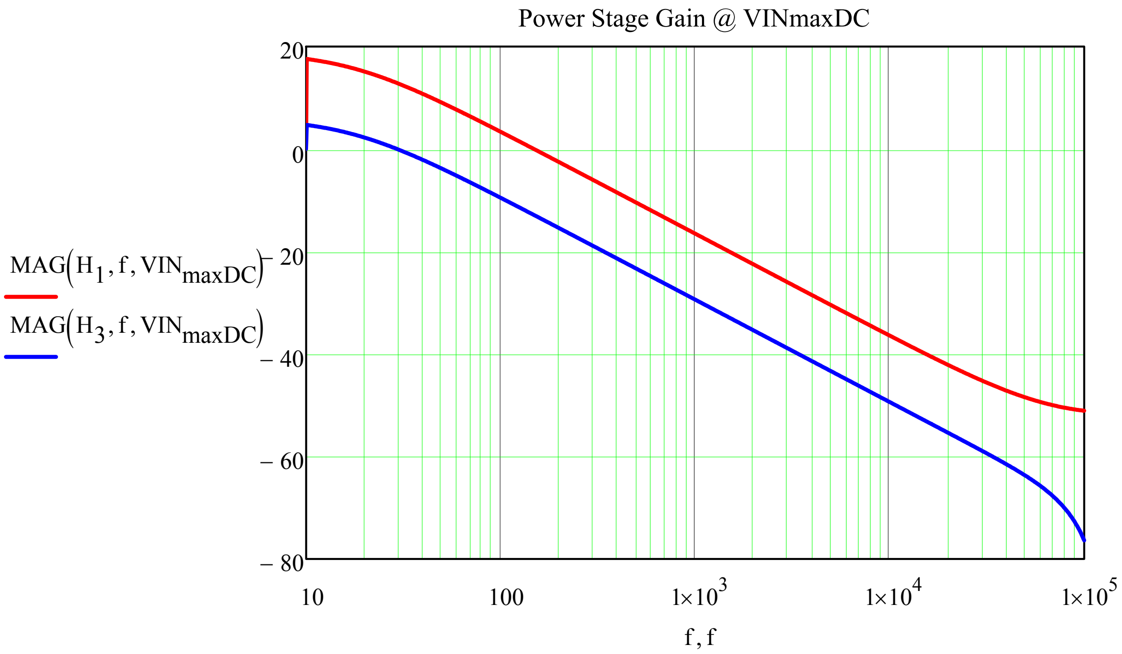
$VIN_{high} = 265\ V$

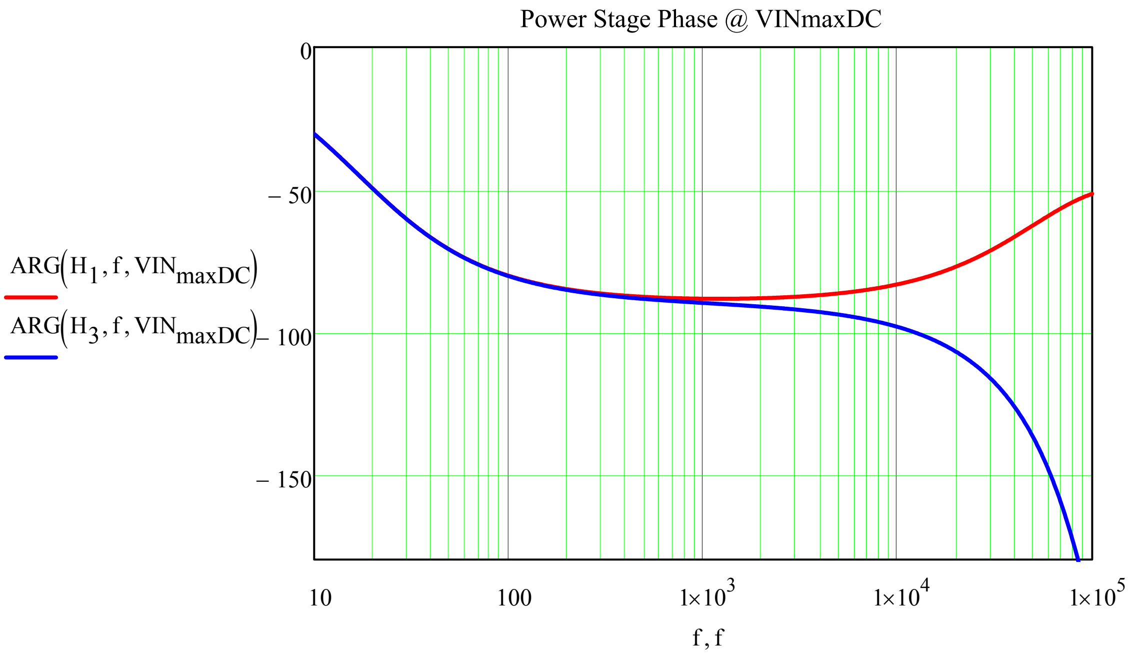


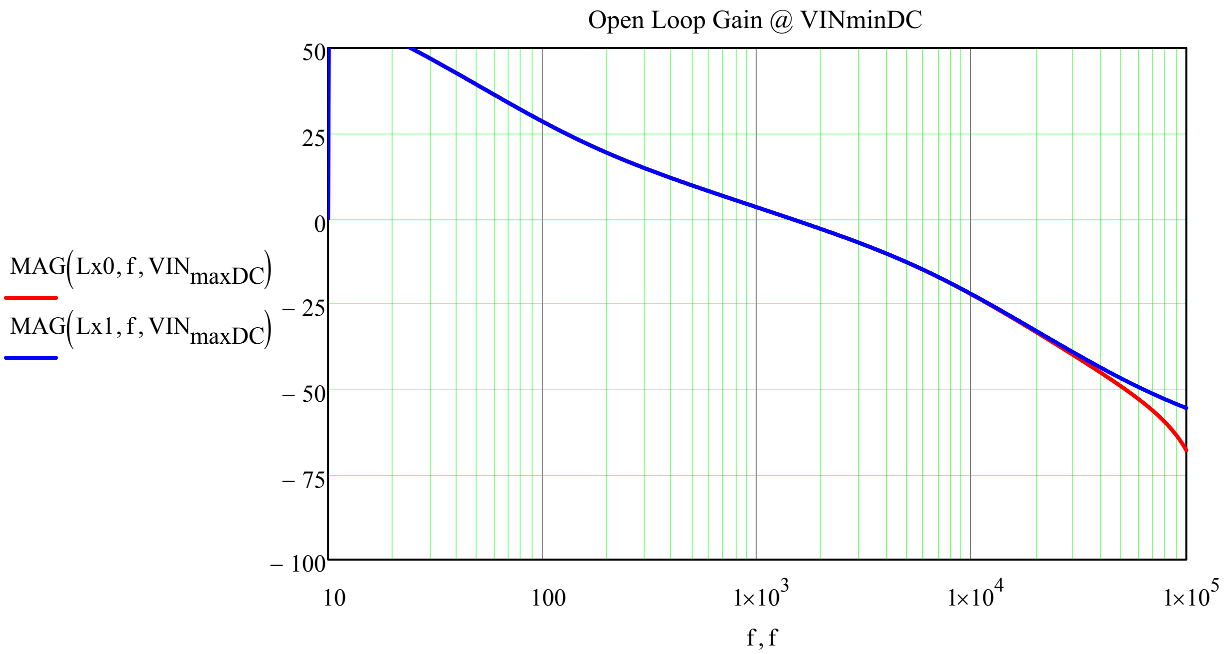
$VIN_{high} = 265\ V$



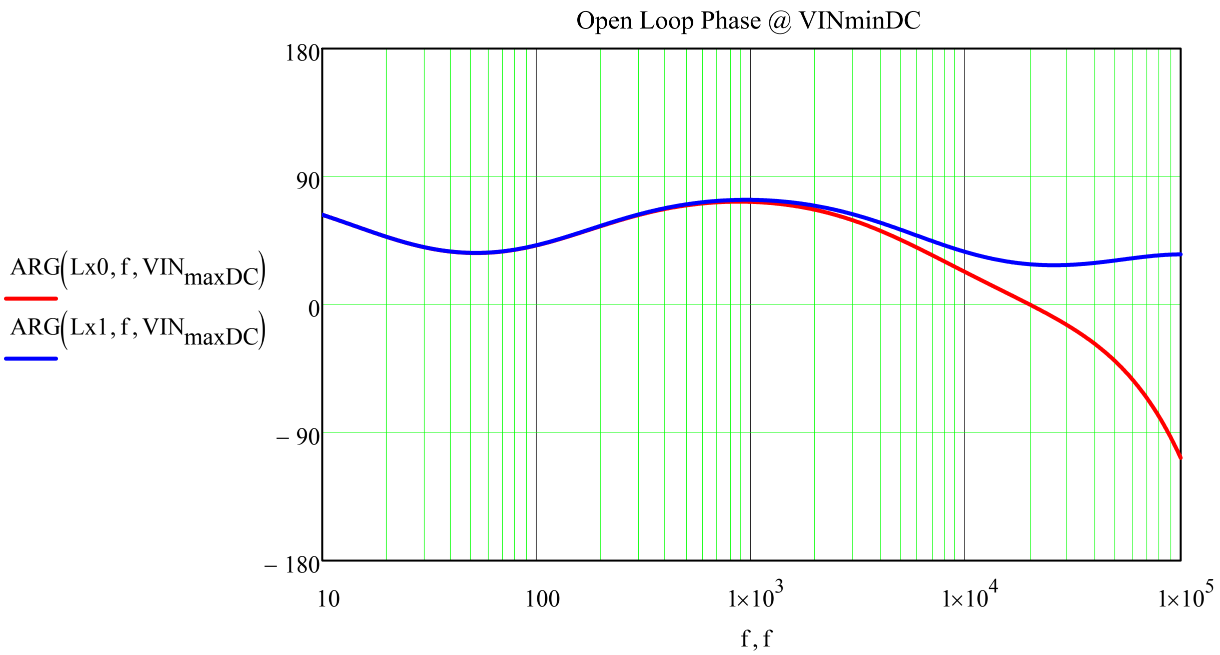
$\text{ndVHI} + P_{SR\_SDVHI})$


Power Stage Gain @ VINmaxDC
20
0
− 20
− 40
− 60
− 80
MAG(H1, f, VINmaxDC)
MAG(H3, f, VINmaxDC)
10
100
1×10^3
1×10^4
1×10^5
f, f


Power Stage Phase @ VINmaxDC
0
− 50
− 100
− 150
ARG(H1, f, VINmaxDC)
ARG(H3, f, VINmaxDC)
10
100
1×10^3
1×10^4
1×10^5
f, f



Open Loop Gain @ VINminDC
MAG(Lx0, f, VINmaxDC)
MAG(Lx1, f, VINmaxDC)
50
25
0
− 25
− 50
− 75
− 100
10
100
1×10^3
1×10^4
1×10^5
f, f



Open Loop Phase @ VINminDC
ARG(Lx0, f, VINmaxDC)
ARG(Lx1, f, VINmaxDC)
180
90
0
− 90
− 180
10
100
1×10^3
1×10^4
1×10^5
f, f