

Computer Aided Design of Power Factor Correction Systems

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Objective:

To develop the skills of average modeling and its application in the analysis and design of APFC systems

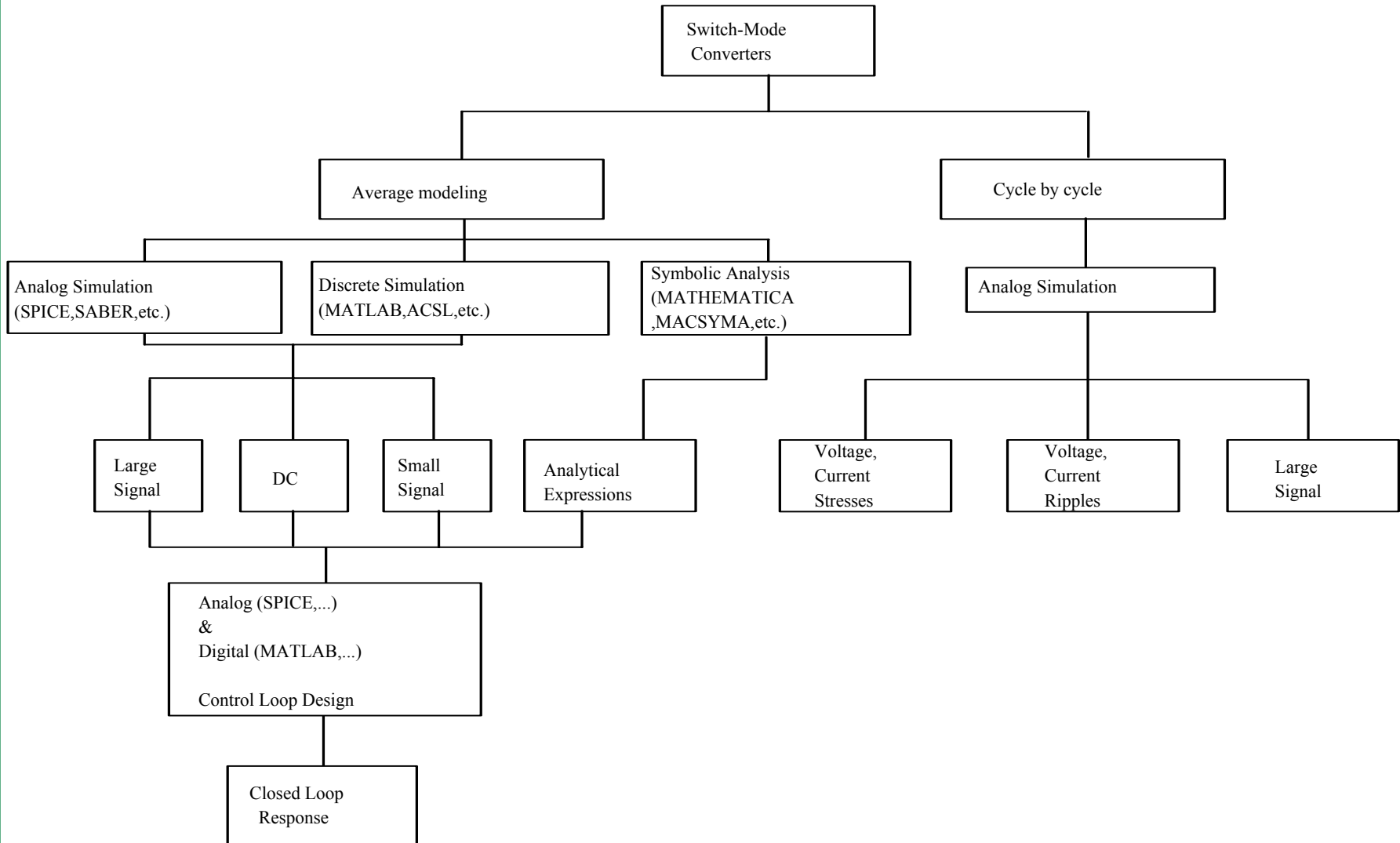
Emphasis on:

- Methodology of Average Simulation
- Small and large signal responses
- Control loop design

Outline

1. Overview of simulation methods
2. The averaging methodology
3. Feedback analysis and design
4. Continuous Conduction Mode (CCM) APFC stages
 - 4.1 Classical (Unitrode) method
 - 4.2 Method with no sensing of input voltage
5. Critical Conduction Mode APFC stages
 - 5.1 Method with no sensing of input voltage
6. Conclusions and Q&A

Computer Simulation of Power Conversion Systems



Average modeling of switch mode systems

Applications:

- DC transfer functions
- Transient (large signal, time domain) phenomena
- Small signal (AC, time domain) transfer functions

Not applicable to:

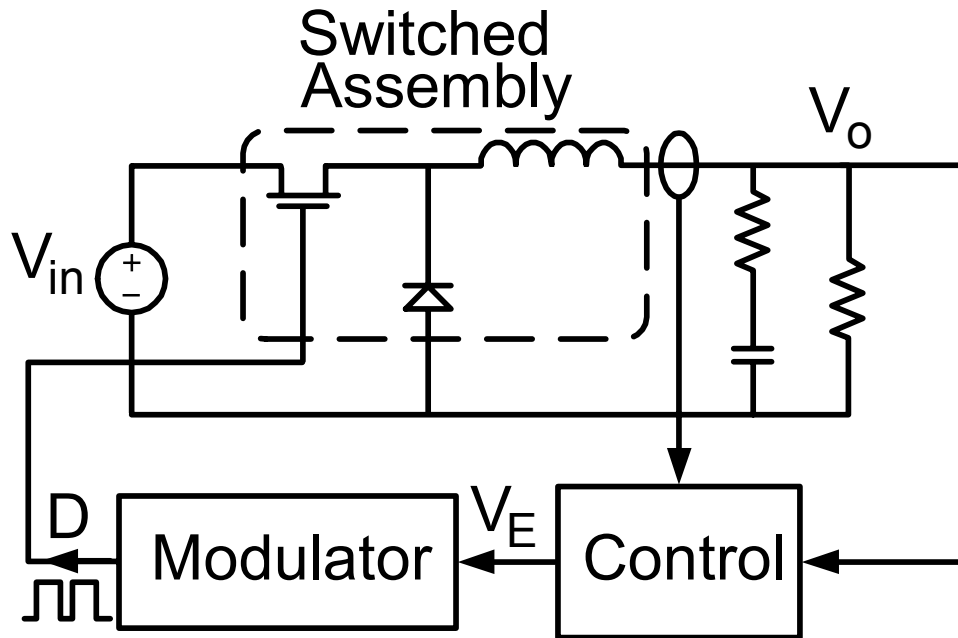
- Switching details, rise and fall times, spikes
 - Device characteristics and losses
 - Subharmonic oscillations
-
- Conduction losses can be accounted for
 - HF ripple can be estimated

The Switched Inductor Model (SIM) Strategy

- Identify the switched assembly
- Replace the switching part by a continuous (analog) equivalent circuit
- Leave the analog part as-is
- Run the combined circuit on a general purpose simulator

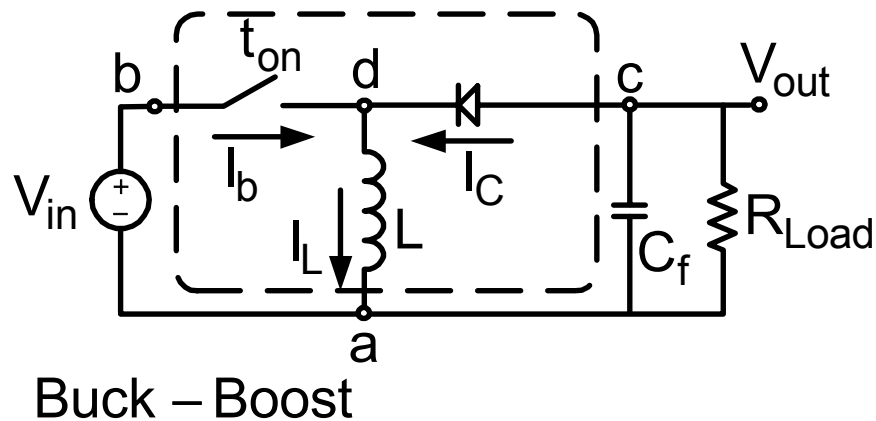
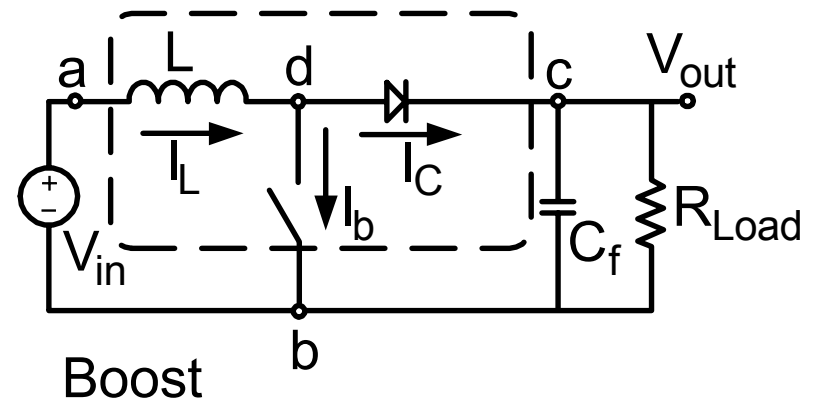
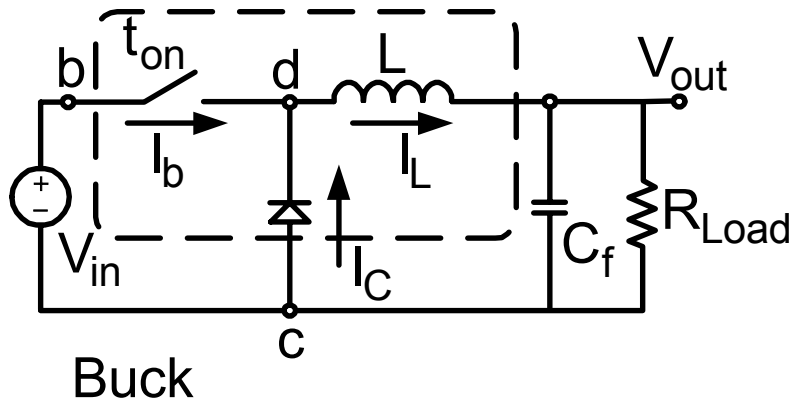
The modeling methodology presented in this seminar is highly 'portable', independent of simulator

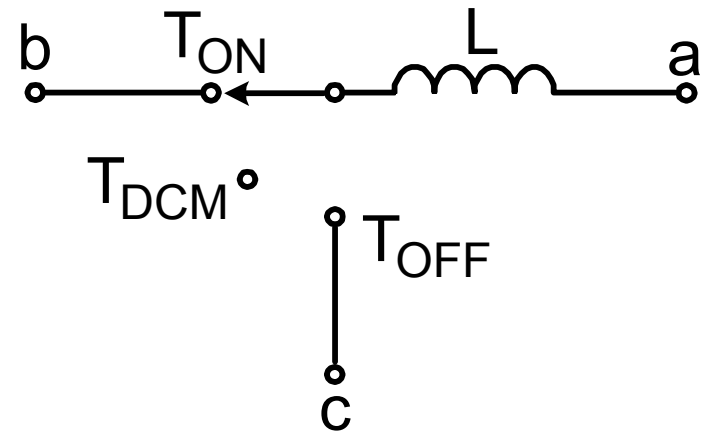
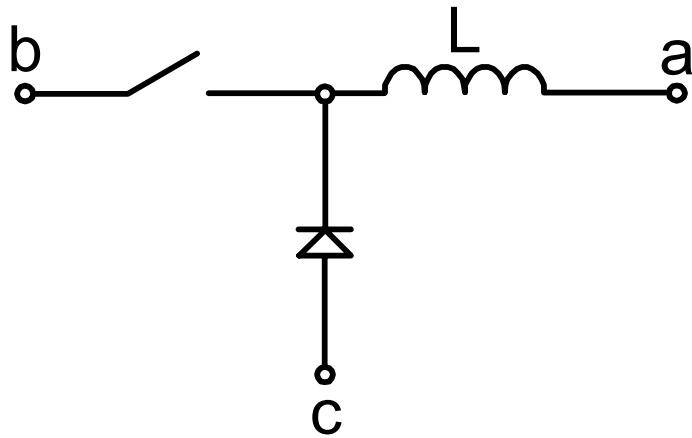
Demonstration by PSPICE Ver. 9.2 (Evaluation)



- The problematic part : Switched Assembly
- Rest of the circuit continuous - SPICE compatible
- The objective : translate the Switched Assembly into an equivalent circuit which is SPICE compatible

Average Simulation of PWM Converters

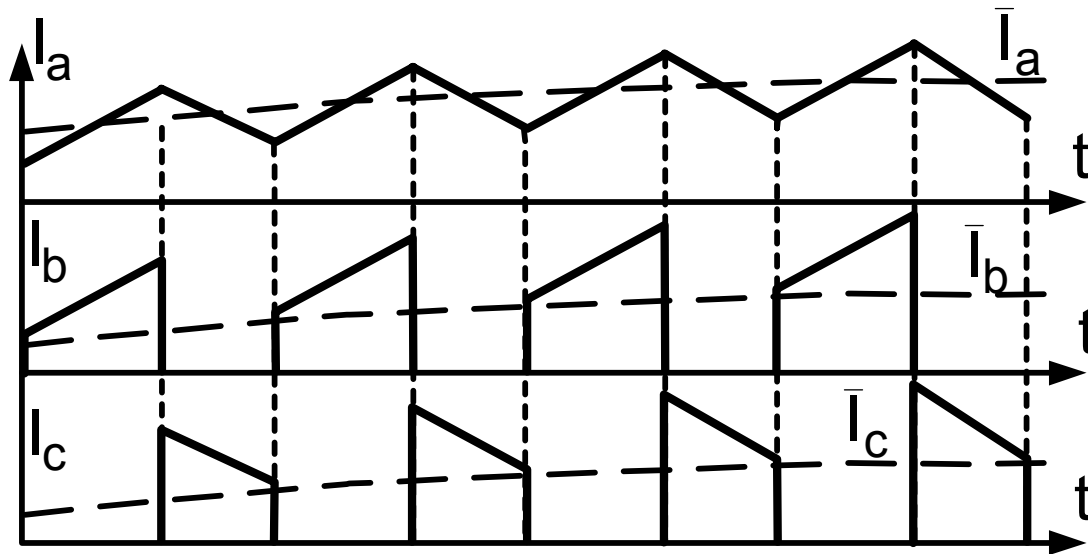
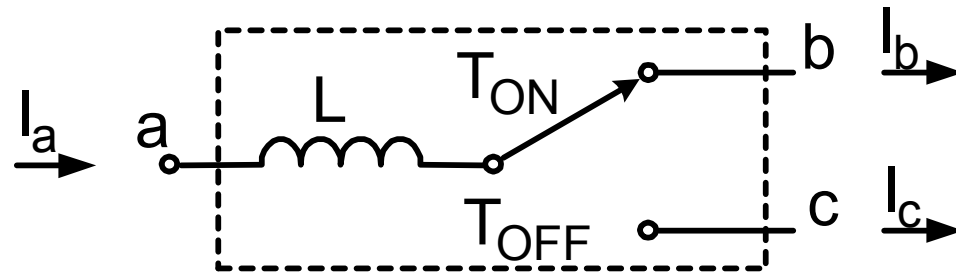




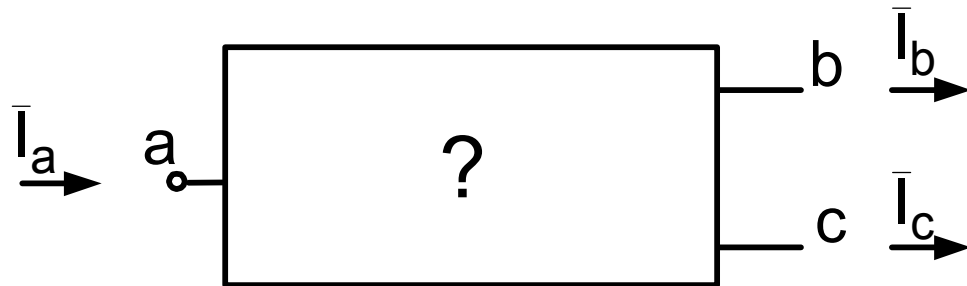
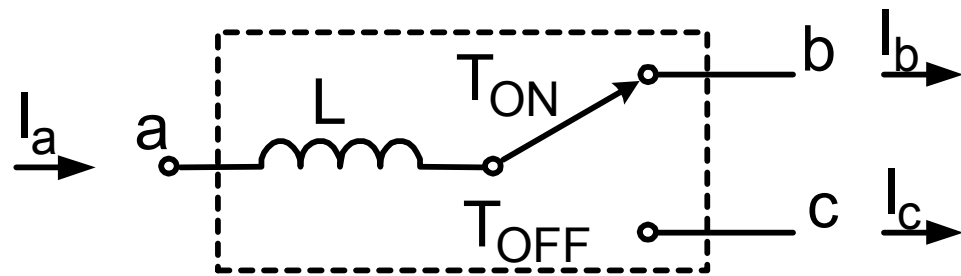
T_{ON} - switch conduction time
 T_{OFF} - diode conduction time
 T_{DCM} - no current time (in DCM)

The Switched Inductor Model (SIM) (CCM)

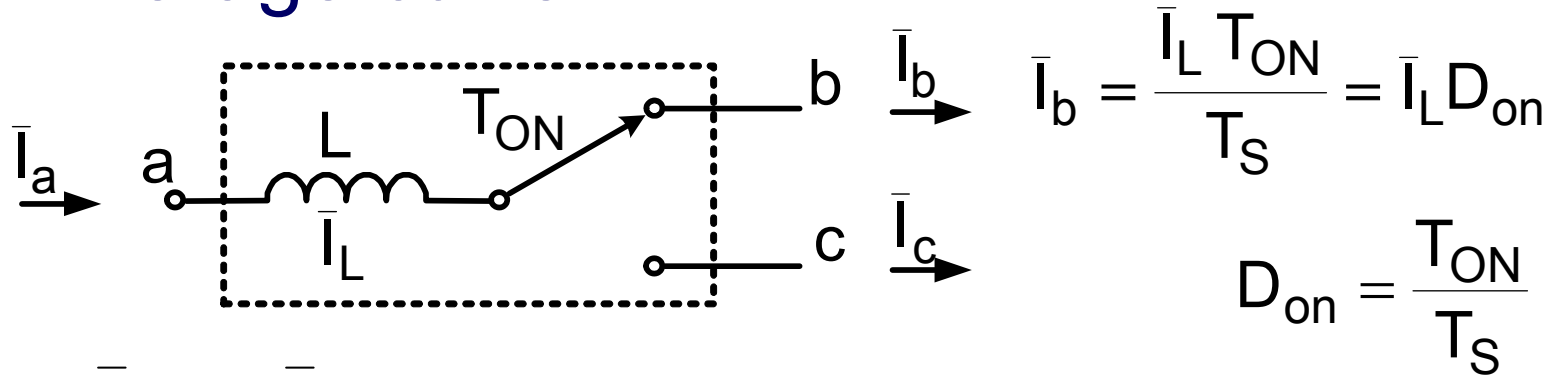
The concept of average signals



Objective : To replace the switched part
by a continuous network



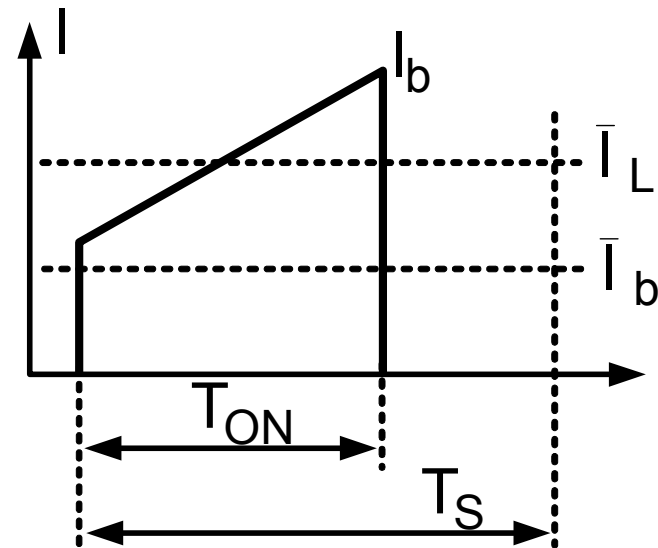
Average current



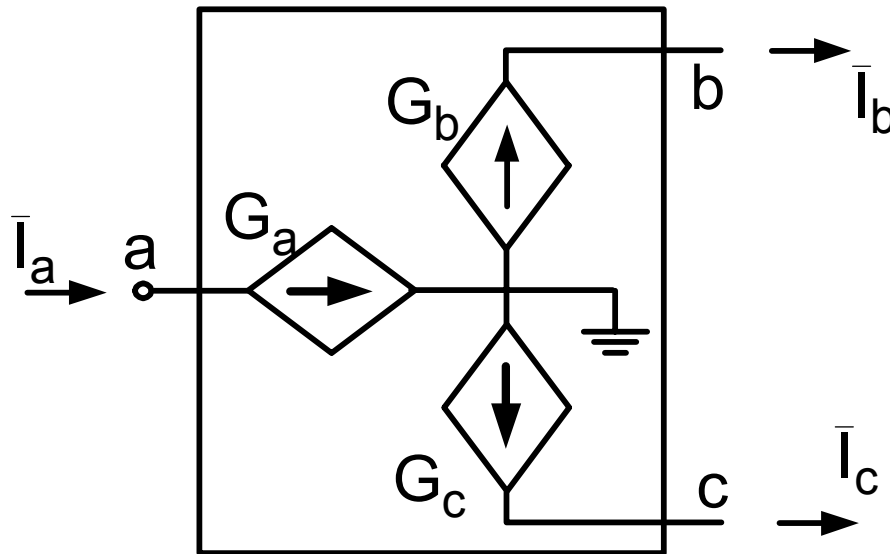
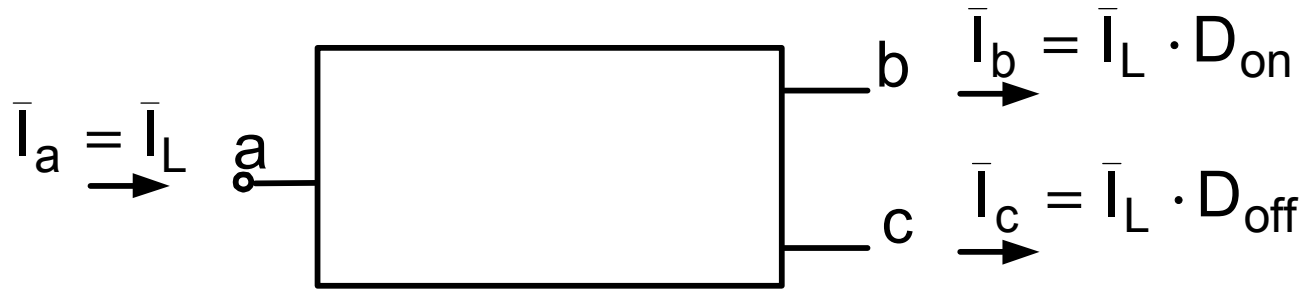
$$\bar{I}_a = \bar{I}_L$$

Similarly :

$$\bar{I}_c = \frac{\bar{I}_L T_{OFF}}{T_S} = \bar{I}_L D_{off}$$



Toward a continuous model



G_a, G_b, G_c - current dependent sources

$$G_a \equiv \bar{I}_L$$

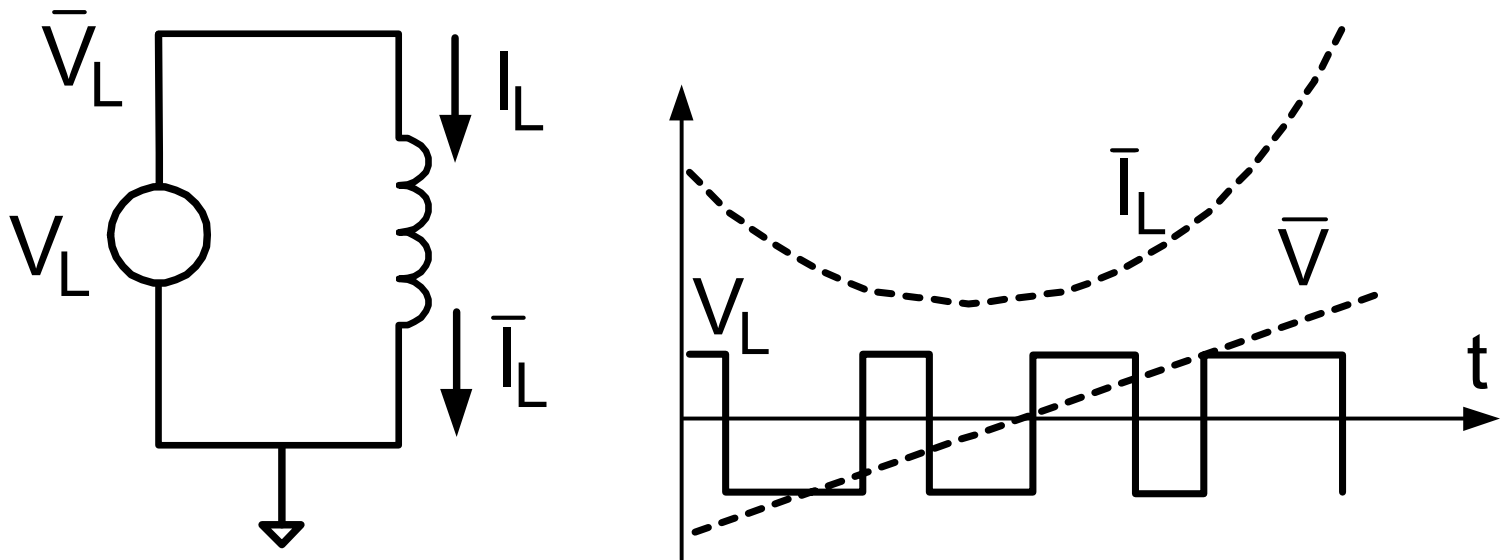
$$G_b \equiv \bar{I}_L \cdot D_{on}$$

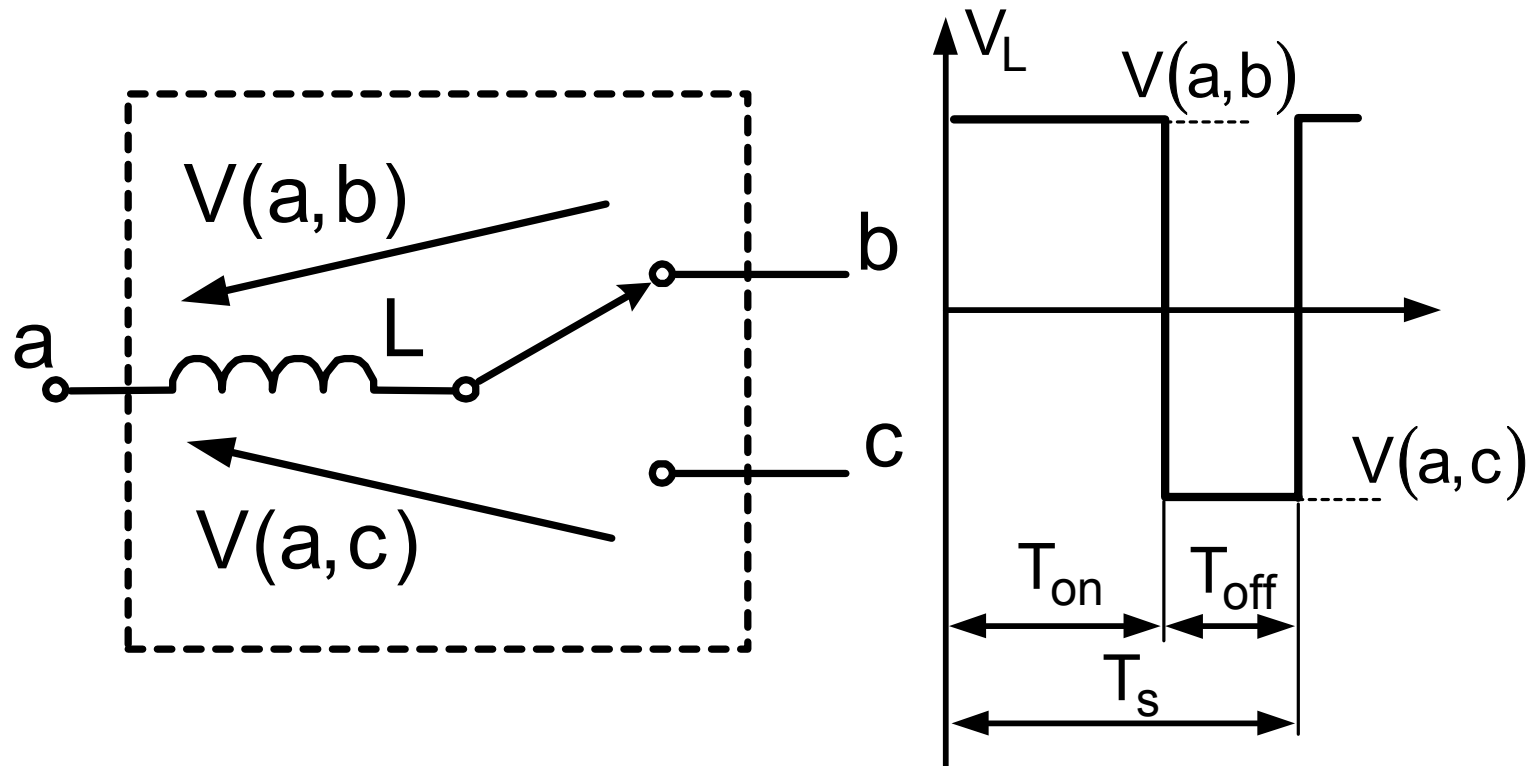
$$G_c \equiv \bar{I}_L \cdot D_{off}$$

Deriving \bar{I}_L

$$\frac{dI_L}{dt} = \frac{V}{L} \quad \Rightarrow \quad \frac{d\langle I_L \rangle}{dt} = \frac{\langle V \rangle}{L}$$

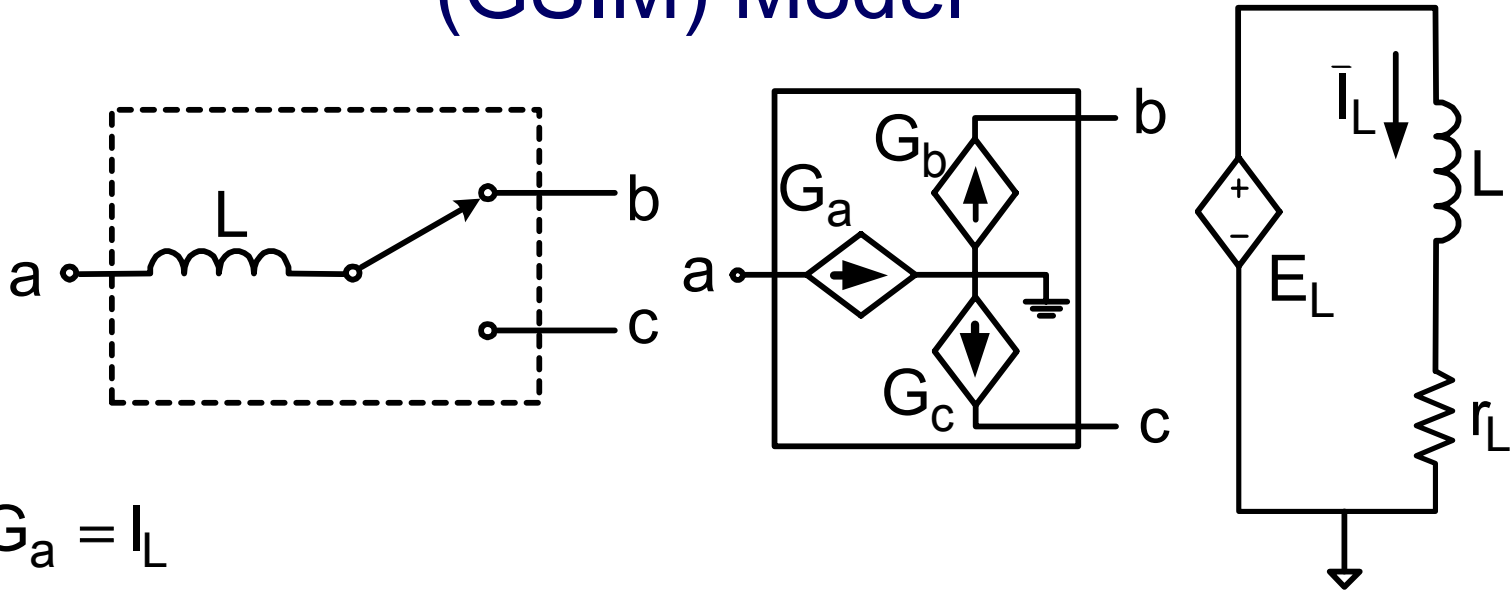
$\langle X \rangle = \bar{X} = \text{Average value}$





$$\begin{aligned} \bar{V}_L &= \frac{V(a,b) \cdot T_{on} + V(a,c) \cdot T_{off}}{T_s} = \\ &= V(a,b) \cdot D_{on} + V(a,c) \cdot D_{off} \end{aligned}$$

The Generalized Switched Inductor Model (GSIM) Model



$$G_a = I_L$$

$$G_b = I_L \cdot D_{on}$$

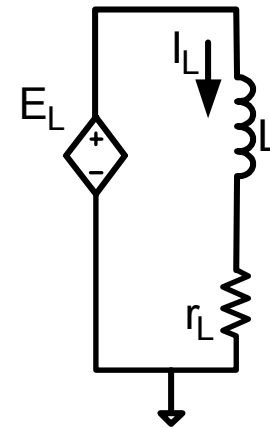
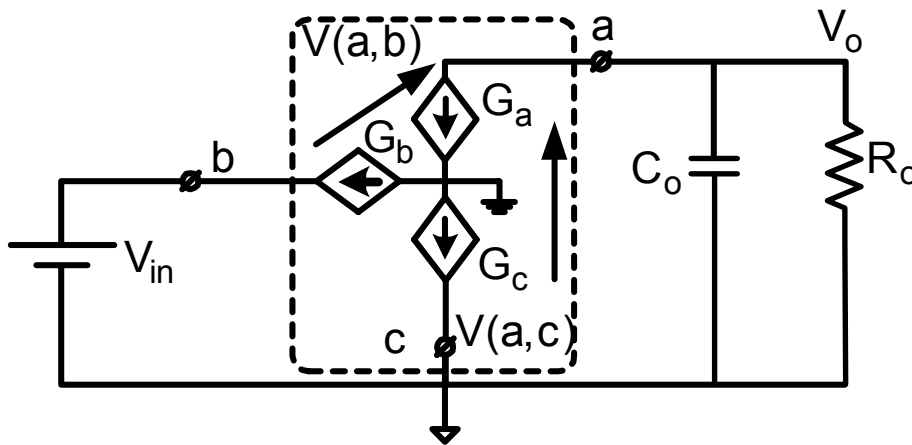
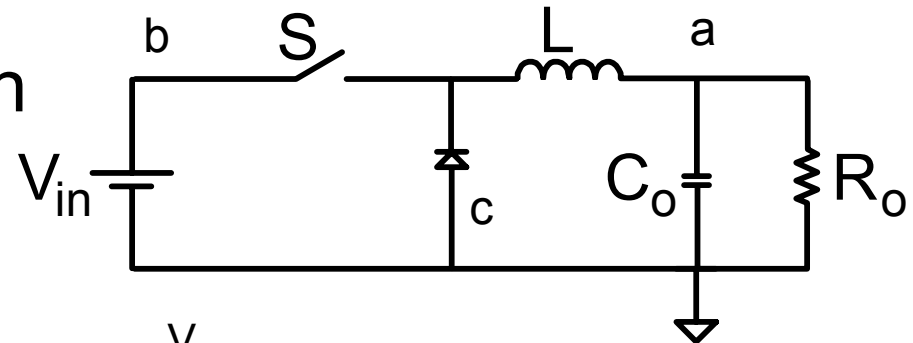
$$G_c = I_L \cdot D_{off}$$

$$\bar{V}_L = V(a,b) \cdot D_{on} + V(a,c) \cdot D_{off}$$

Topology independent !

Example Implementation in Buck Topology

1. The formal approach

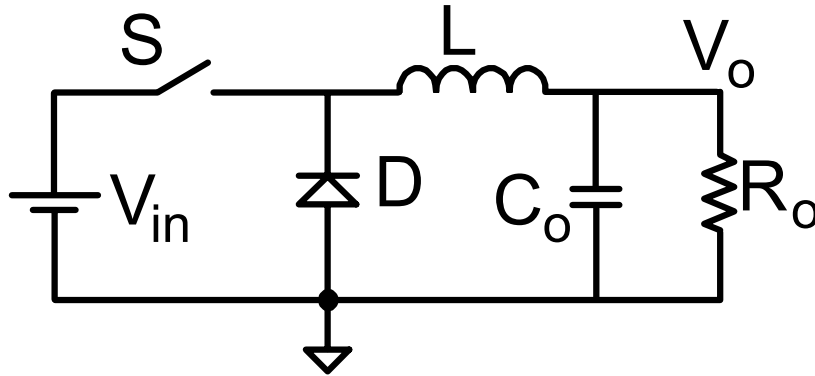


$$G_a = I(L) \quad G_b = I(L) \cdot D_{\text{on}} \quad G_c = I(L) \cdot D_{\text{off}}$$

$$E_L = [V_0 - V_{\text{in}}] \cdot D_{\text{on}} + [V_0 - 0] \cdot D_{\text{off}}$$

Implementation in Buck Topology

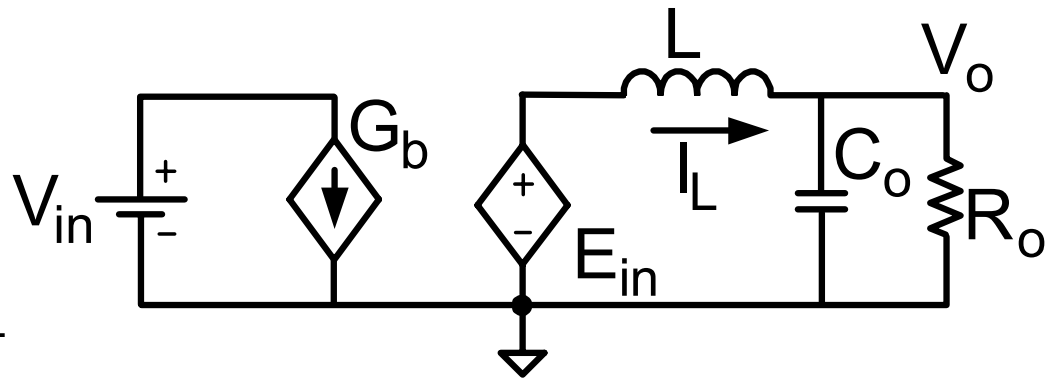
2. The intuitive approach - by inspection



$$E_{in} = V_{in} \cdot D_{on}$$

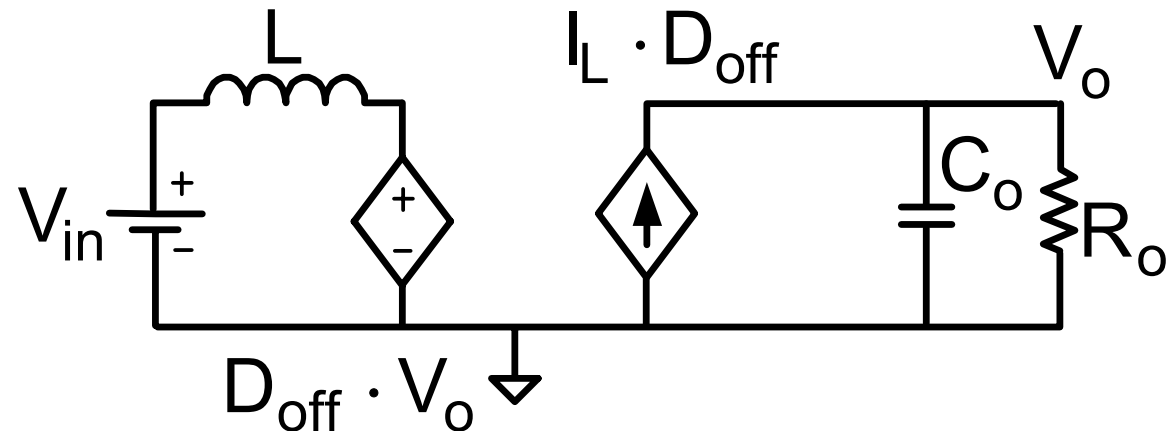
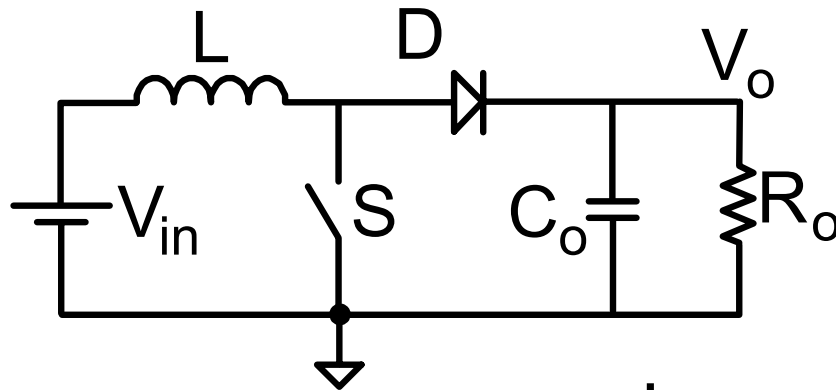
$$G_b = \bar{I}_L \cdot D_{on}$$

$$E_{in} + V_o \rightarrow \bar{V}_L$$



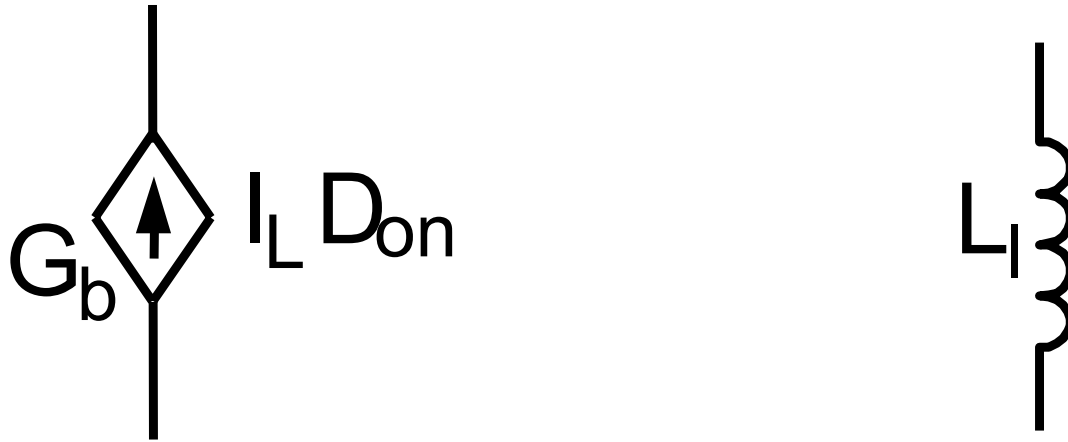
Polarity: (voltage and current sources) selected by inspection

Boost



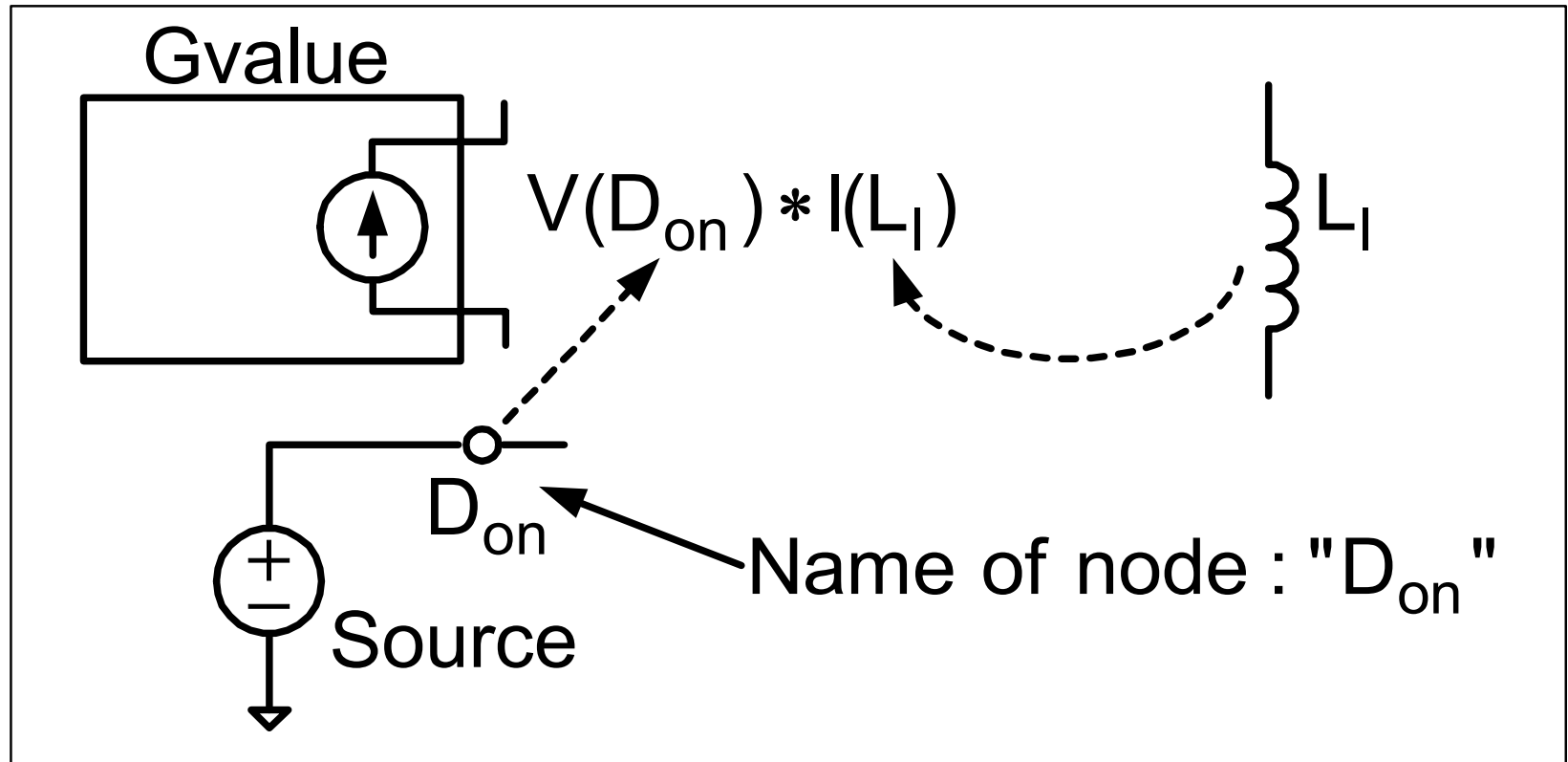
- Emulate average voltage on inductor
- Create I_L dependent current sources

Making the model SPICE compatible



I_L and D_{ON} are time dependent Variables $\{I_L(t), D_{ON}(t)\}$
 D_{ON} is not an electrical variable

In SPICE environment



D_{on} is coded into voltage

Running SPICE simulation

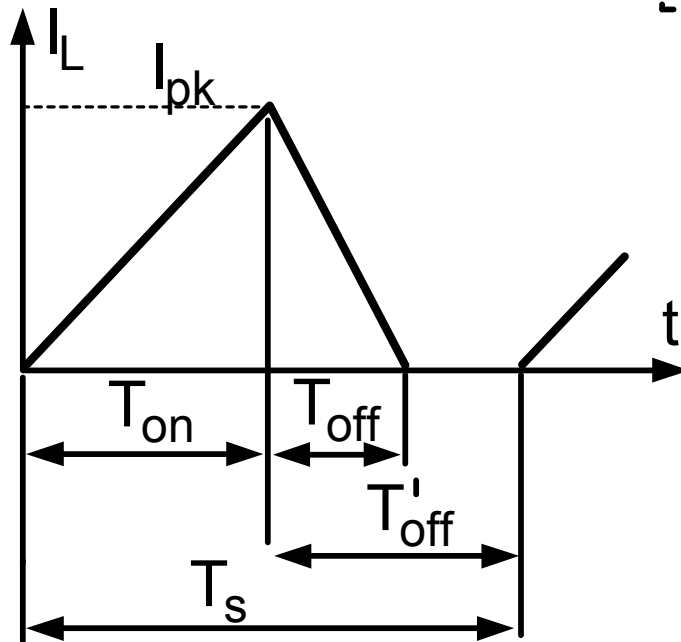
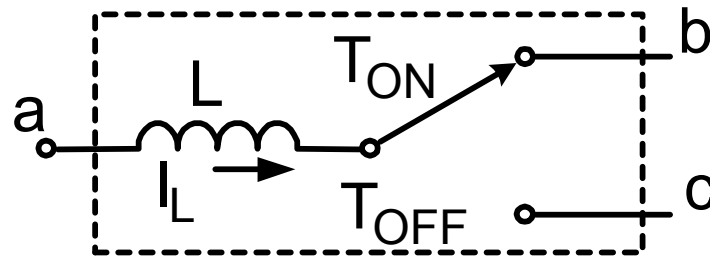
DC (steady state points) - as is

TRAN (time domain) - as is

AC (small signal) - as is

* Linearization is done by simulator !

Discontinuous Model (DCM)

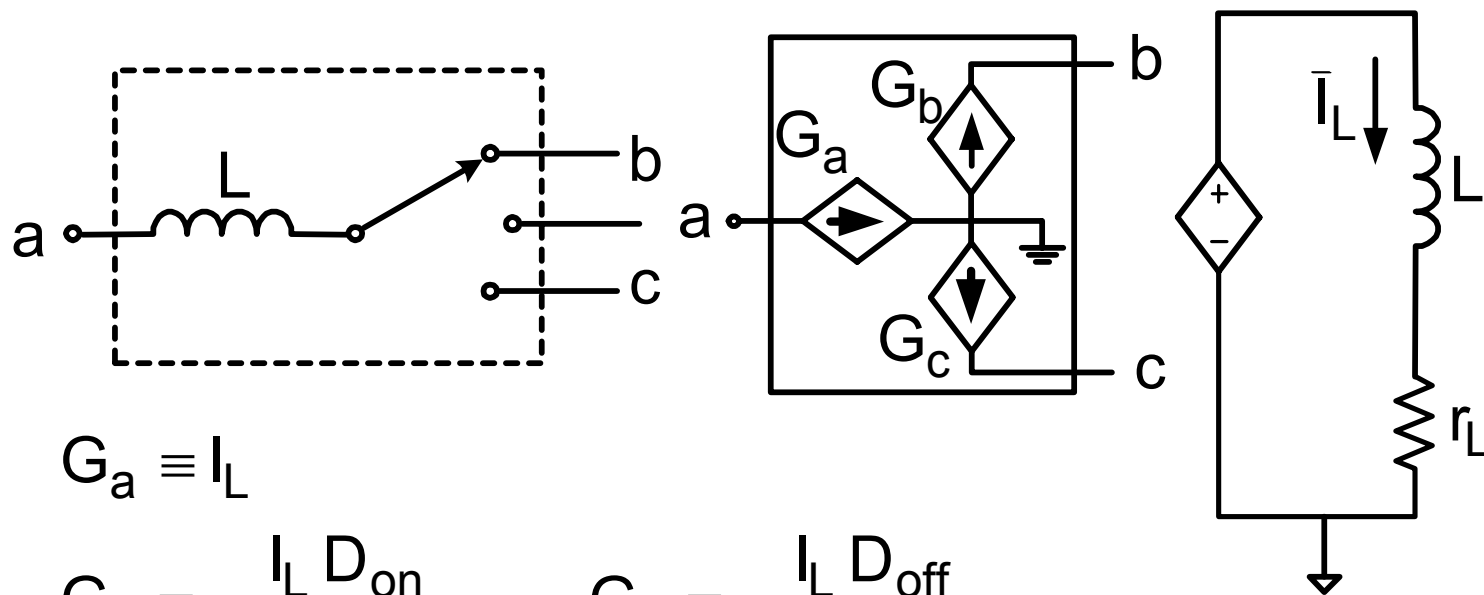


$$T'_{\text{off}} = T_s - T_{\text{on}}$$

$$D'_{\text{off}} = \frac{T_s - T_{\text{on}}}{T_s} = 1 - D_{\text{on}}$$



The combined DCM / CCM mode



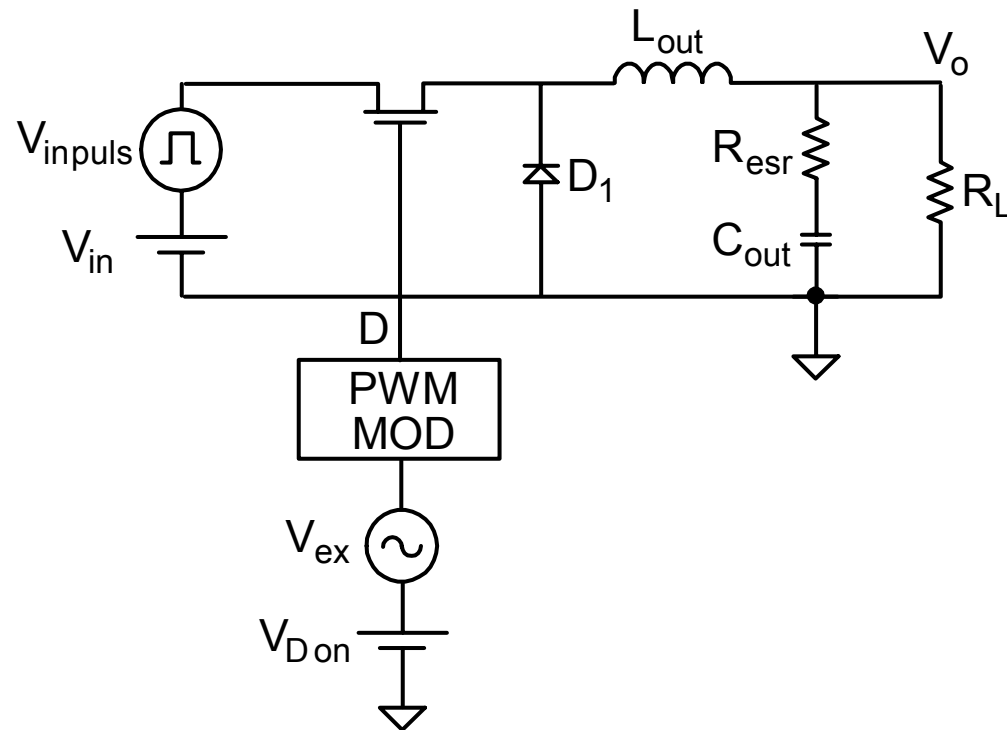
$$G_a \equiv I_L$$

$$G_b \equiv \frac{I_L D_{on}}{D_{on} + D_{off}} \quad G_c \equiv \frac{I_L D_{off}}{D_{on} + D_{off}}$$

$$V_L = V(a,b)D_{on} + V(a,c)D_{off}$$

$$D_{off} = \min \left\{ (1 - D_{on}), \left(\frac{2I_L L f_s}{V(a,b)D_{on}} - D_{on} \right) \right\}$$

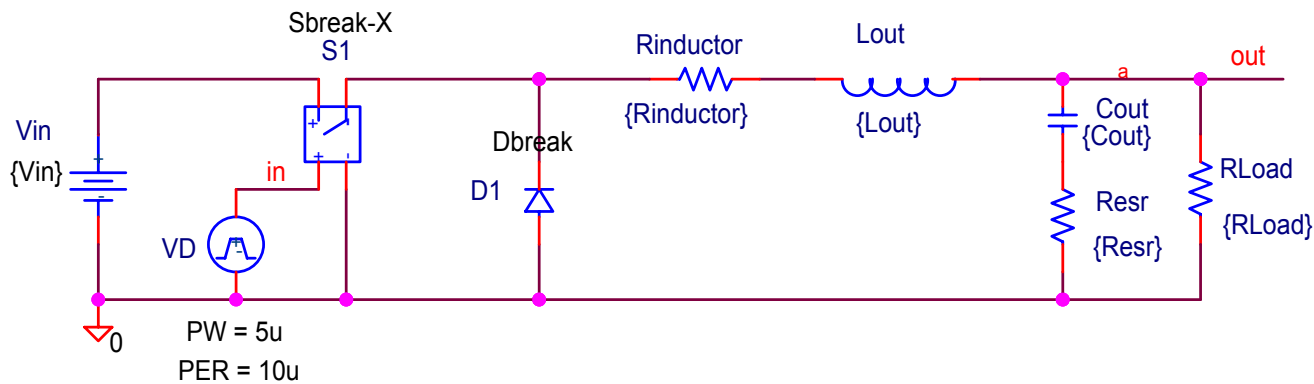
Example: Buck Converter



File: Buck_cy_by_cy.OPJ

Cycle by Cycle simulation of PWM Buck converter

buck_cy_by_cy.sch



PARAMETERS:

VIN = 10v

PARAMETERS:

LOUT = 75u
 COUT = 220u
 RLOAD = 10

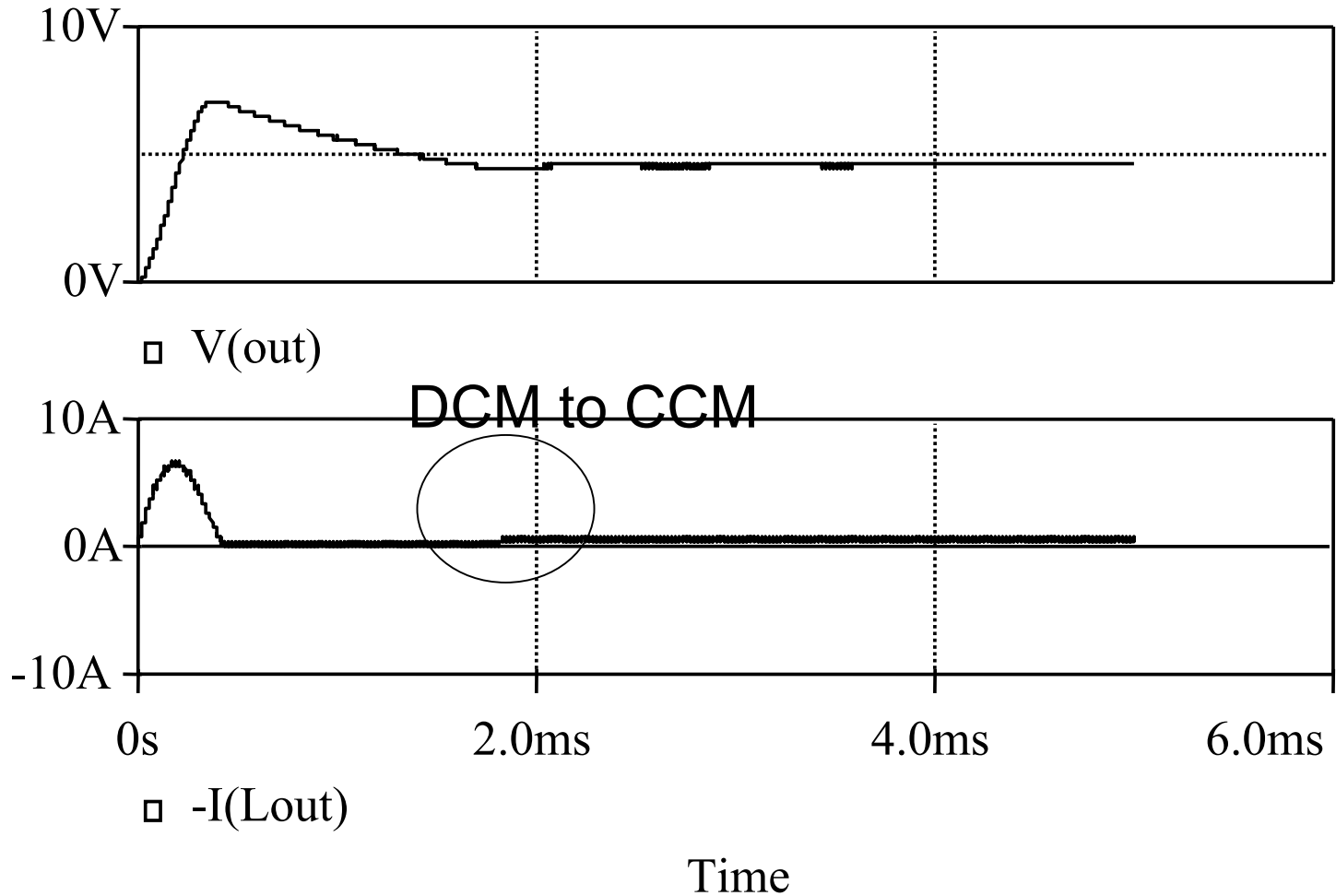
PARAMETERS:

RESR = 0.07
 RINDUCTOR = 0.1

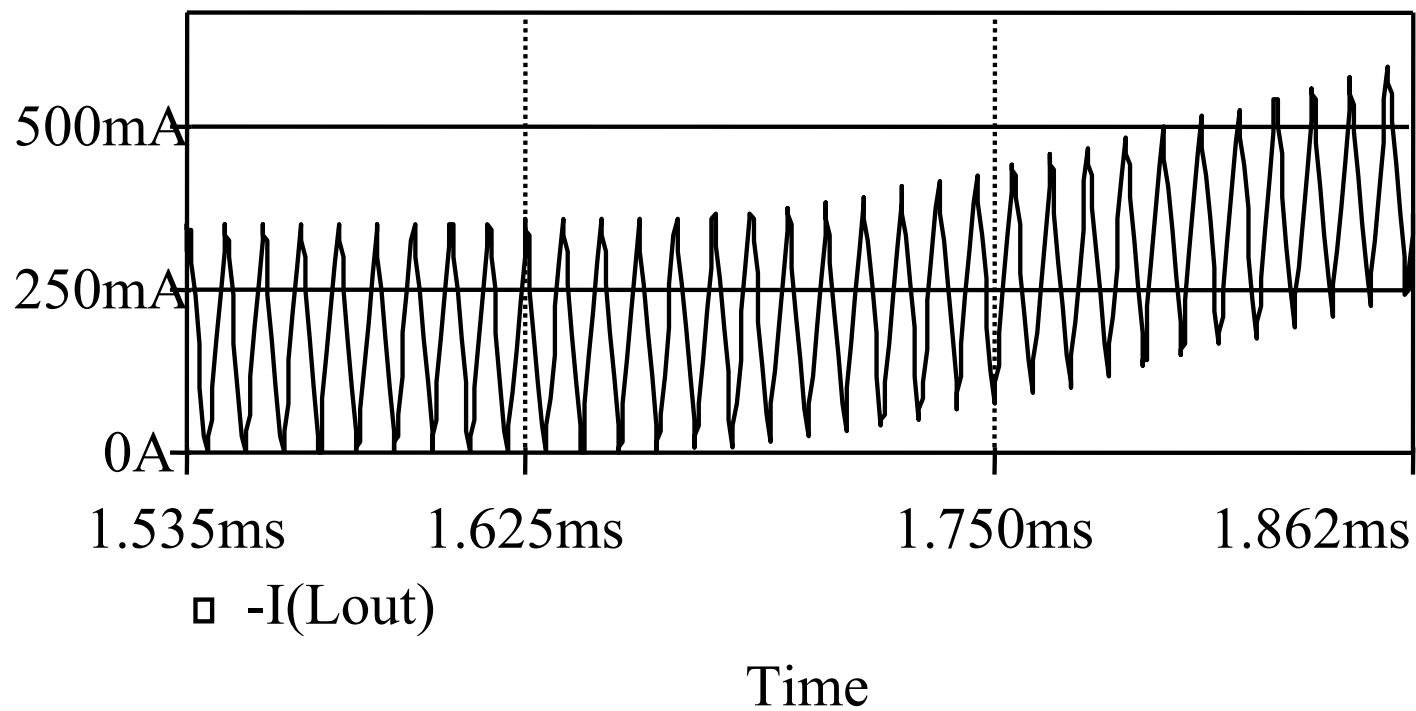
PARAMETERS:

FS = 100k
 TS = {1/fs}

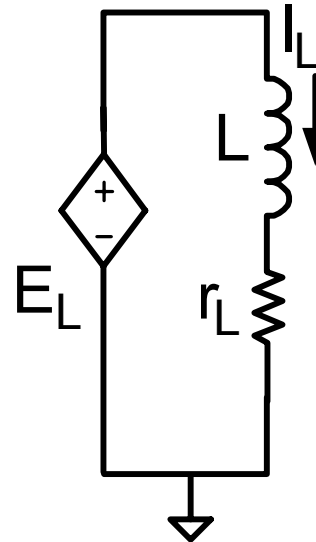
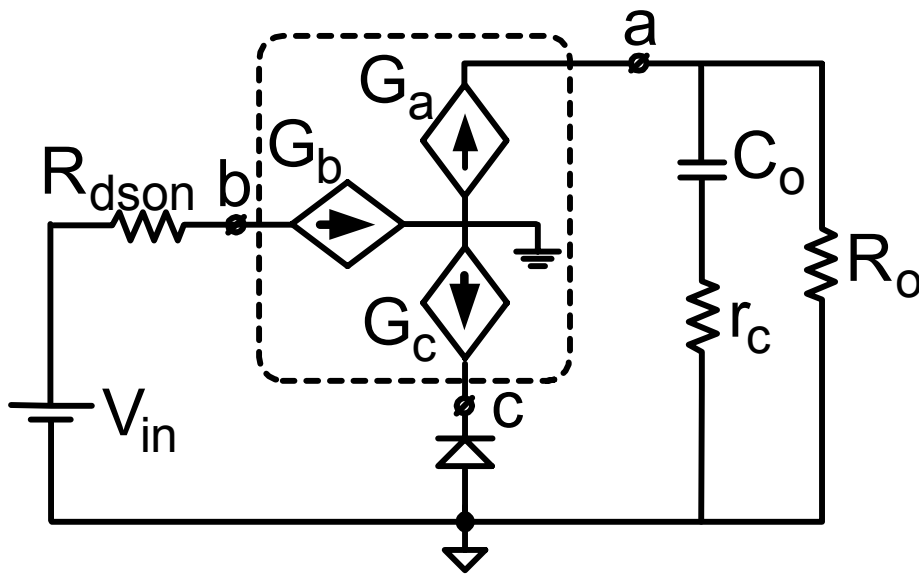
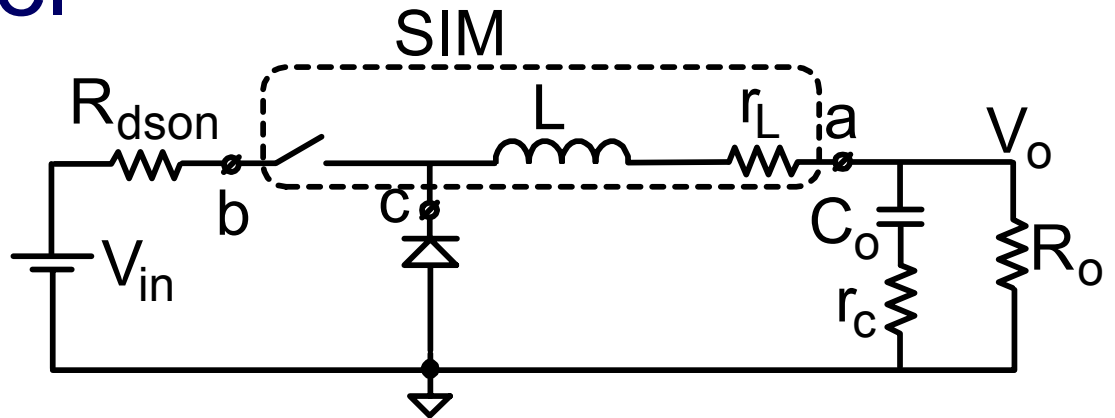
Power Start-Up at Constant D_{on}



Zooming up

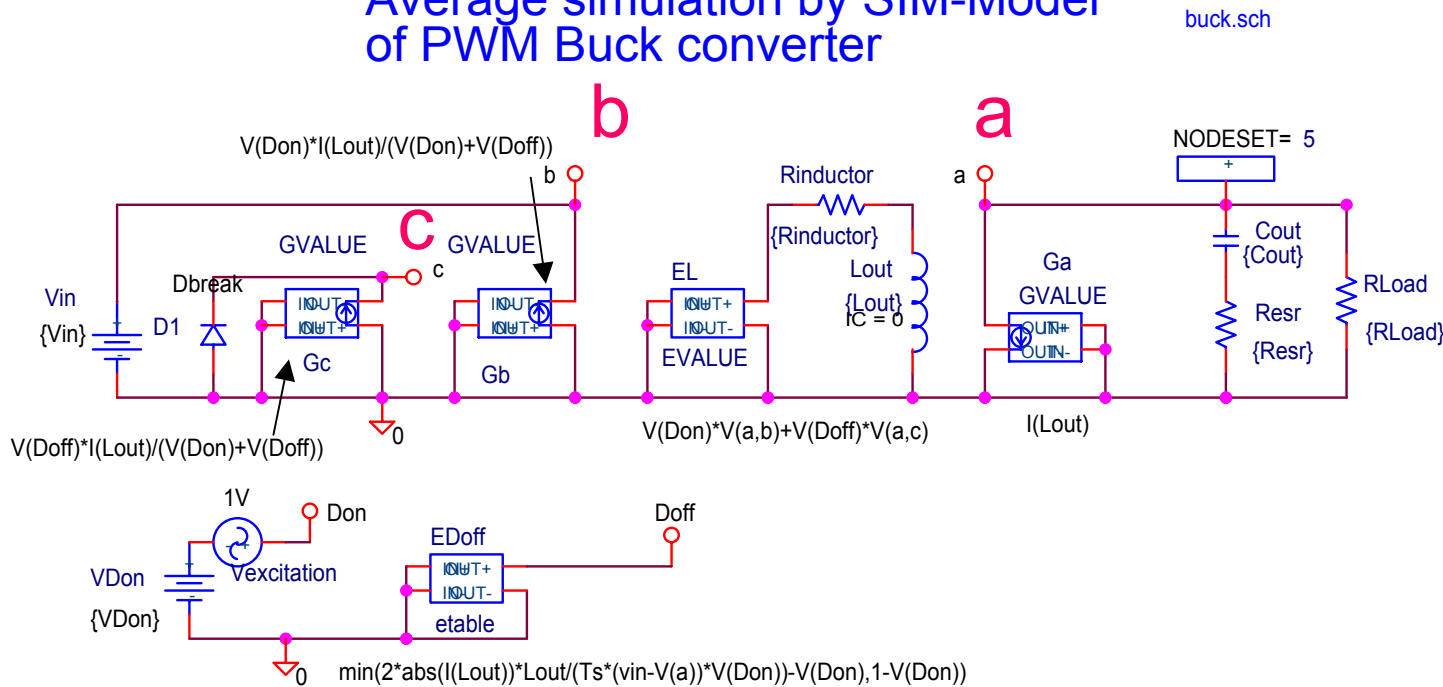


Average model



File: Buck.OPJ

Average simulation by SIM-Model of PWM Buck converter



PARAMETERS:
 VIN = 10v
 VDON = 0.5

PARAMETERS:
 LOUT = 75u
 COUT = 220u
 RLOAD = 10

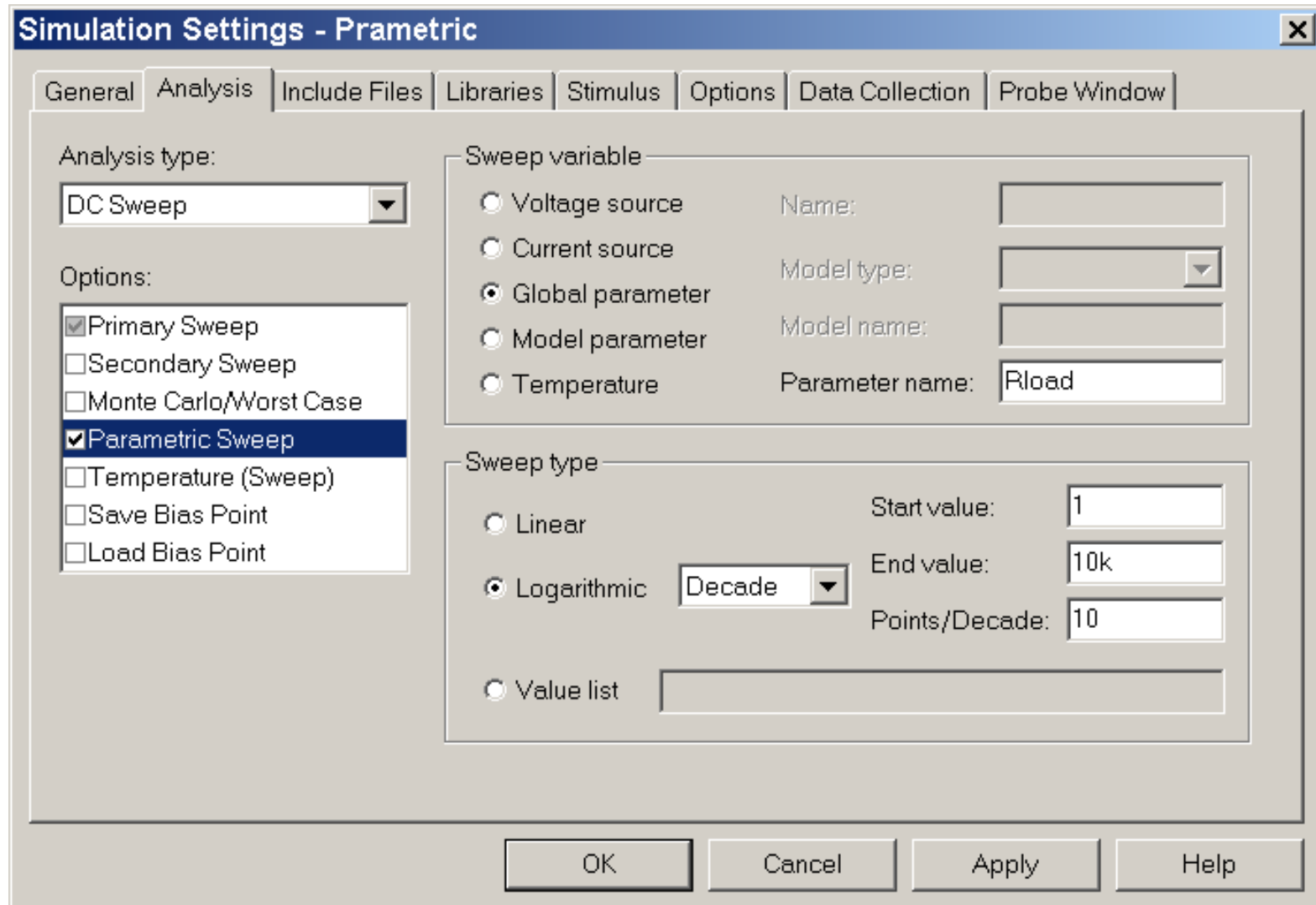
PARAMETERS:
 RESR = 0.07
 RINDUCTOR = 0.1

PARAMETERS:
 FS = 100k
 TS = {1/fs}

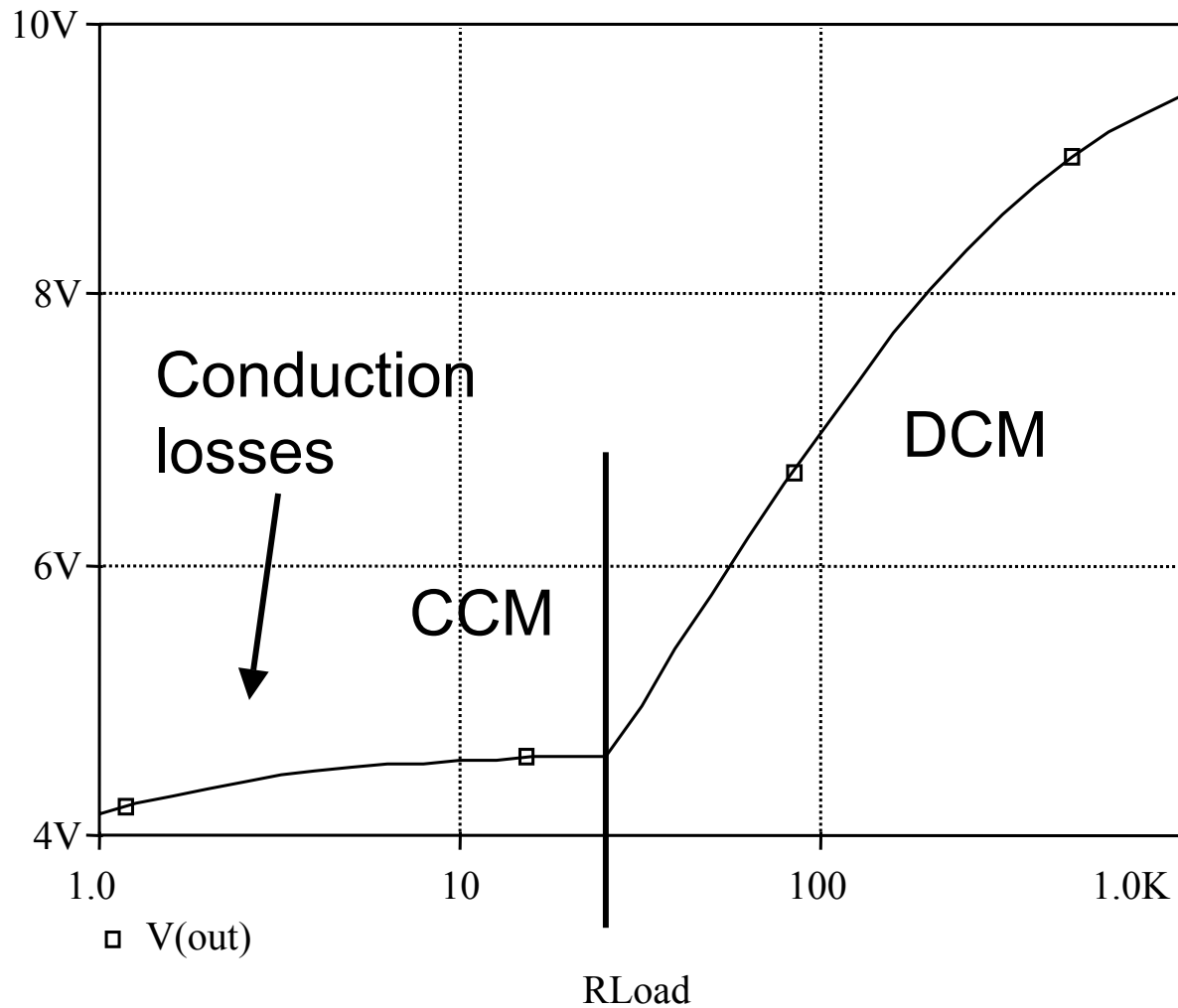
- D_{on} coded into voltage
- D_{off} for CCM/DCM



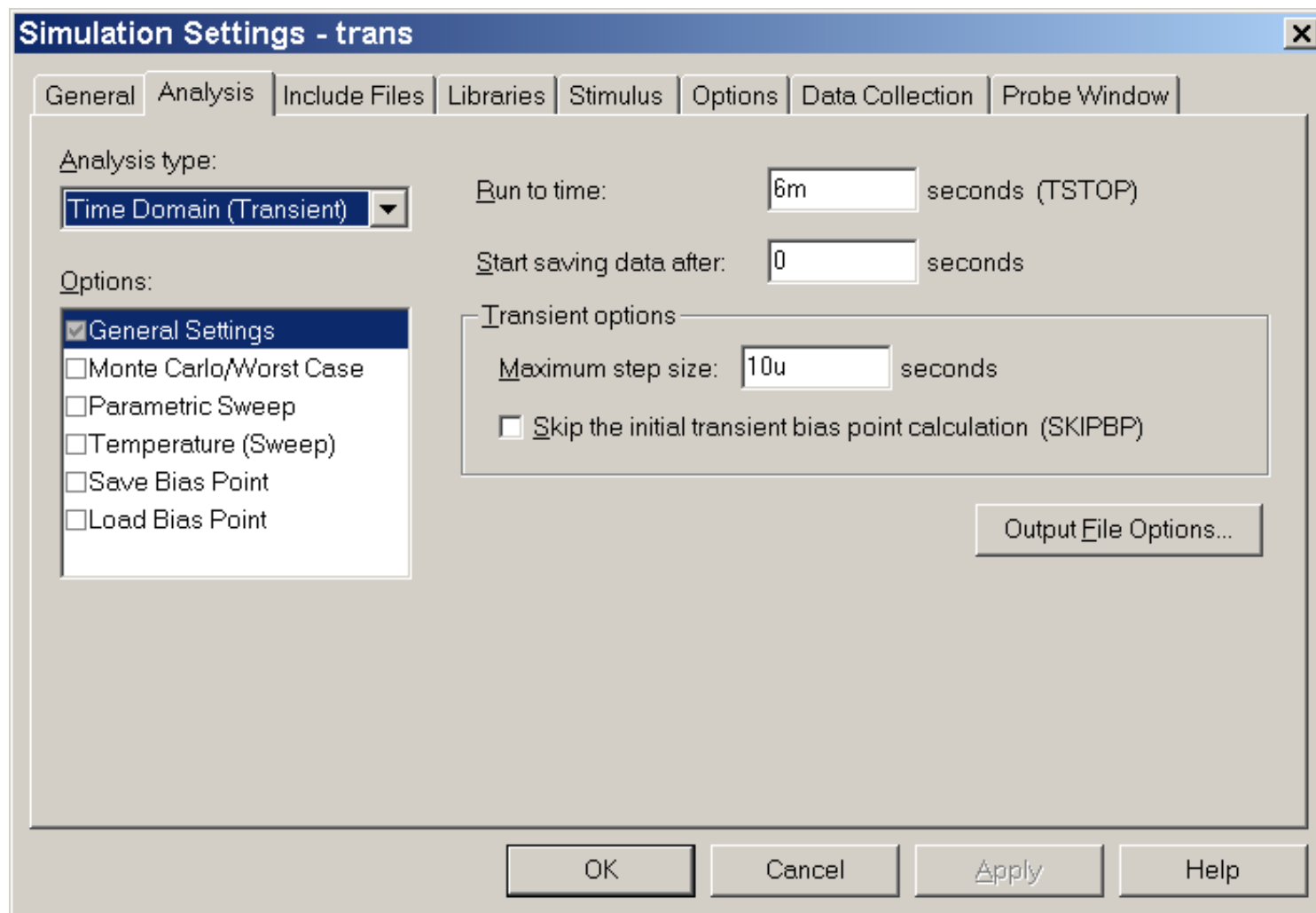
DC Sweep plus Parametric (on Rload)



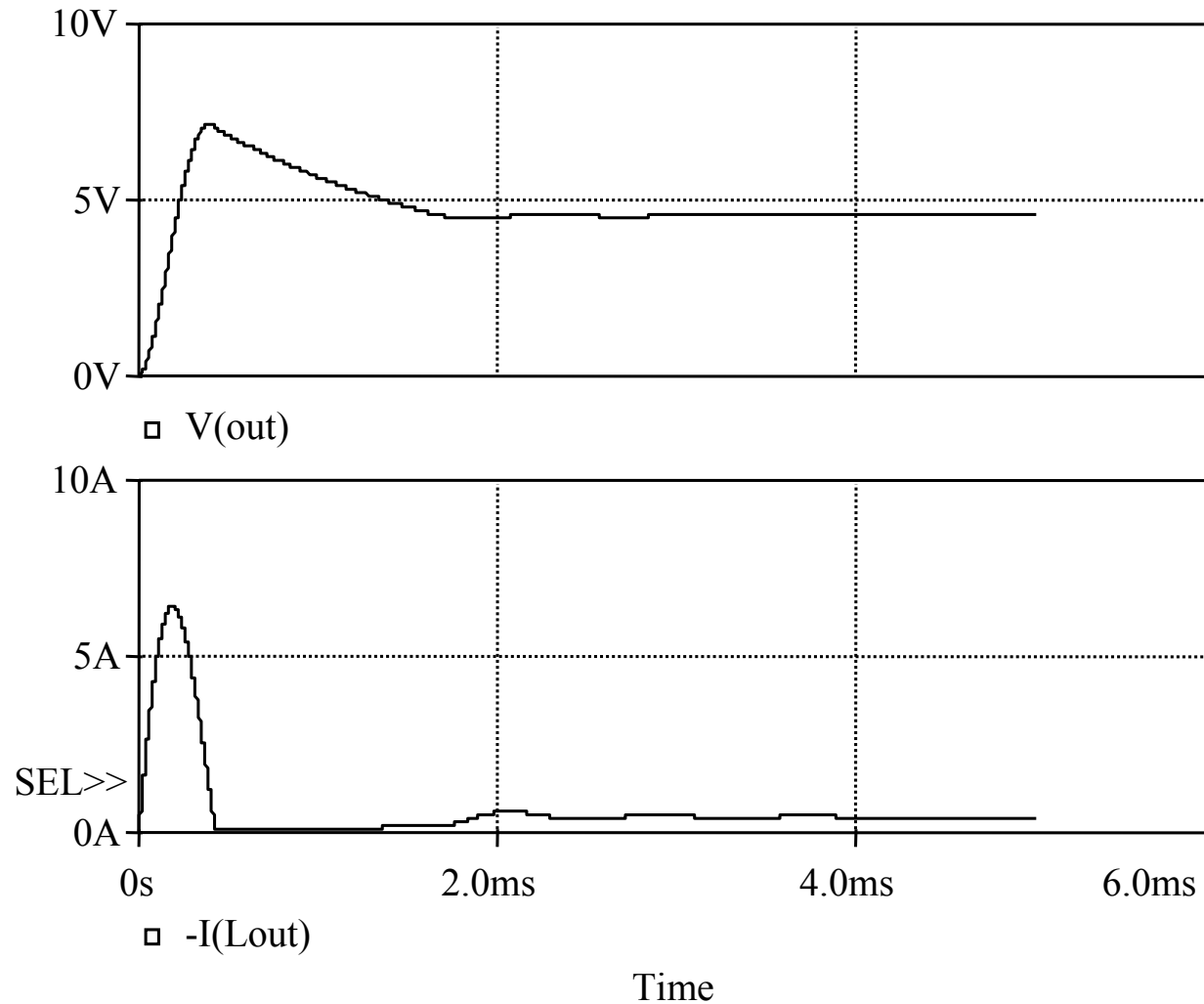
Sweeping R_{load} Constant D_{on}



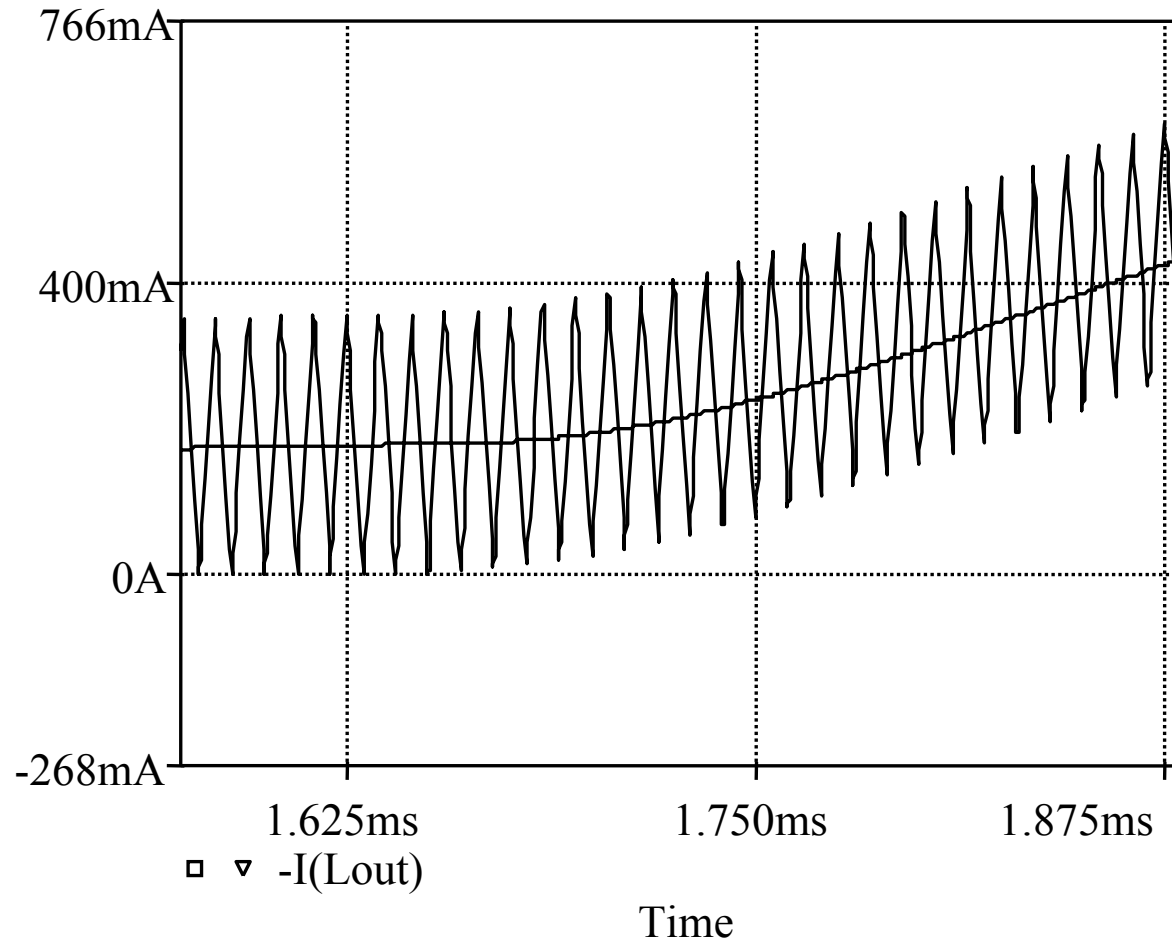
Transient Analysis –Power Turn-On



Power Start-Up at Constant D_{on}

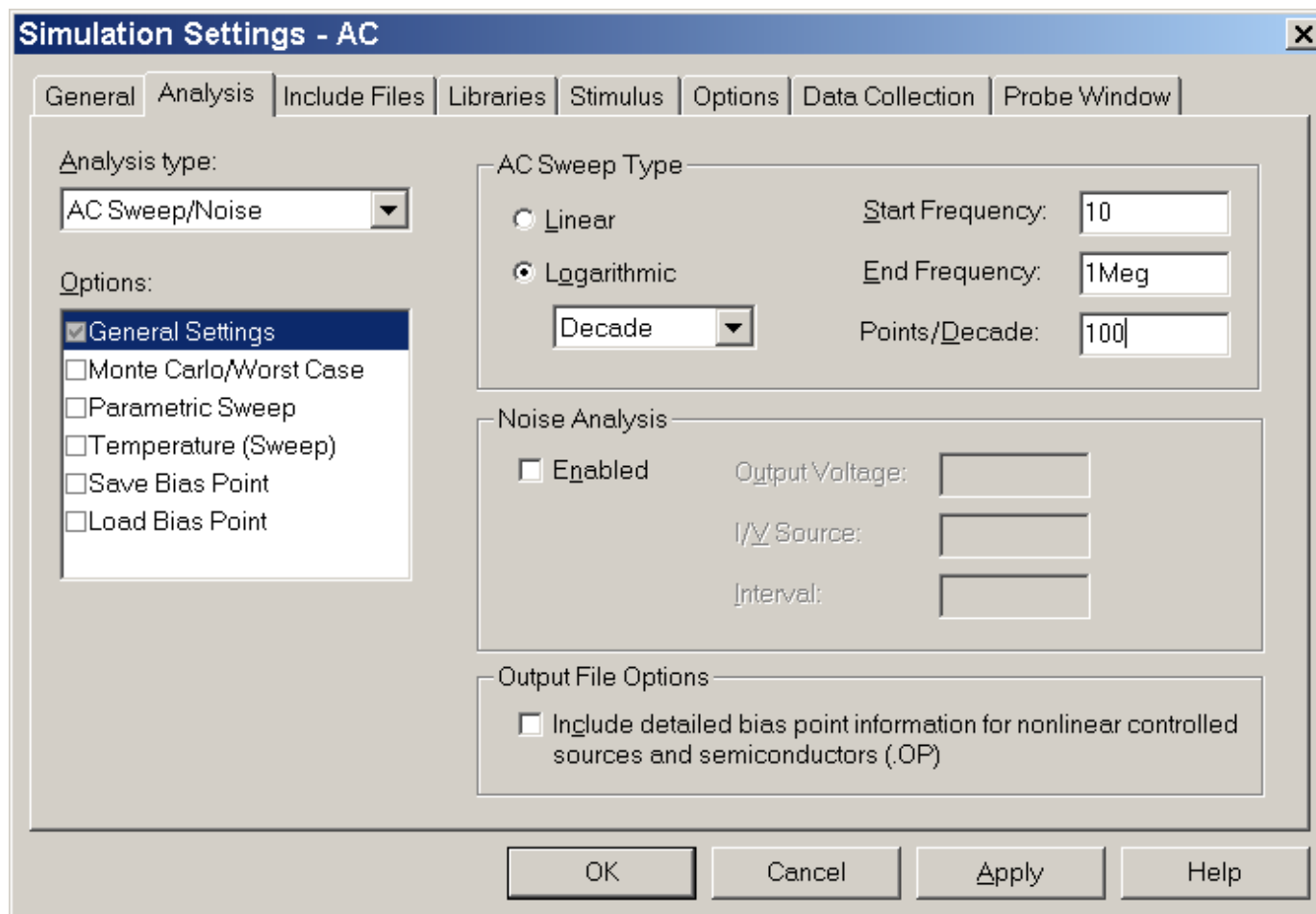


Comparing Cycle-by-Cycle to Average Simulation



AC Analysis

The Real Strength of Average Simulation

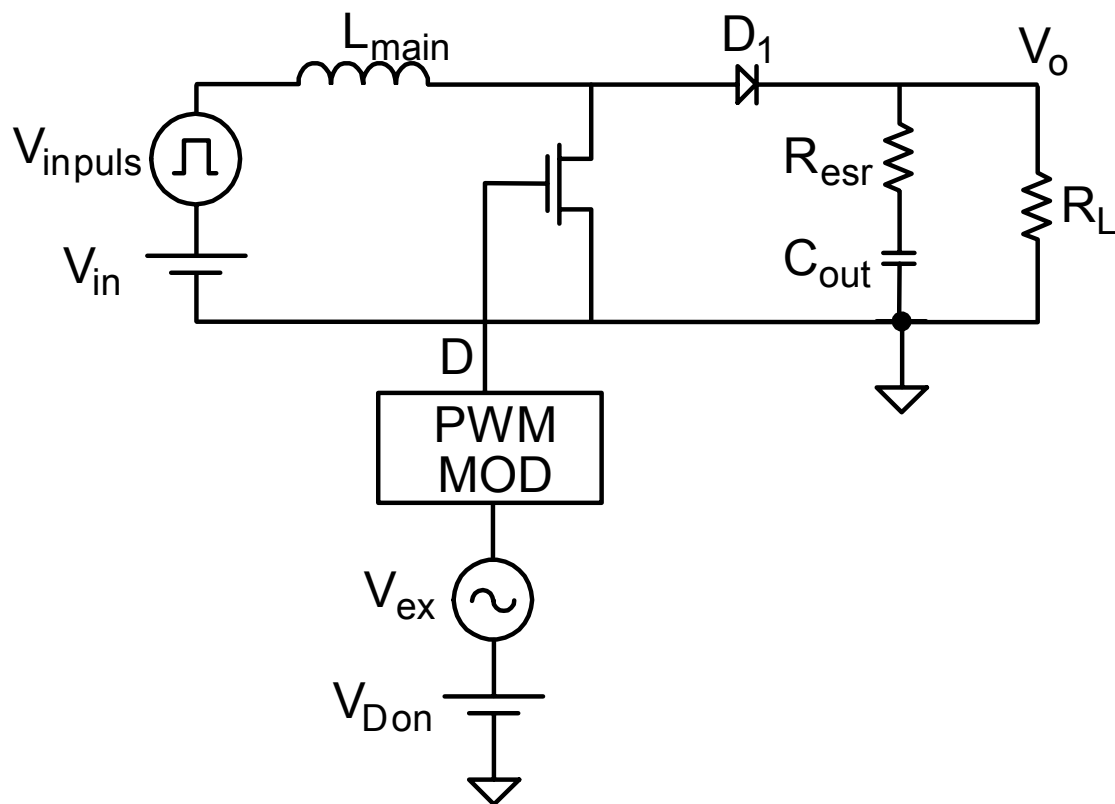


- The circuit is linearized by simulator (elements, devices and expressions)
- Numerical linearization !
e.g. a source $f(x,y,z)$ is replaced by:

$$\begin{aligned} & \frac{f(X + \Delta X, Y, Z) - f(X, Y, Z)}{\Delta X} x \\ & + \frac{f(X, Y + \Delta Y, Z) - f(X, Y, Z)}{\Delta Y} y \\ & + \frac{f(X, Y, Z + \Delta Z) - f(X, Y, Z)}{\Delta Z} z \end{aligned}$$

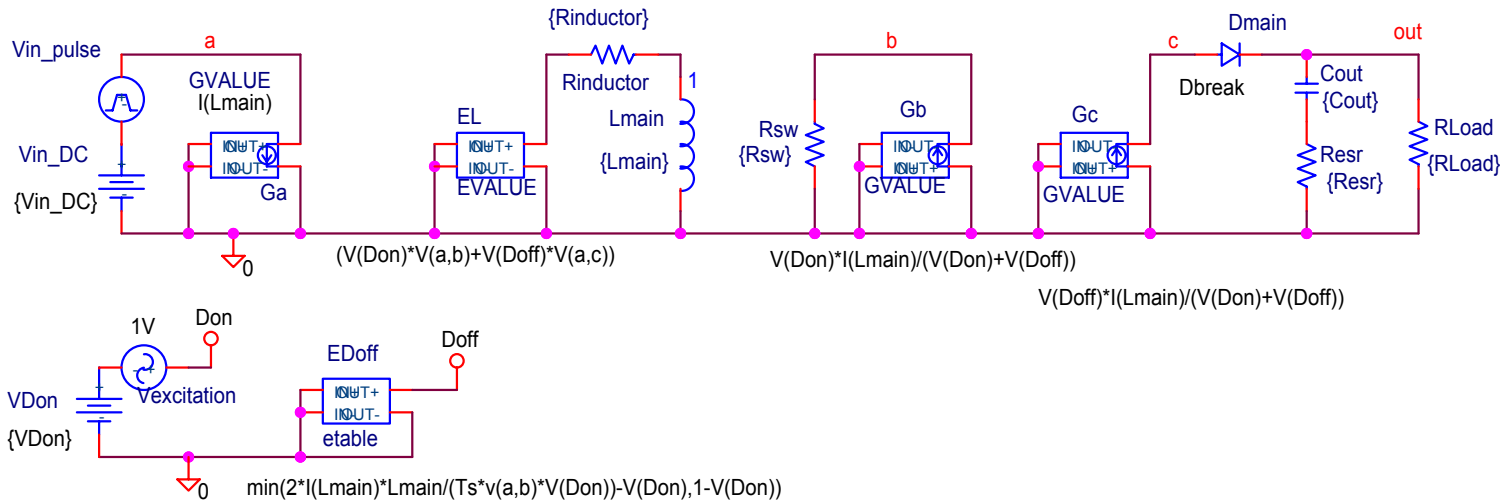
- Transparent to user

Boost



SIM-Model under CCM & DCM for PWM Boost converter

Boost.sch



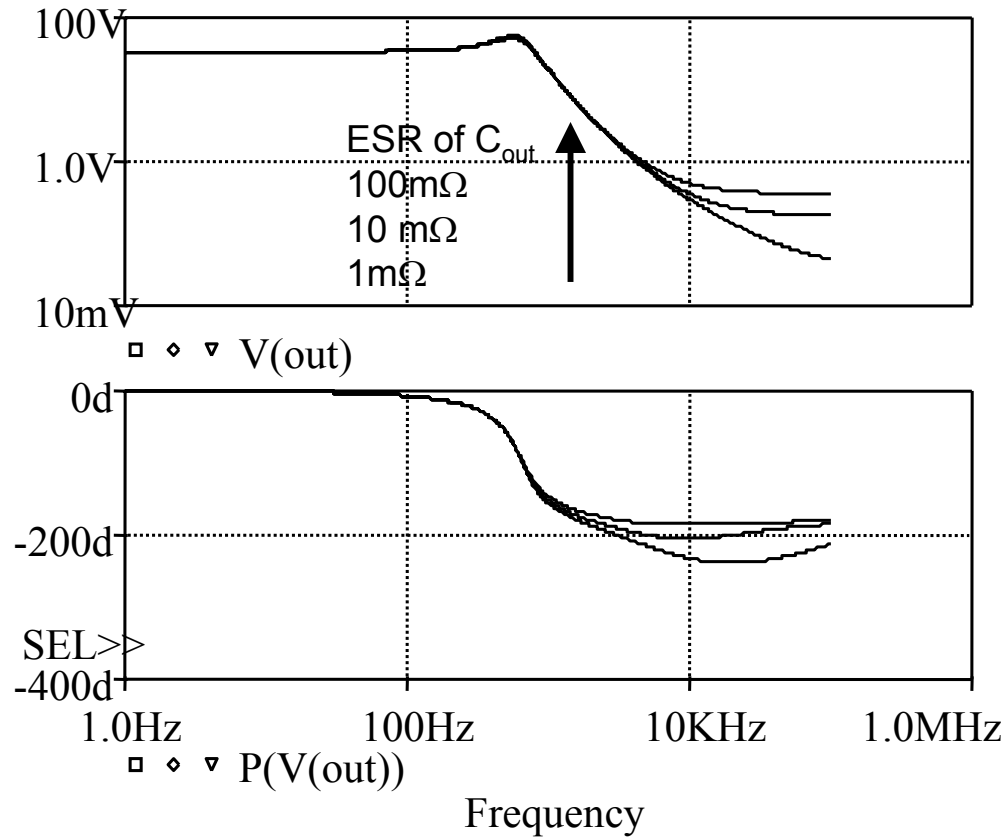
PARAMETERS:
 VIN_DC = 10v
 VDON = 0.5

PARAMETERS:
 LMAIN = 75u
 COUT = 220u
 RLOAD = 10

PARAMETERS:
 RESR = 0.07
 RINDUCTOR = 0.1
 RSW = 0.1

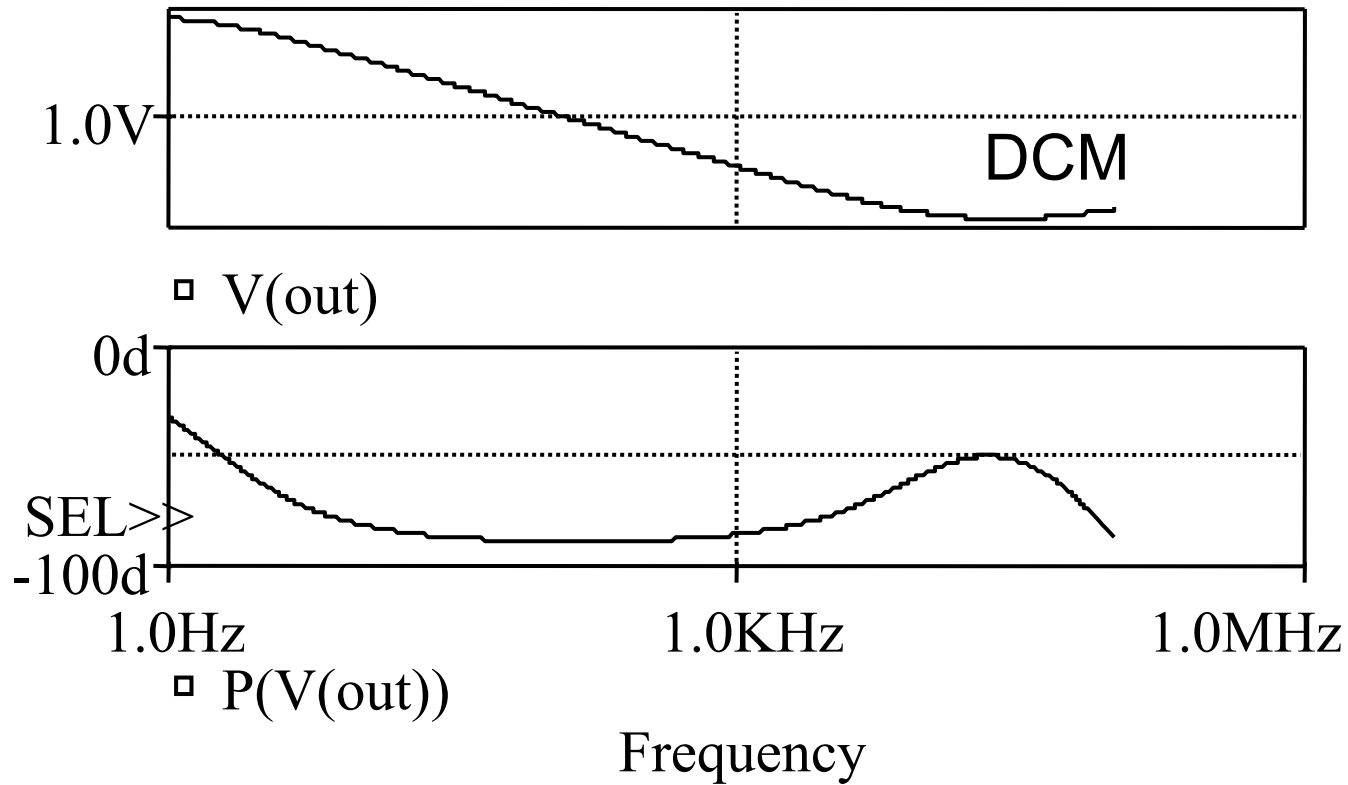
PARAMETERS:
 FS = 100k
 TS = {1/fs}

CCM



$R_{Load} = 10\Omega$

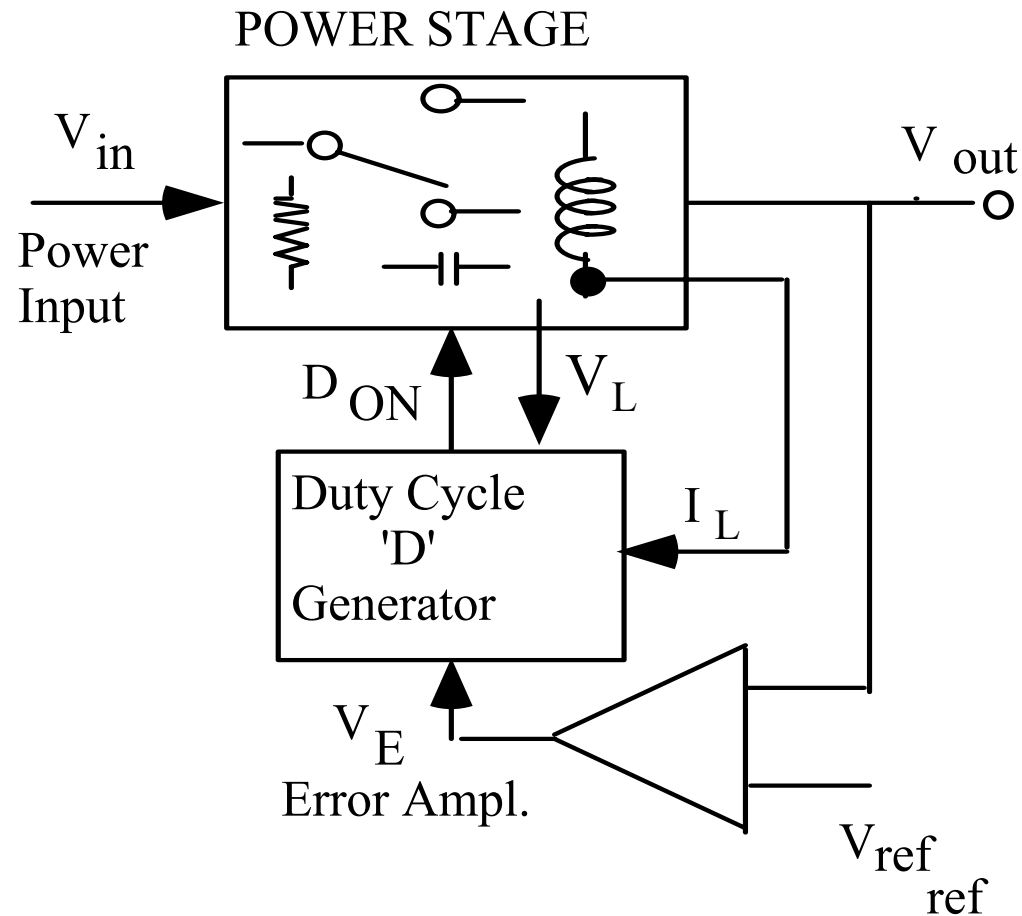
$R_{load} = 1000\Omega$



Live Simulation 1

- Boost CCM-DCM

Duty Cycle Generators

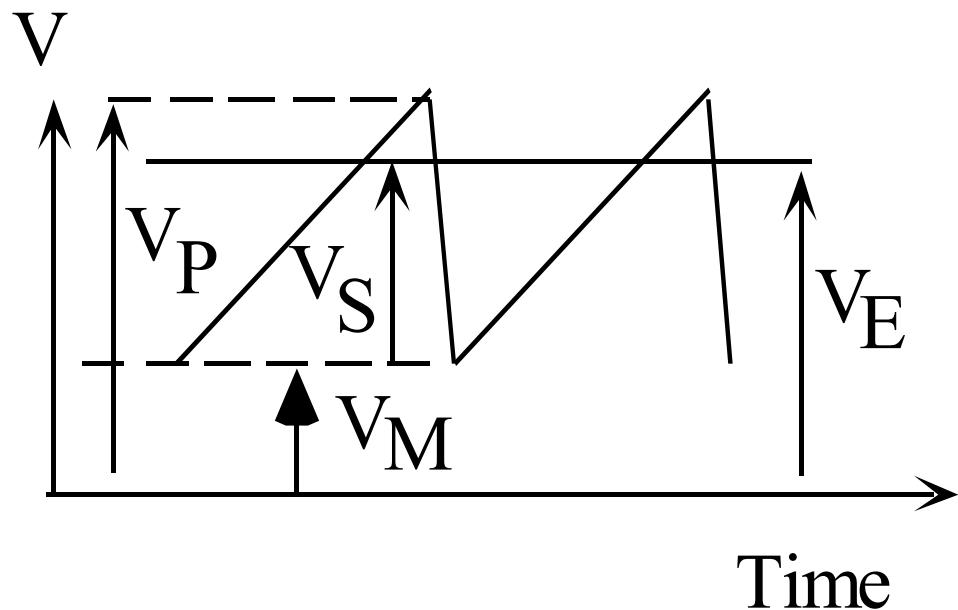


- General representation of a switch mode DC-DC converter.

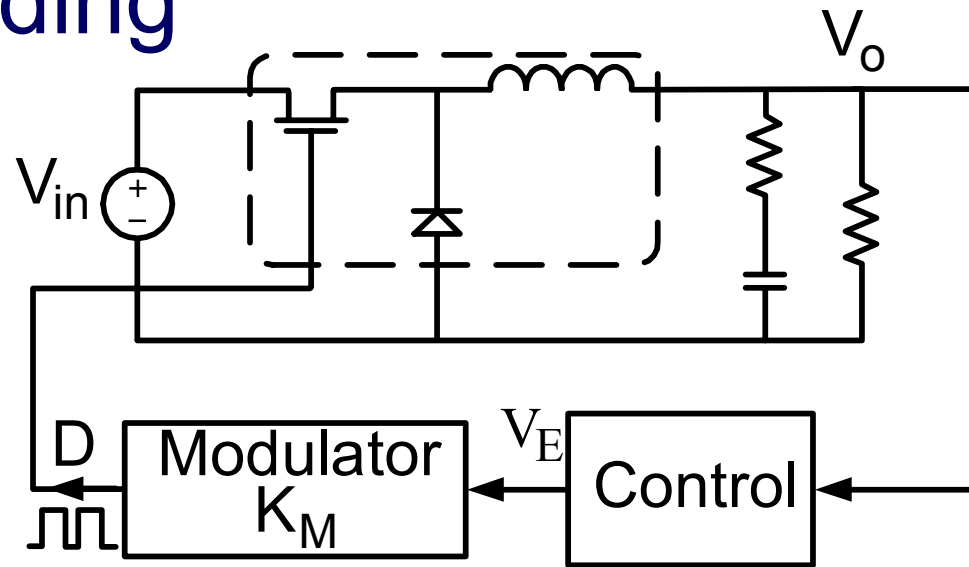
PWM MODULATOR - Voltage Mode

$$K_M (\text{voltage mode}) = \frac{V_E - V_M}{V_P - V_M}$$

$$K_{M(V_M=0)} = \frac{V_E}{V_P}$$



Coding



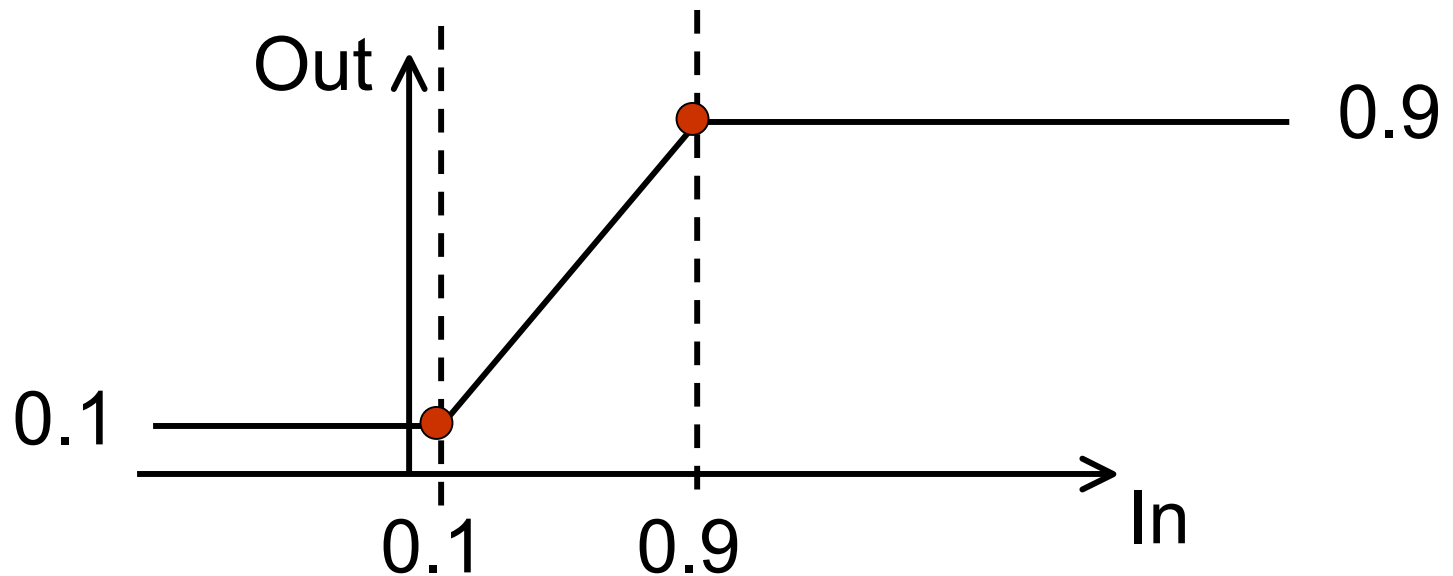
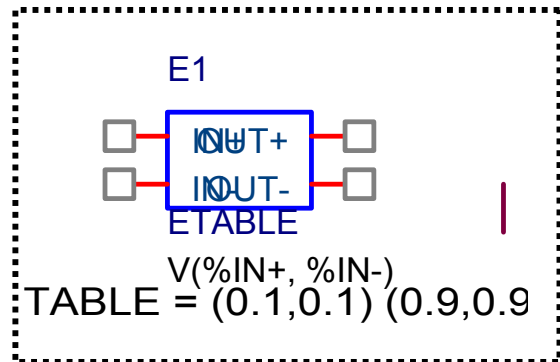
$$K_M \text{ (voltage mode)} = \frac{V_E - V_M}{V_p - V_M}$$

D coded into voltage

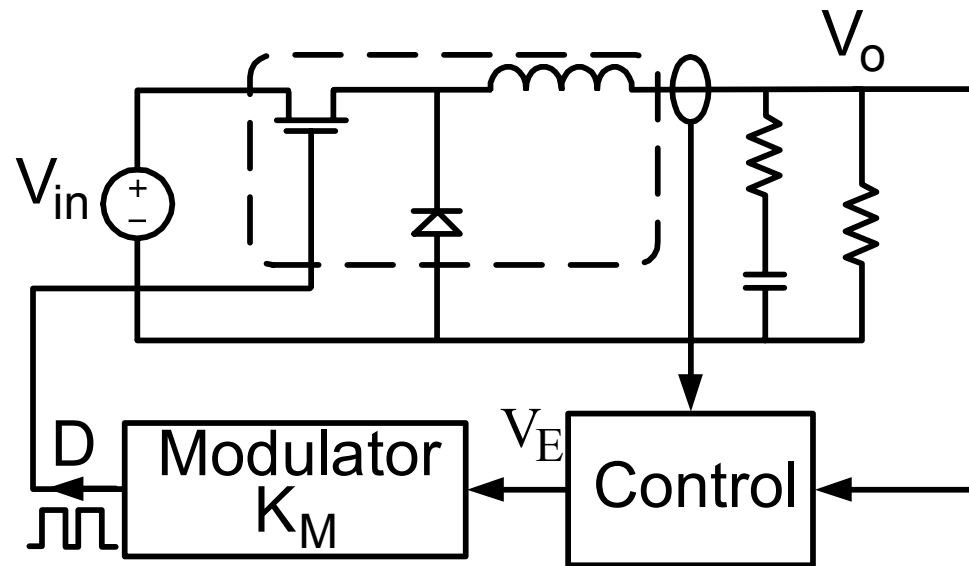
$$0 \leq V_D \leq 1$$

Duty Cycle Limiter

- Behavioral dependent source ETABLE

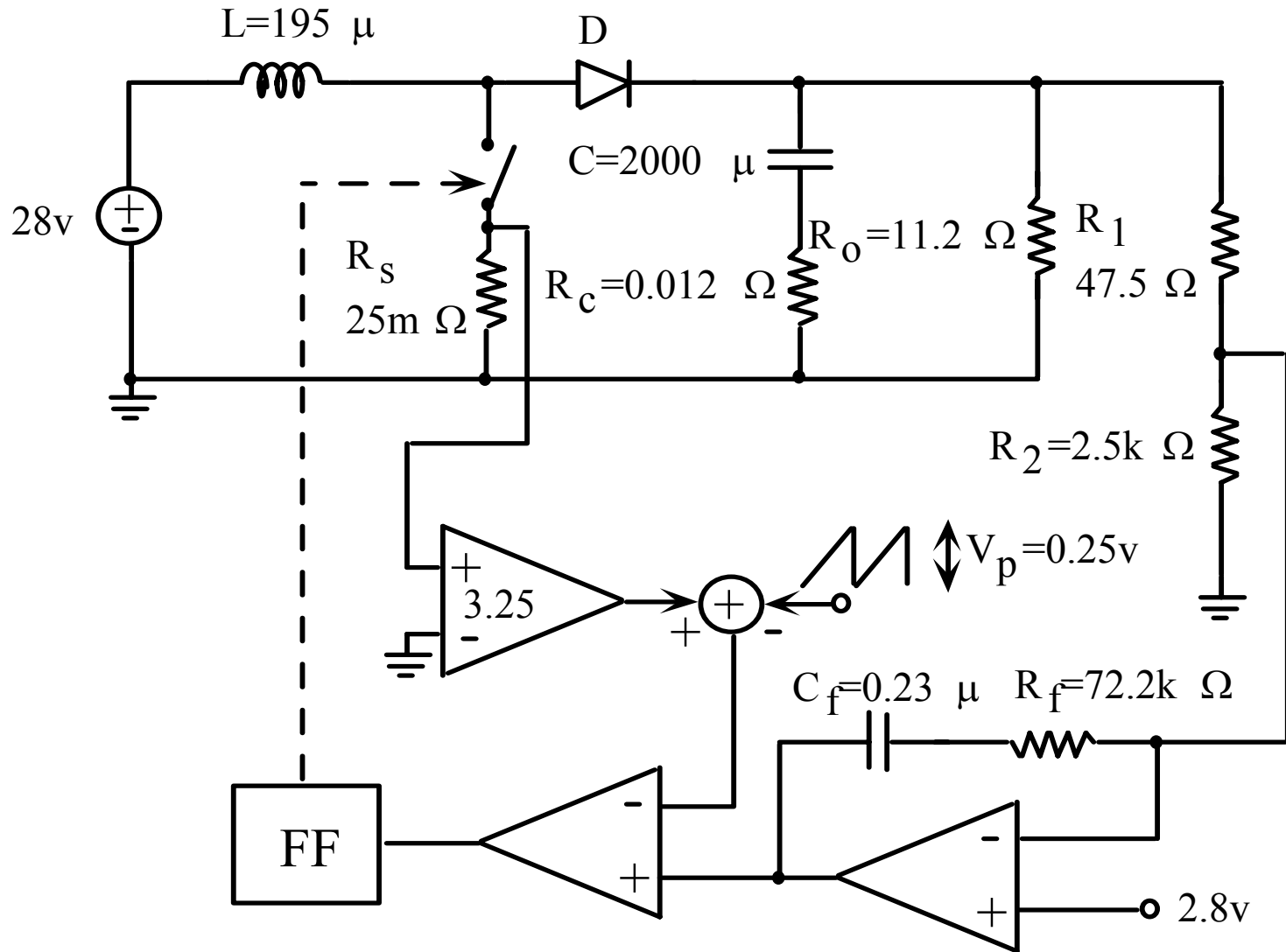


Average Current Mode



- V_E is a function of V_o and I_L
- 'control' is the original analog circuit

Peak Current Mode Control



• Current Mode CCM

$$E_{Don} = \frac{V(V_e) - KS \frac{|I(L)|}{V(D_{on}) + V(D_{off})}}{TS \left(MC + KS \frac{V(a, b)}{2L} \right)}$$

$V(V)$

KS = Current Loop Gain

MC = Slope Compensation

TS = Switching Period

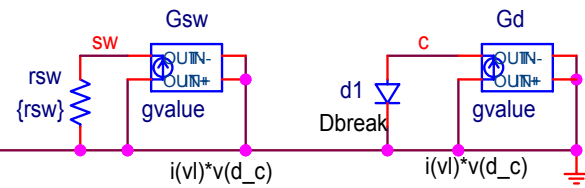
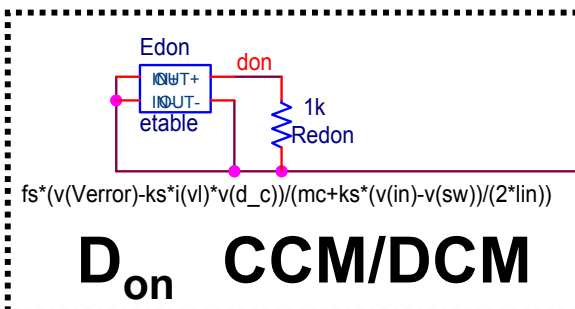
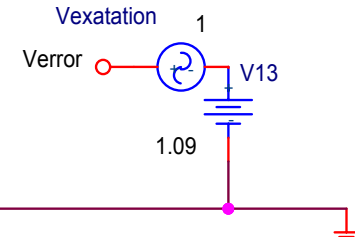
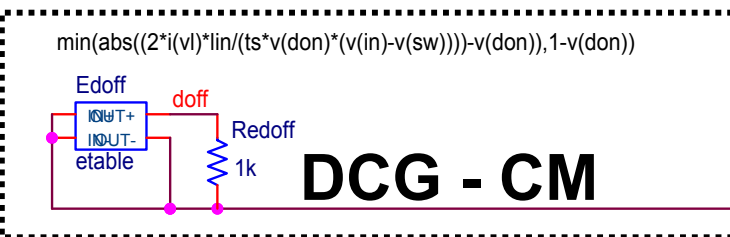
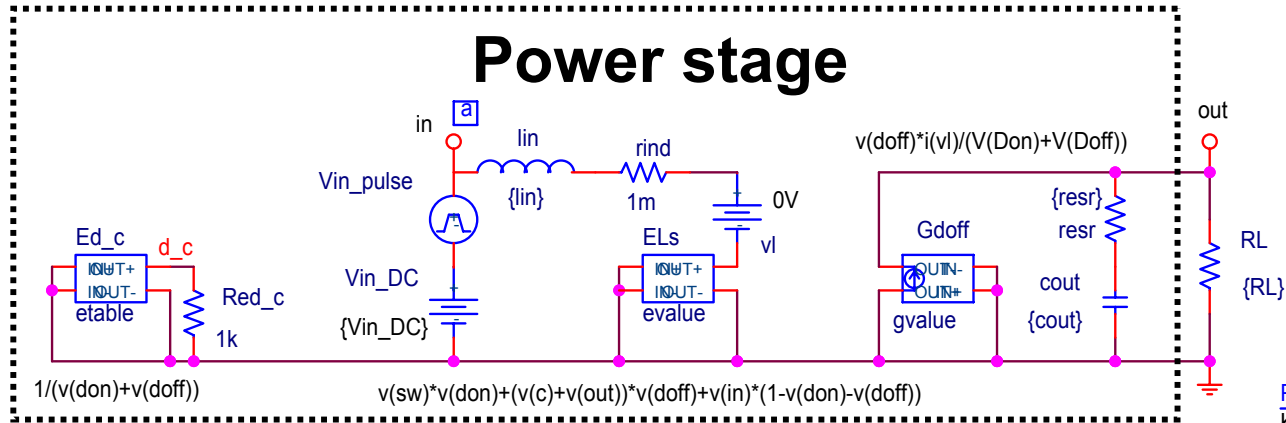
L = Inductance of main inductor

$|I(L)|$ = Average inductor current

If you can write an expression, it can be modeled !

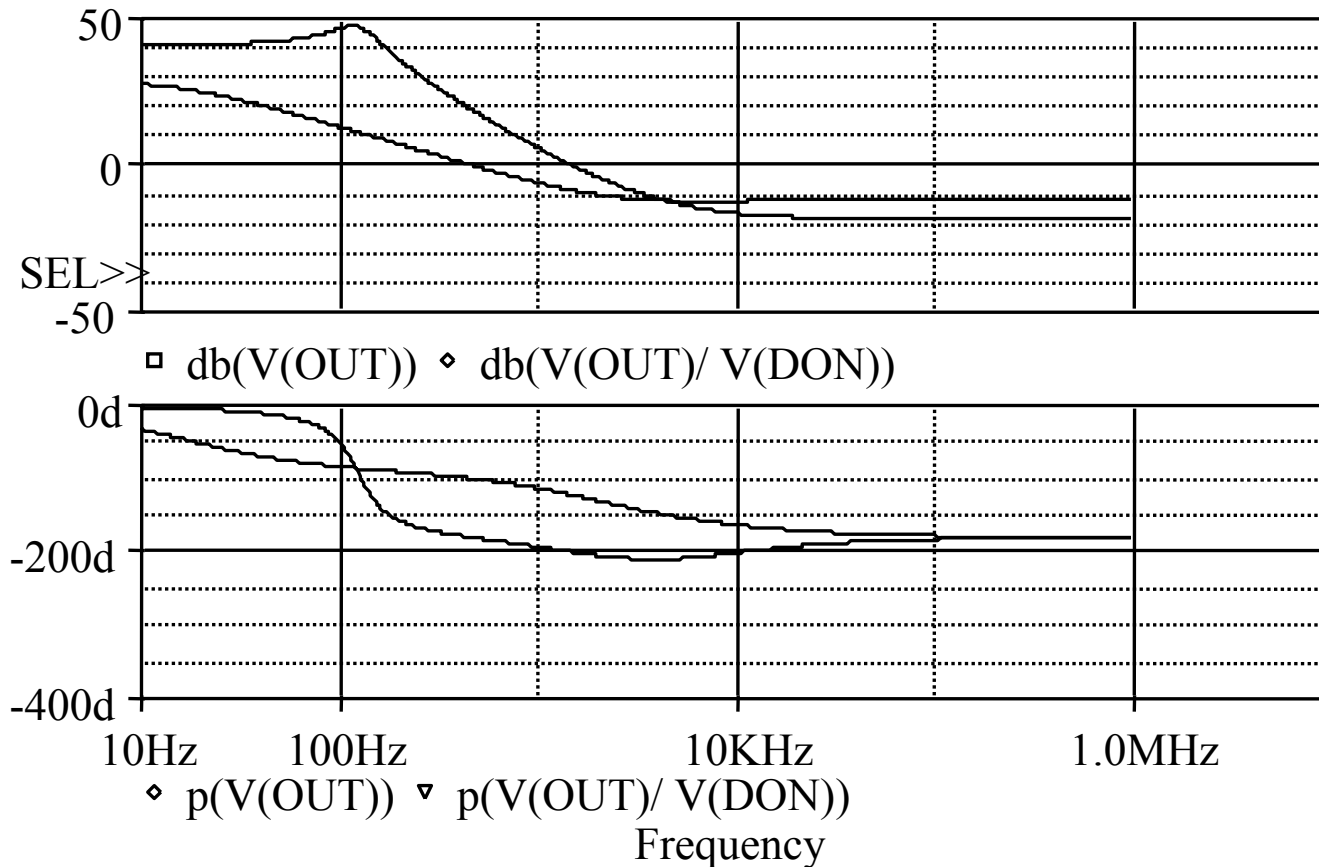
SIM-Model under CCM & DCM for Current-Mode PWM Boost converter **CM-Boost.opj**

Schematic file name: CM-Boost\CM-Boost.sch



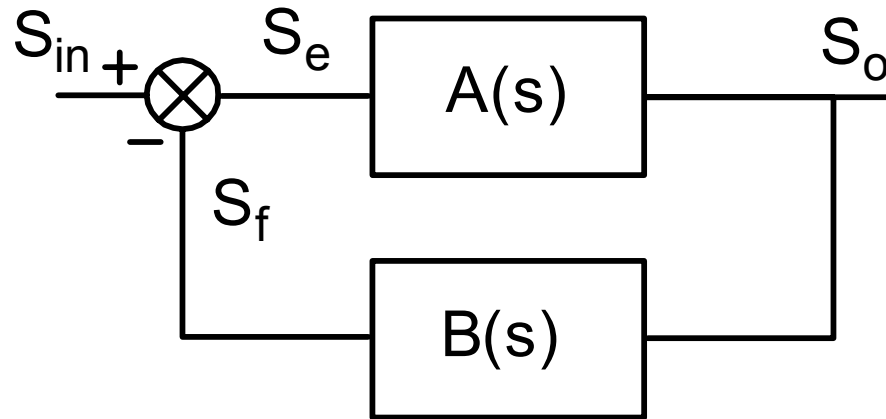
- PARAMETERS:**
 KS = 81.25m
 TS = 40u
 MC = 6250
- PARAMETERS:**
 LIN = 195u
 RSEN = 0.025
 FS = {1/ts}
- PARAMETERS:**
 RSON = 1m
 RSW = {rson+rSEN}
 RL = 11.2
- PARAMETERS:**
 RESR = 0.012
 COUT = 2m
 VIN_DC = 28





$V(\text{out})/V(\text{Don})$ as normal

$V(\text{out})/V(\text{Verror})$ lower order

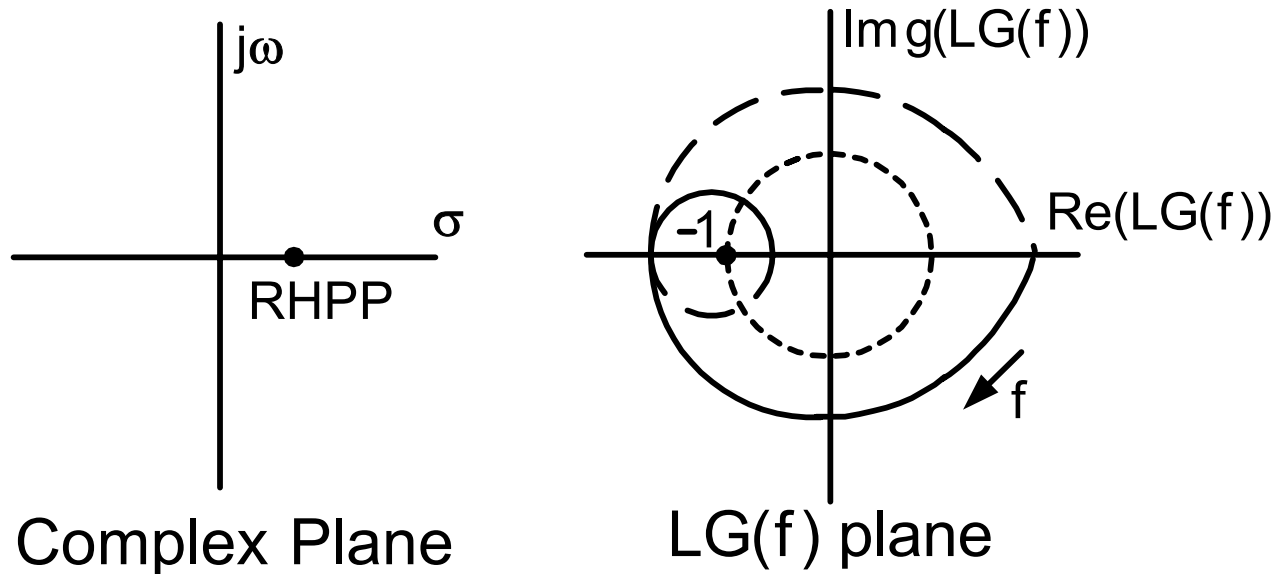


$$\left(\frac{S_o}{S_{in}} \right) = A_{CL}(S) = \frac{A(S)}{1 + A(S)B(S)}$$

- $A(S)B(S)$ = Loop Gain (LG)
- + sign already assumes negative feedback

System stable if $\{1 + LG(S)\}$ has no roots (poles) in **RIGHT HALF** complex plane (RAPP)

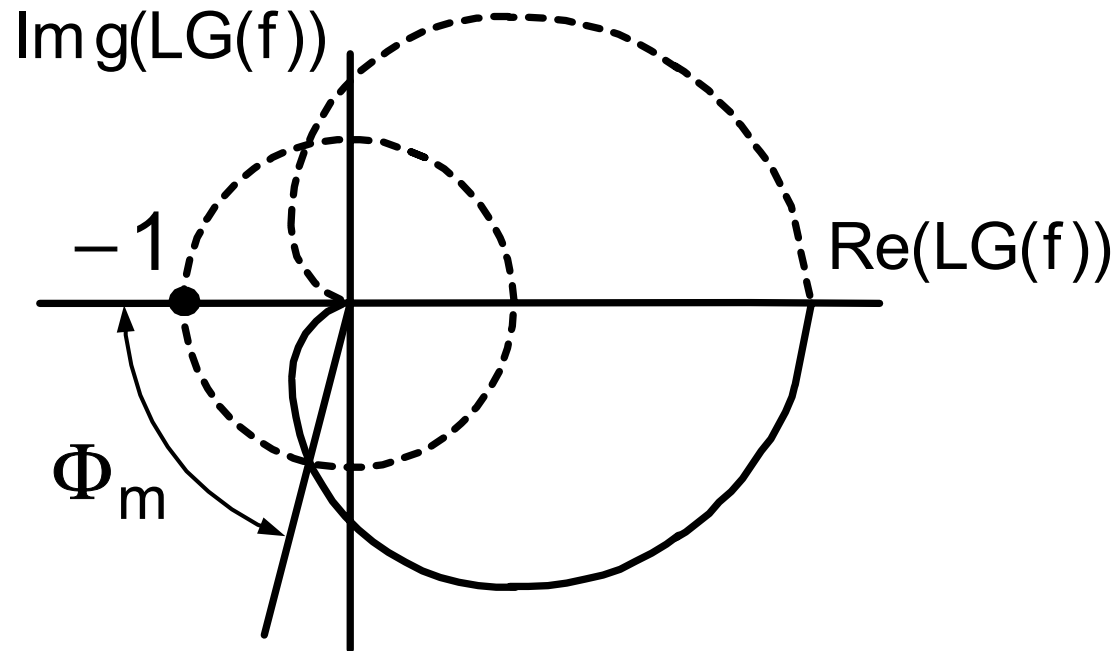
Nyquist Criterion



The number of RHPP is equal to the number of turns $\text{LG}(f)$ circles (clockwise) the (-1) point in the $\text{LG}(f)$ plane, as f swings from $-\infty$ to ∞ .

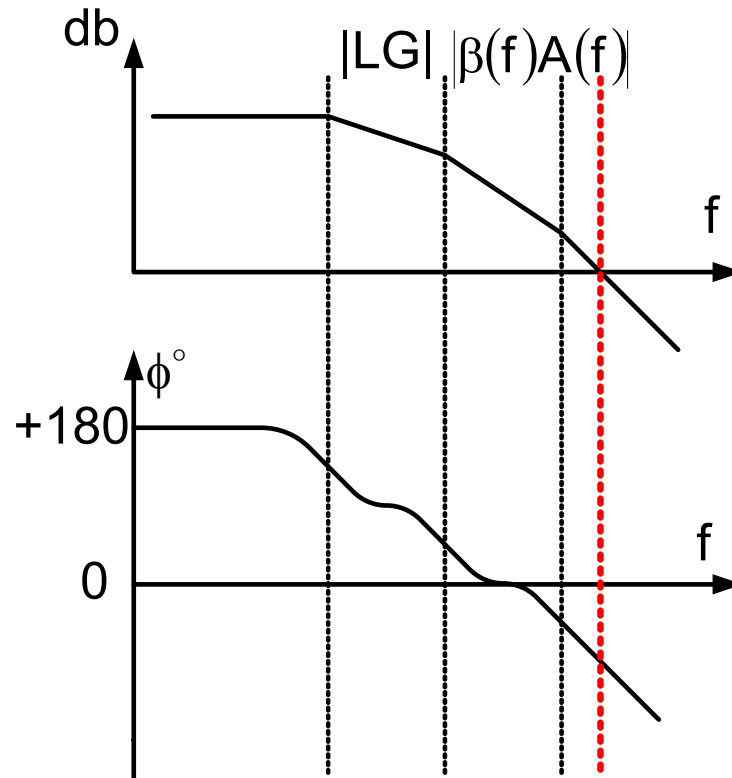
{ This assumes that $\text{LG}(f)$ by itself has no RHPP }

Stability



The system is stable if $\text{LG}(f)$ does circle the -1 point
 Φ_m is the phase margin

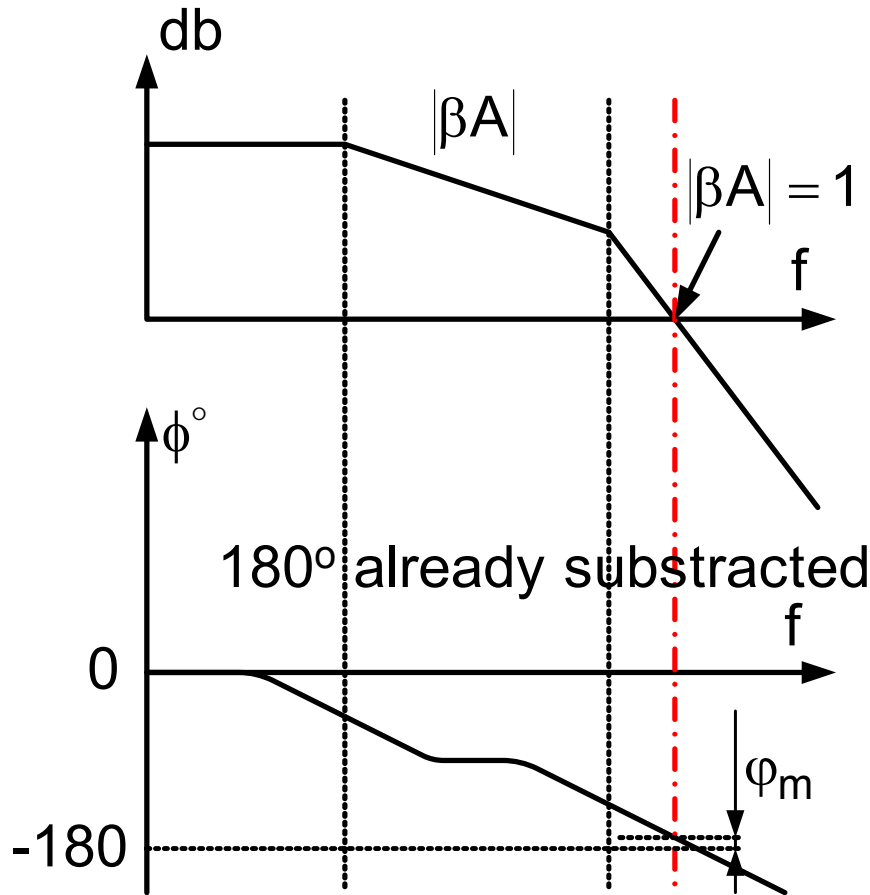
Bode Plot



In negative feedback systems

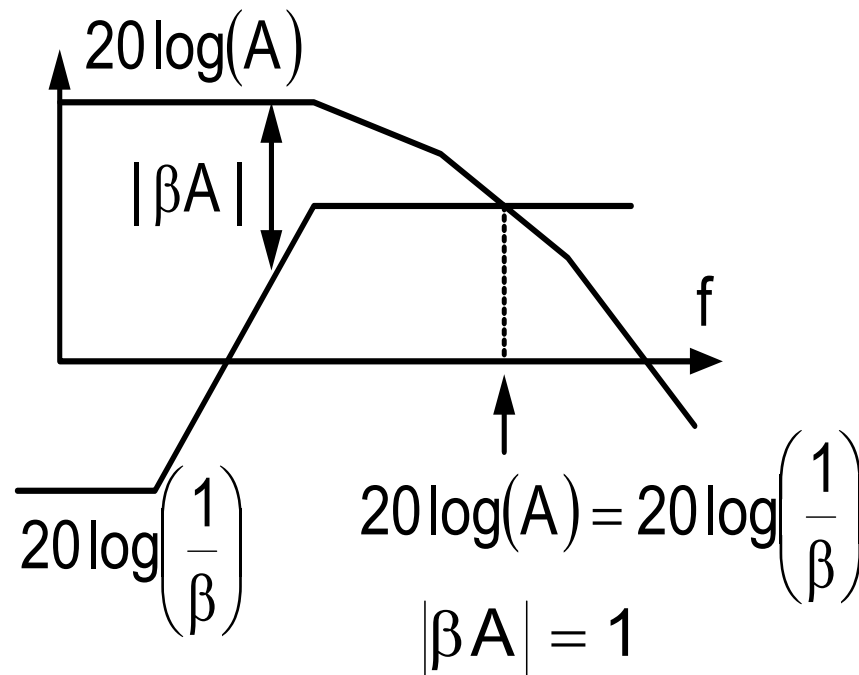
At $f \rightarrow 0$ $\phi = 180^\circ$ or (-180°)



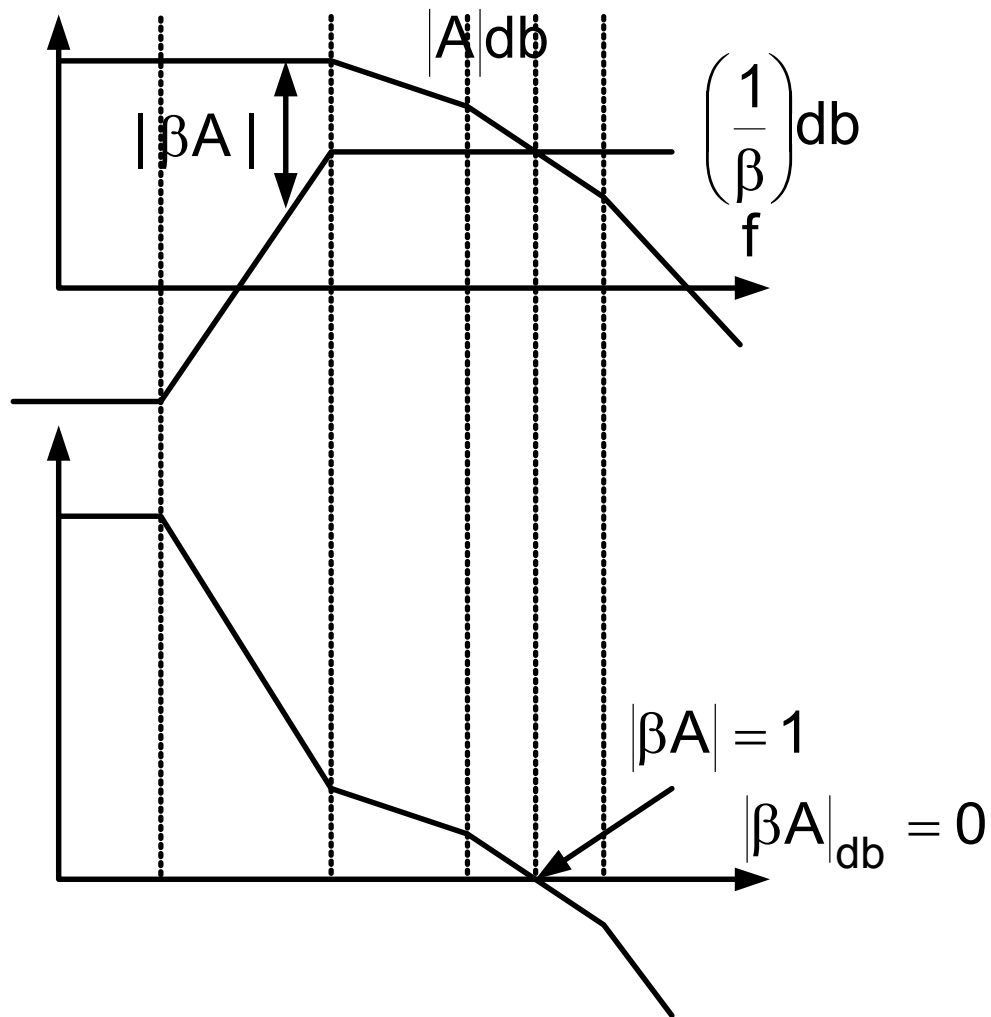


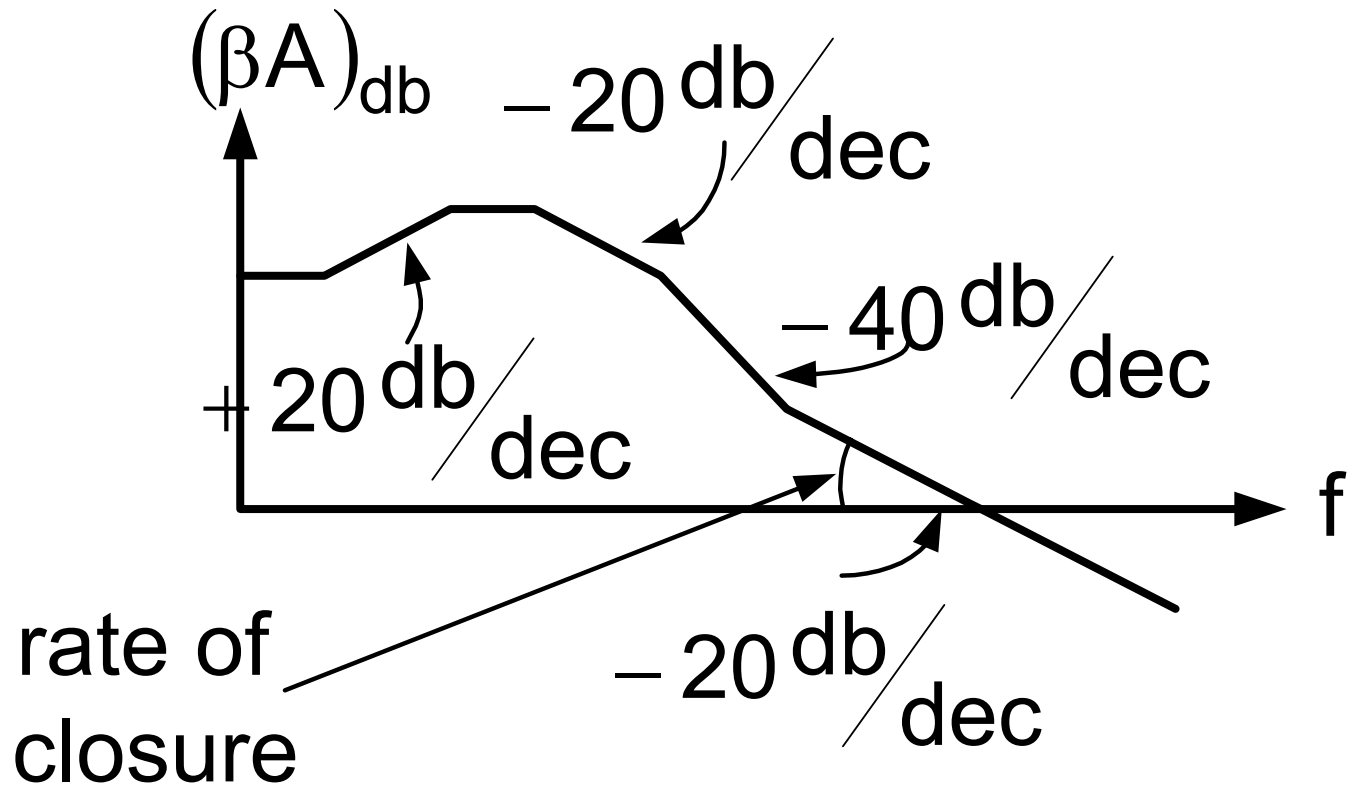
$$\begin{aligned} \phi_m &= \phi_{|\beta A|=1} - (-180^\circ) \\ &= \phi_{|\beta A|=1} + 180^\circ \end{aligned}$$

The design problem: Given $A(f)$, find $\beta(f)$

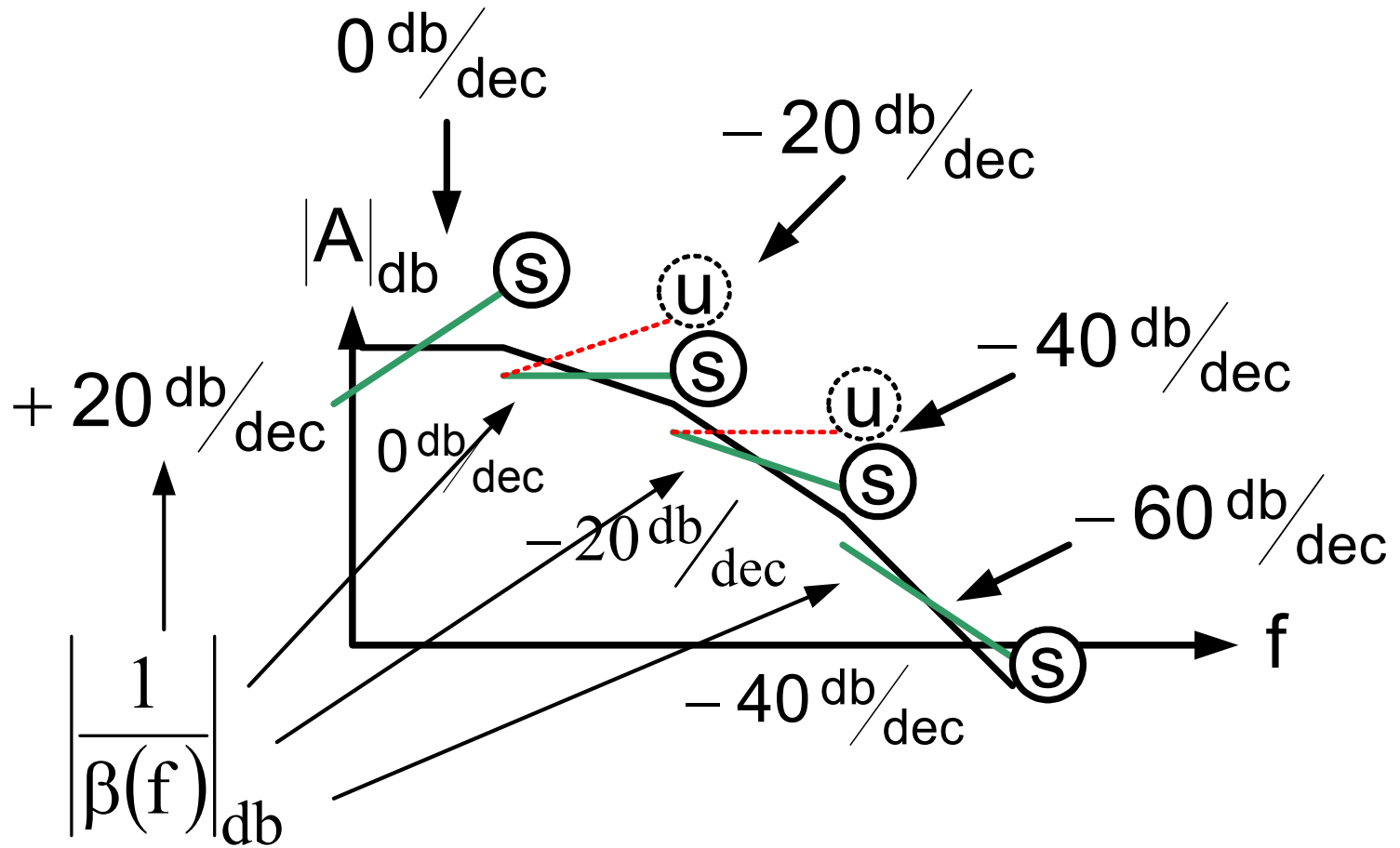


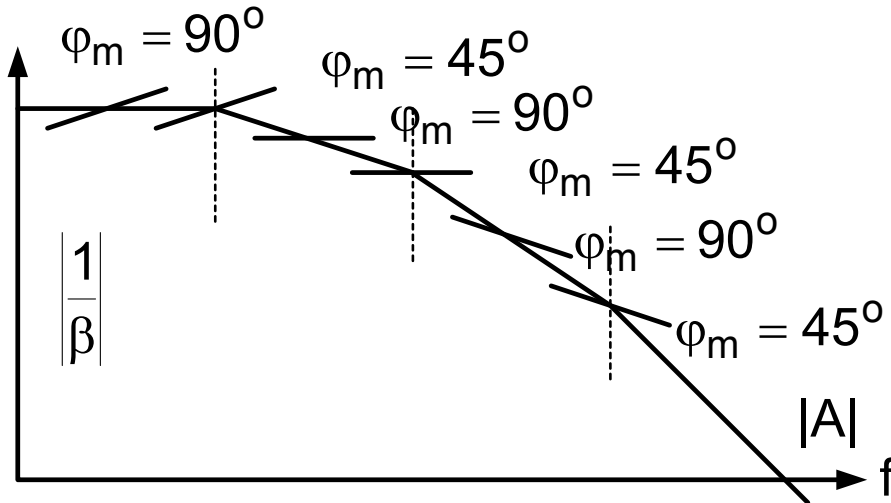
$$20\log(A) - 20\log(\beta) = 20\log(\beta A)$$



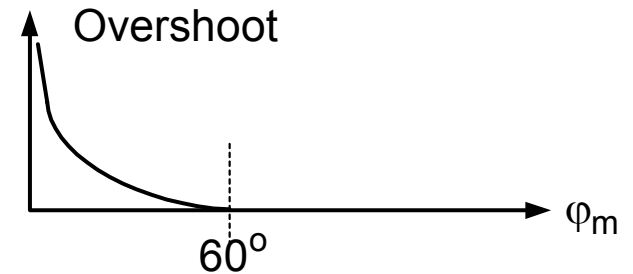
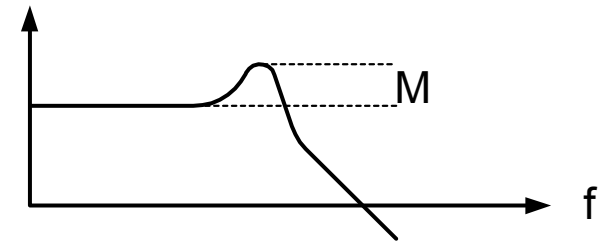
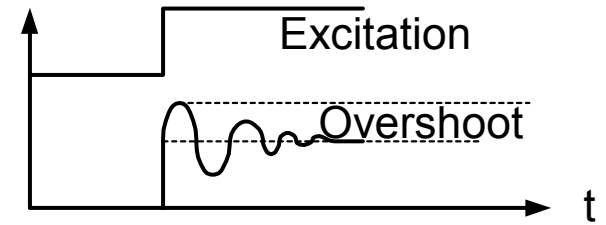


If rate of closure is -20 dB/dec system is stable



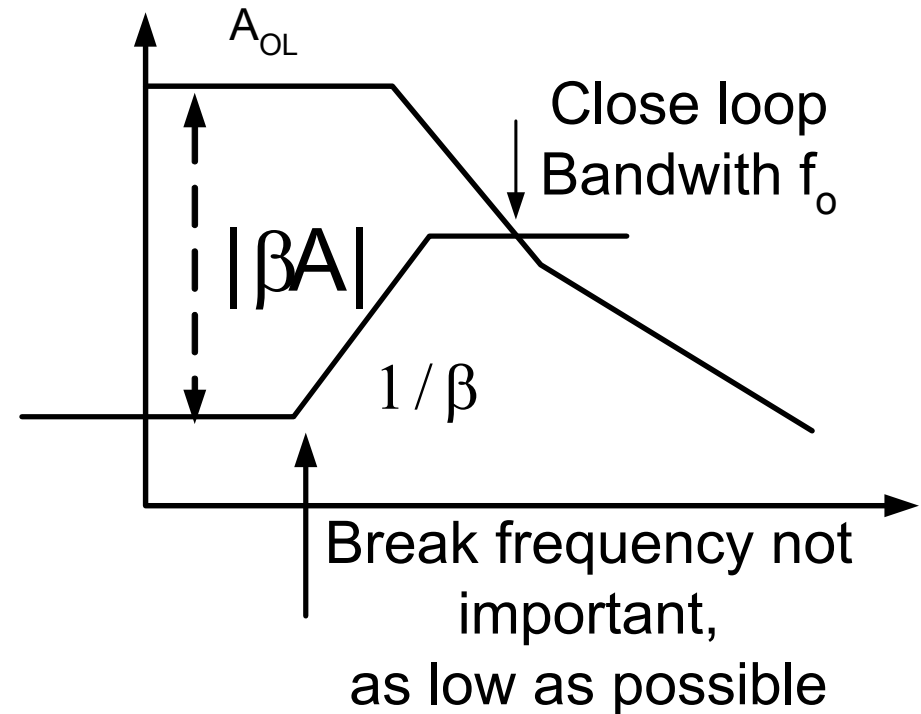


Choose $\varphi_m > 40^\circ$

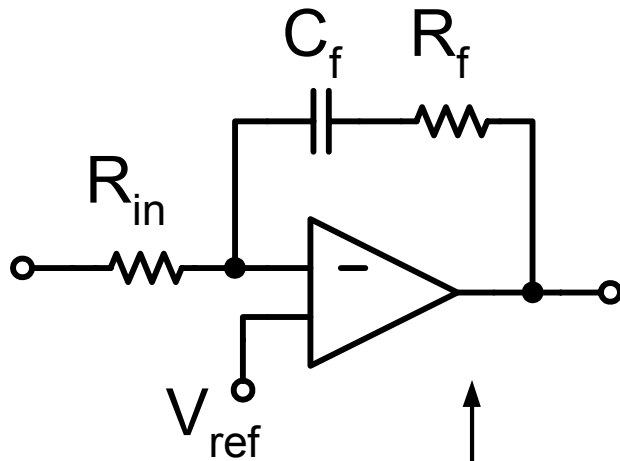


Feedback Loop Design

1. Find $A(f)$ of Power stage
2. Decide on f_0
3. Choose type of compensating network
4. Calculate feedback network



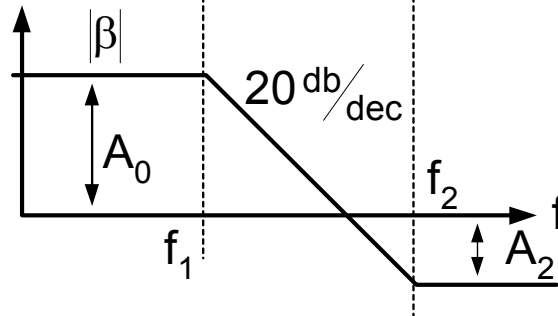
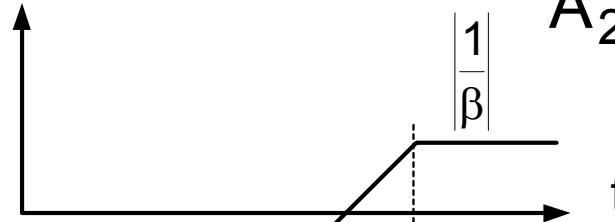
Make $|\beta A|$ as large as possible



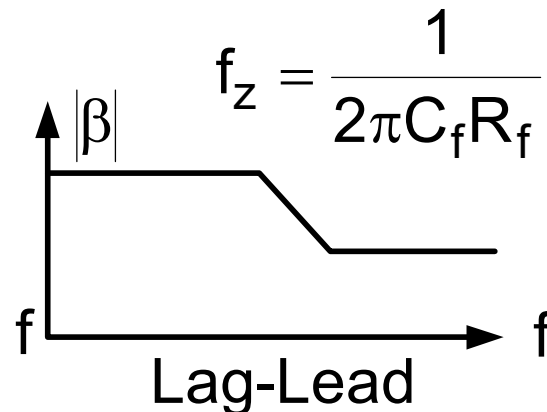
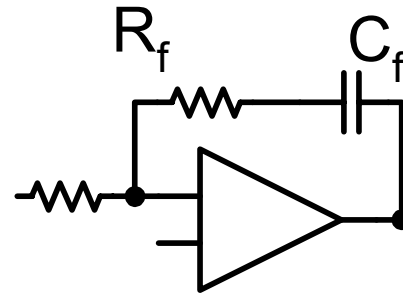
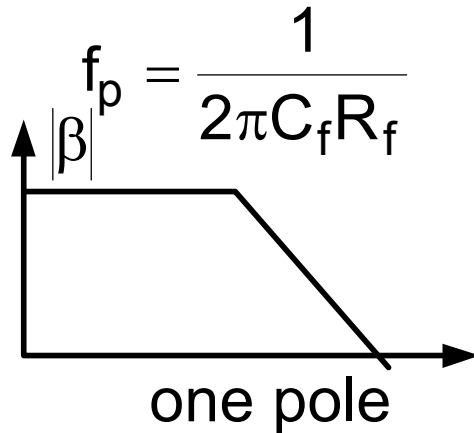
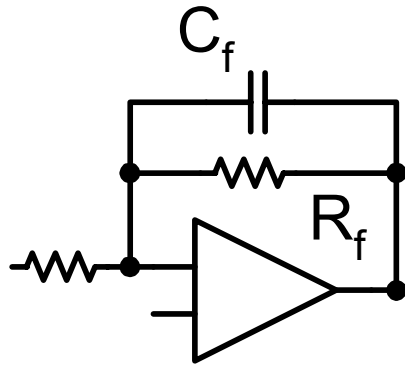
$$A_o = A_{OL} \text{ (ampl.)}$$

$$f_L = \frac{1}{2\pi C_f R_f}$$

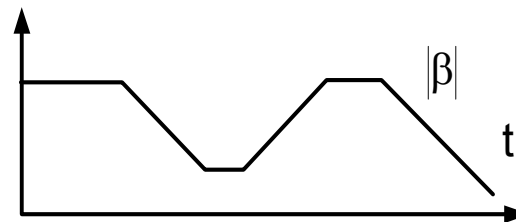
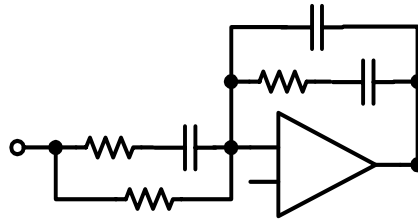
$$A_2 = \frac{R_f}{R_{in}}$$



Possible phase compensation schemes

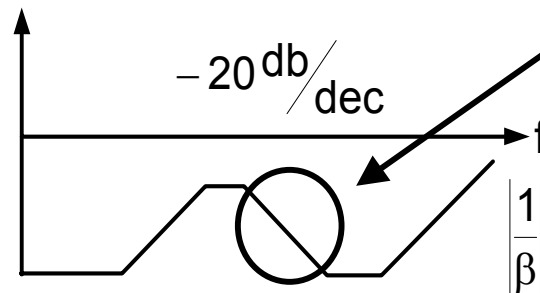


Double zero compensation scheme



double zero

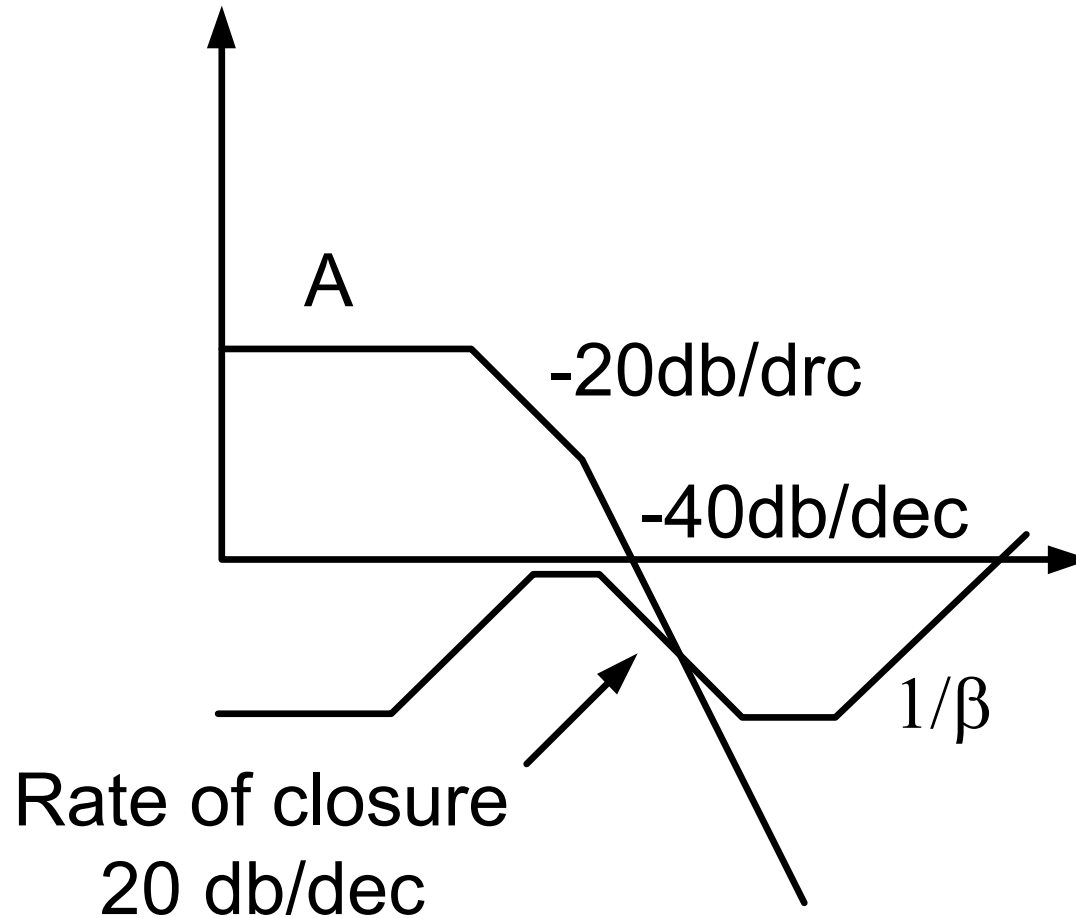
Useful region



-20 db/dec

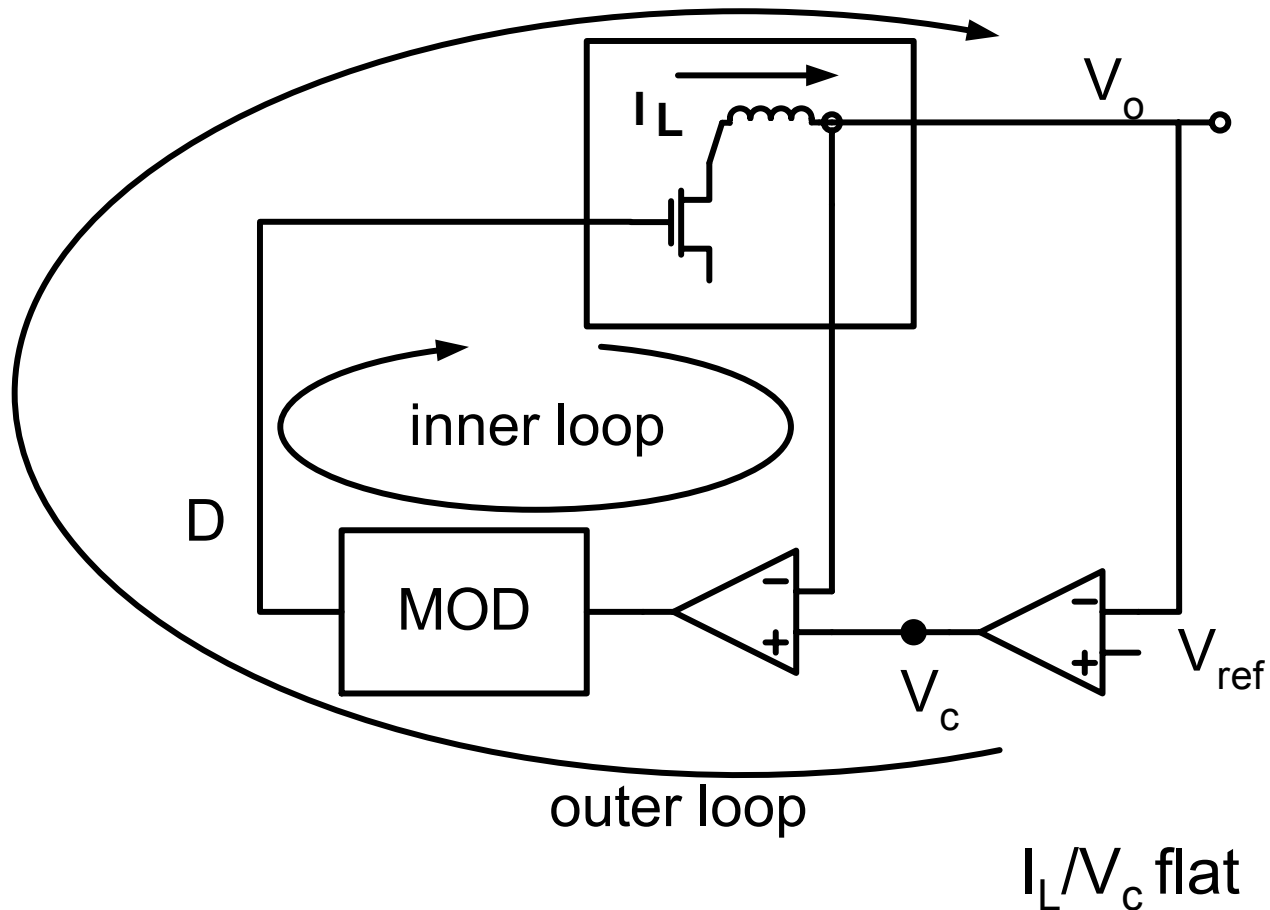
f

$1/|\beta|$

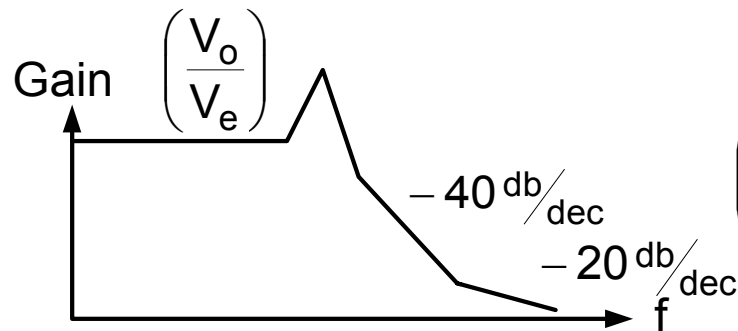


Phase advance by compensator

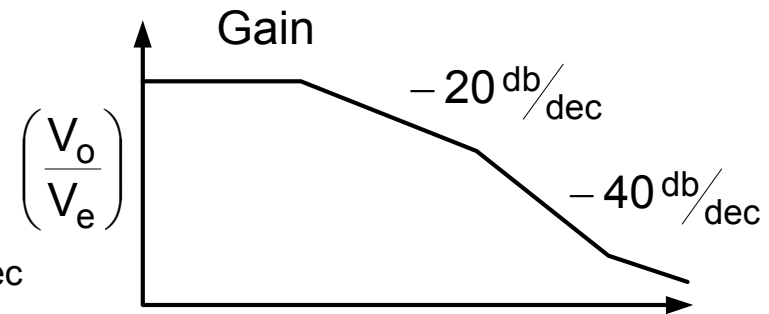
Peak and Average Current Mode



The advantages of current feedback (PCM or ACM)

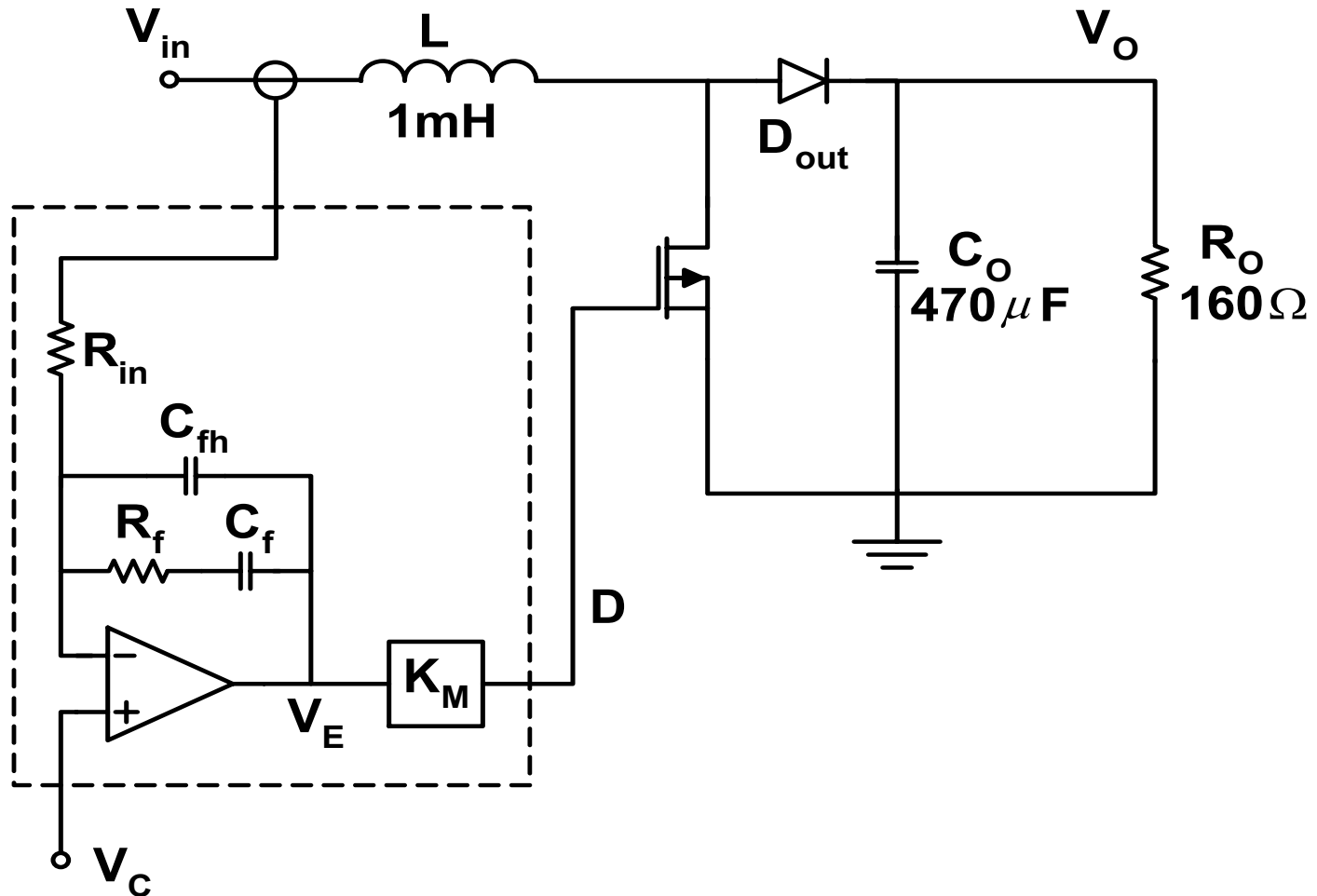


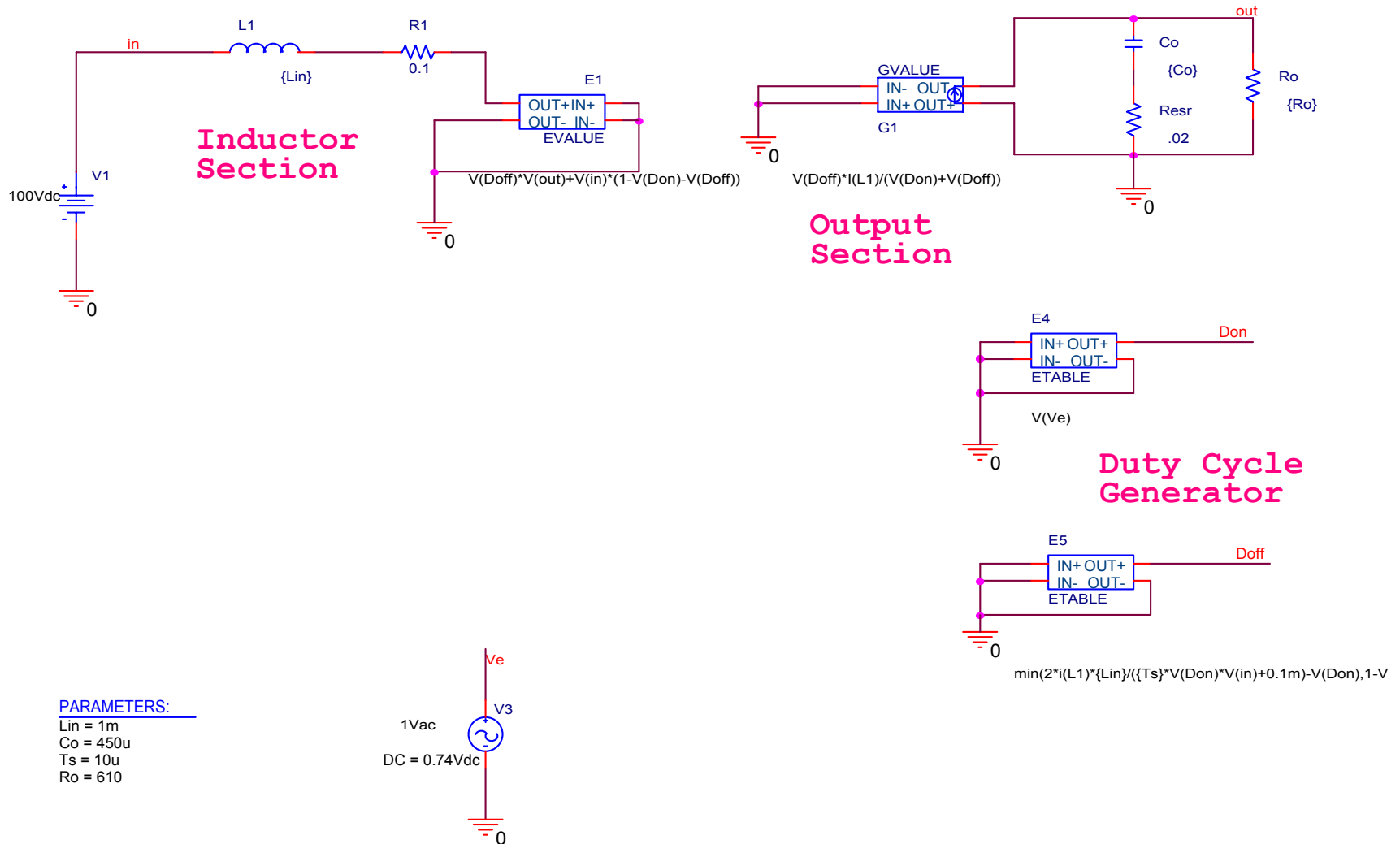
Typical power stage VM

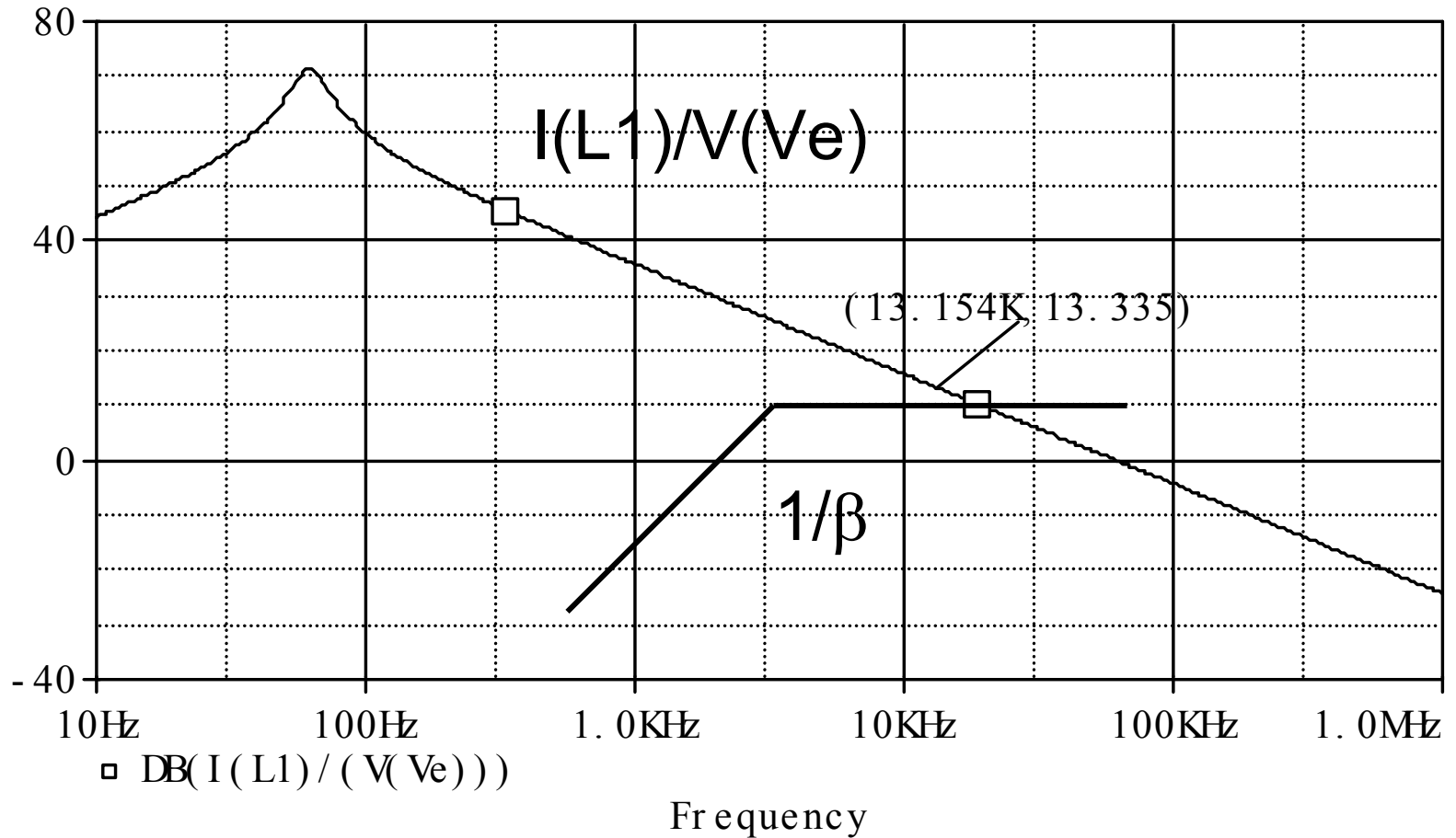


Same power stage
(outer loop) with CM

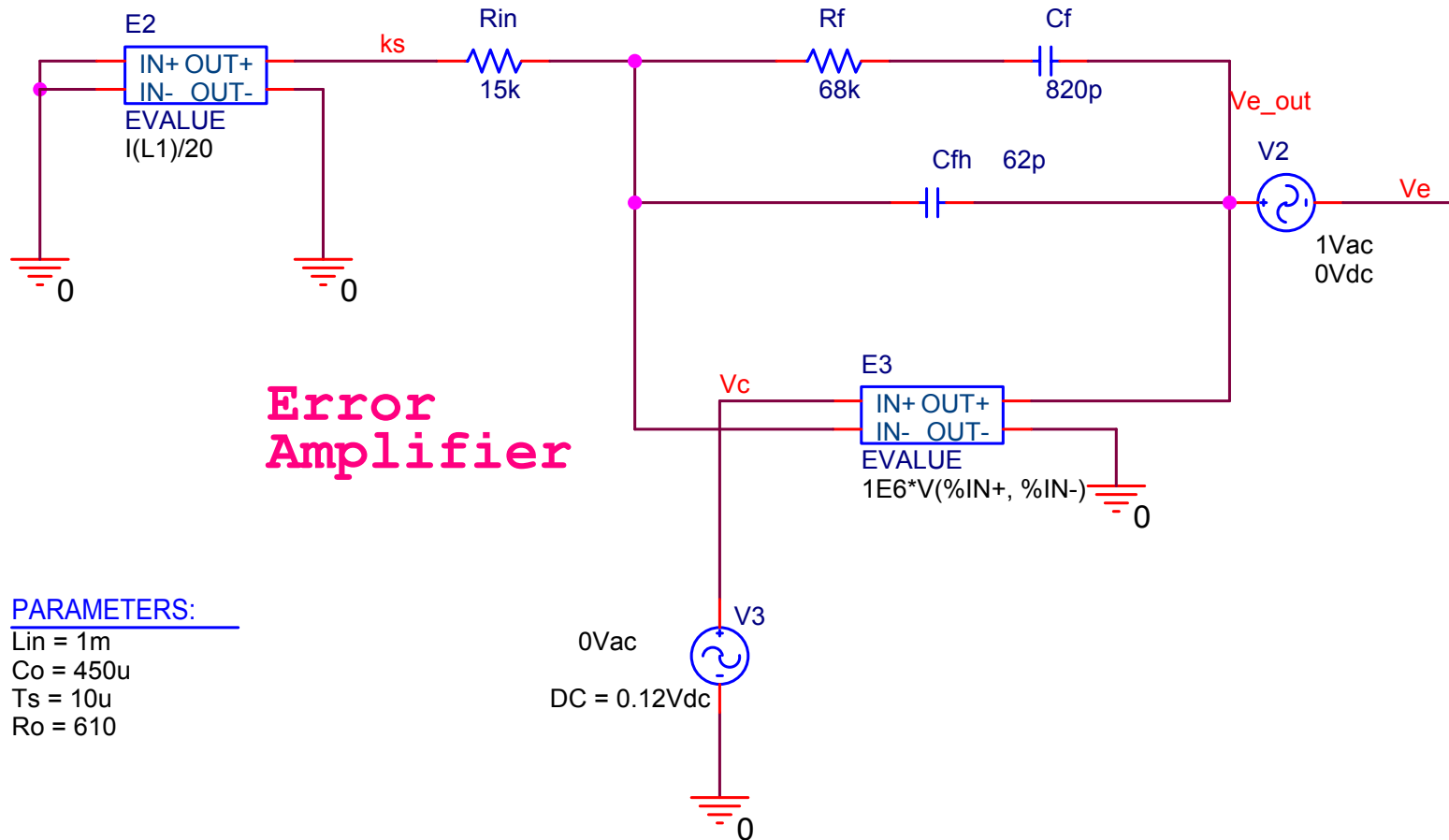
Average Current Loop



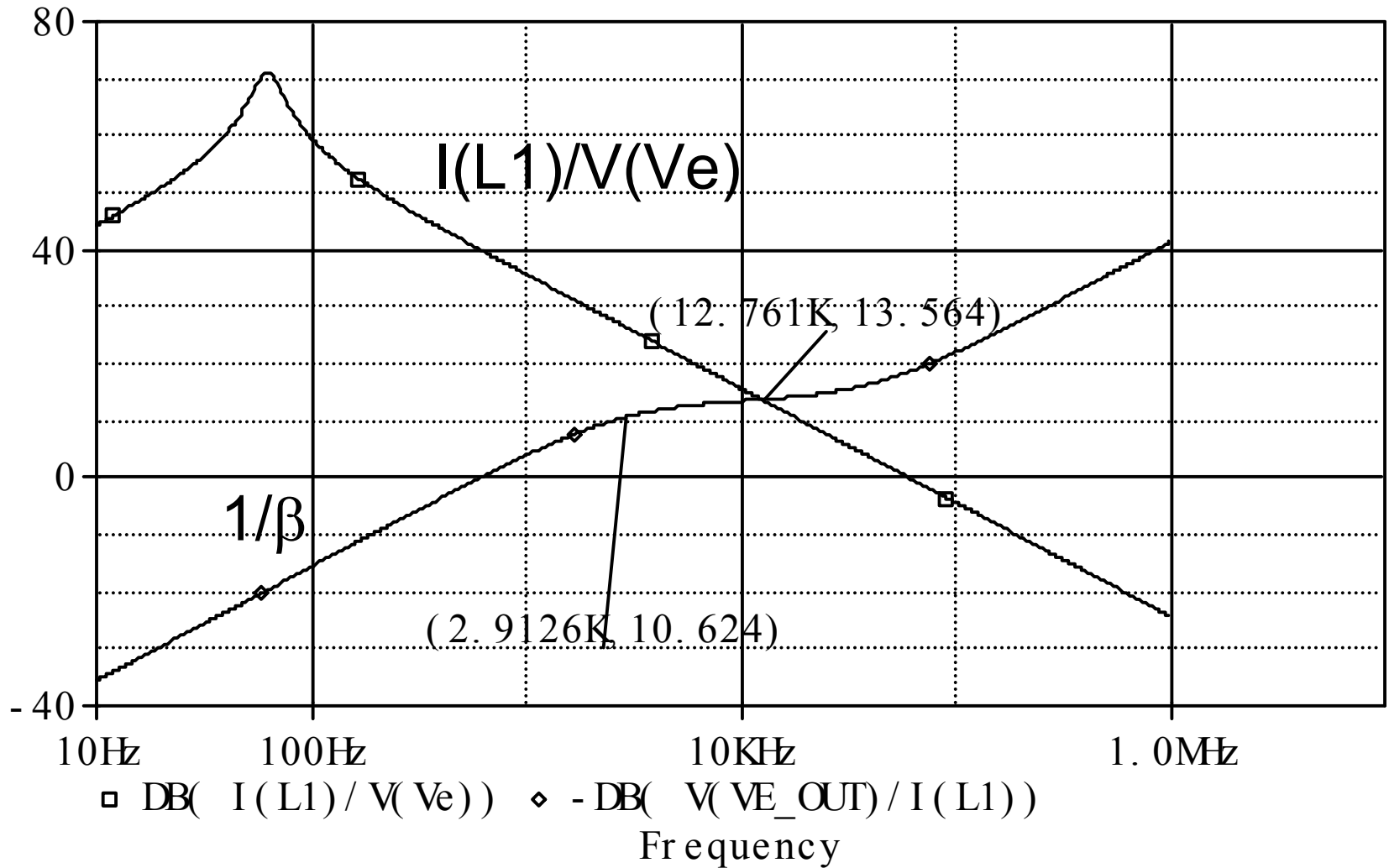


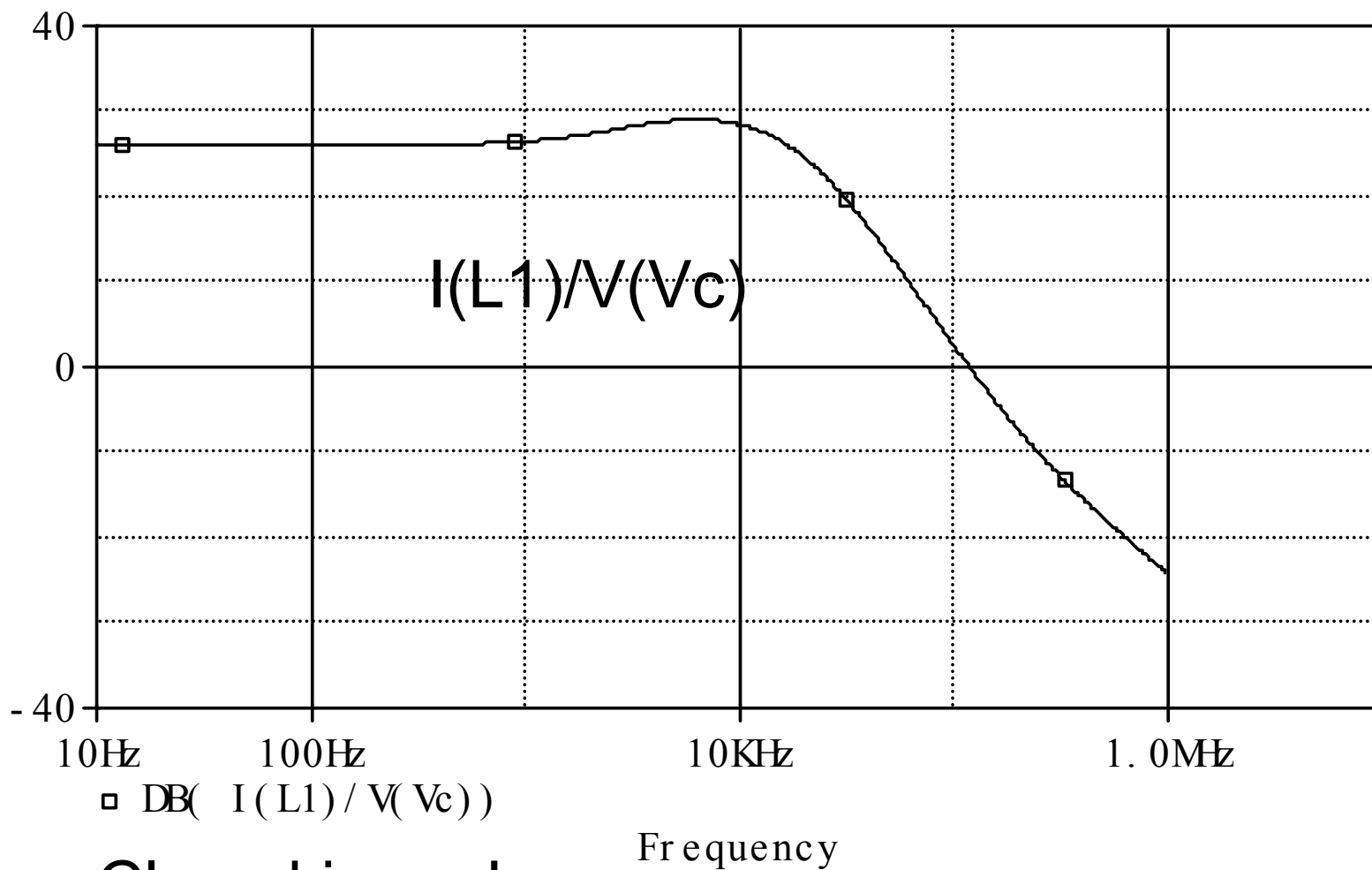


F=13kHz; Gain= -13.3db=0.22



- The error amplifier ($KS = 1/20$)

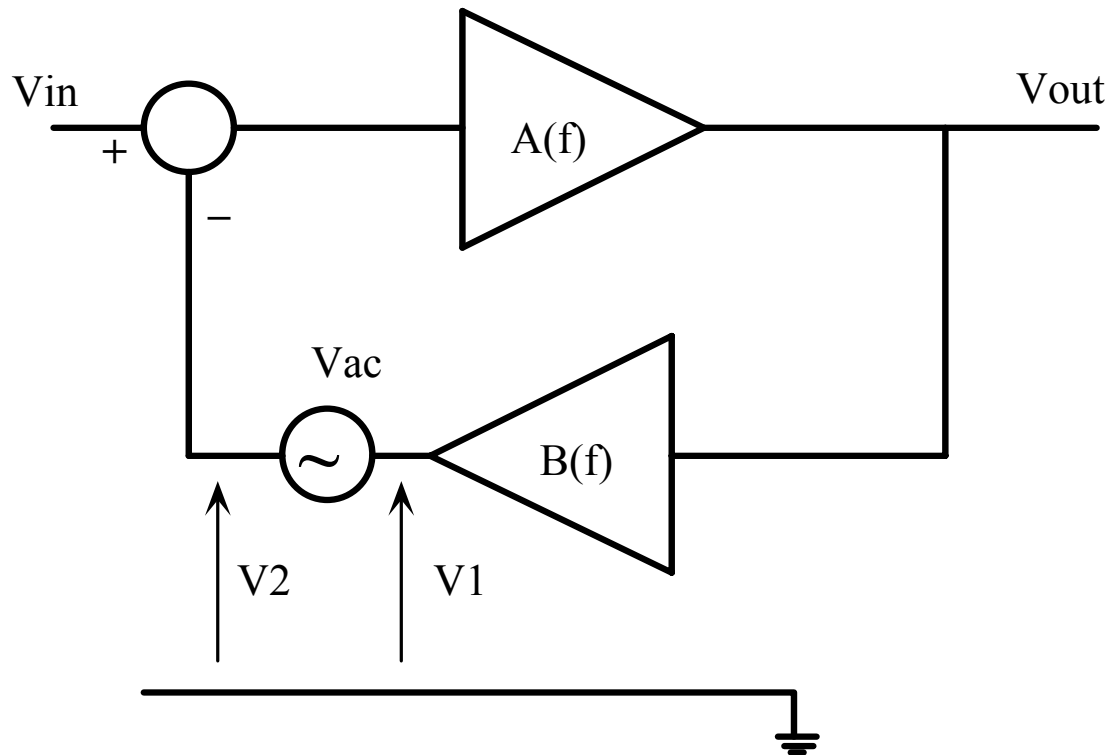




Closed inner Loop

Loop-Gain

Getting Loop-Gain under closed loop response $\{A(f)*B(f)\}$

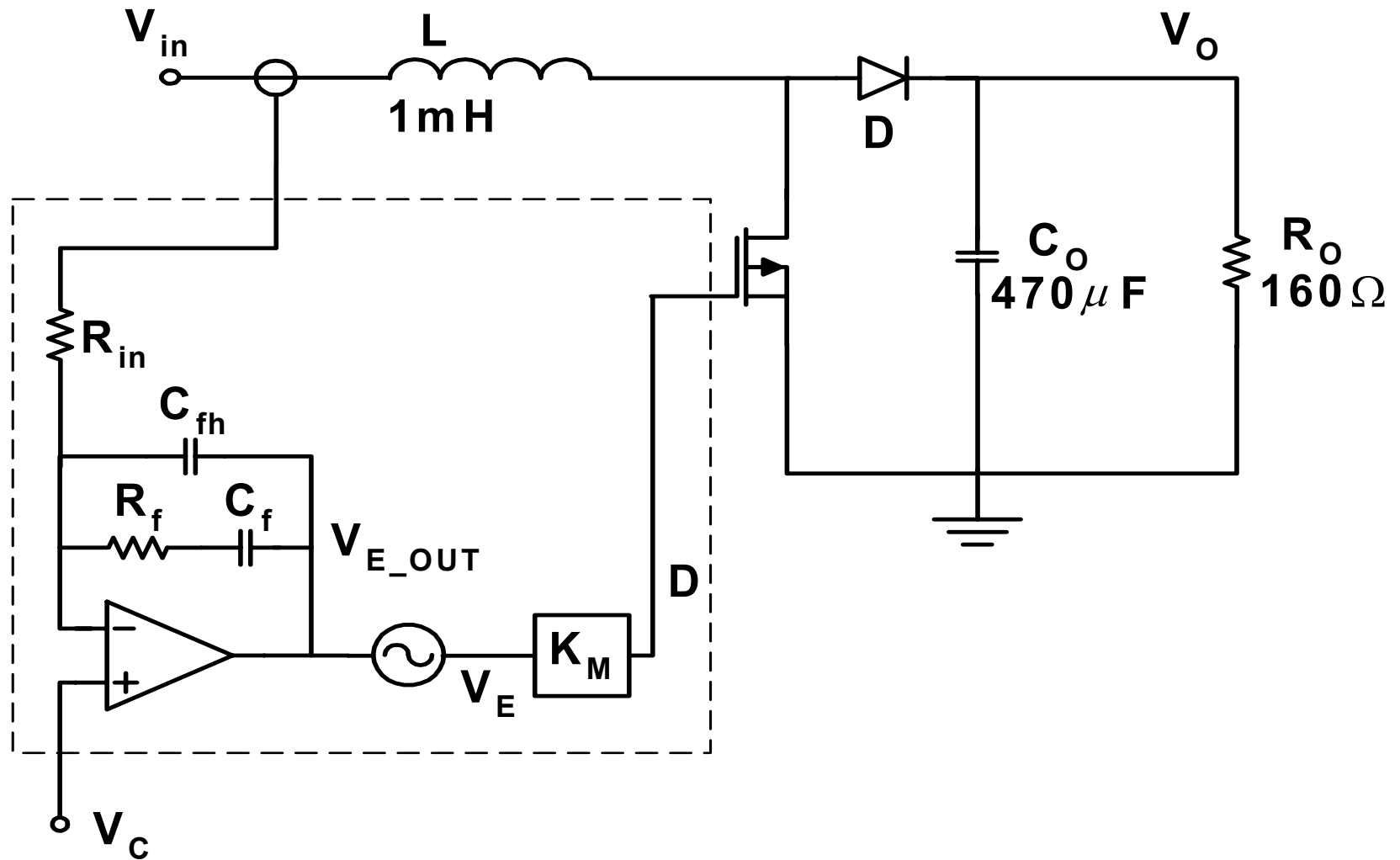


$$LG(f) = V1/V2$$

Rules for Getting Loop-Gain by Simulation

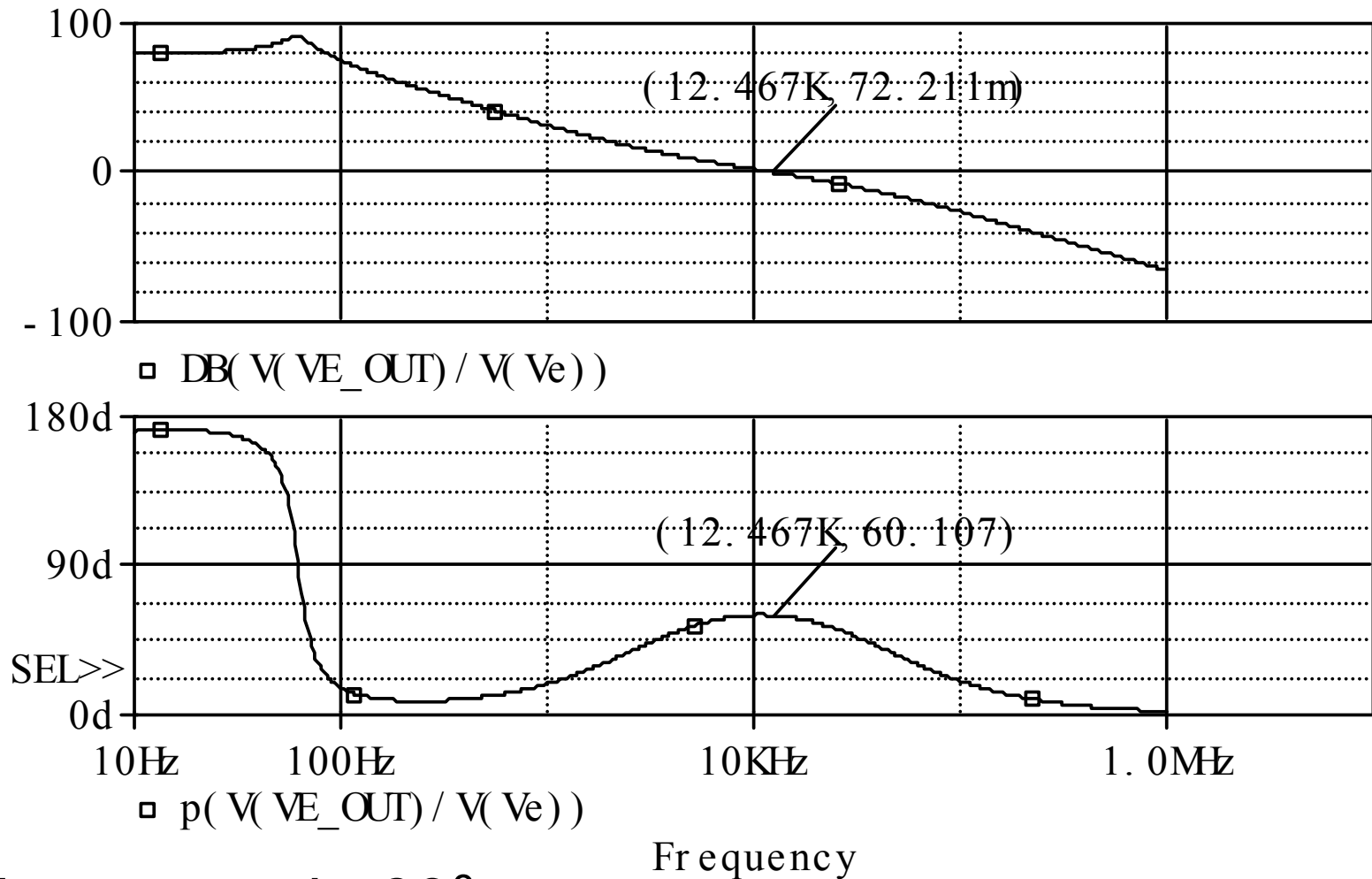
The relevant analysis is .AC

- Locate the AC source at the output of a low impedance device (could be real or behavioral)
- Set the AC value to any value (1 V is fine)
- Make sure that there are no other AC sources in the system
- Check bias point (.OUT file)
- Remember that the classical stability criteria take into account the phase reversal (180°)

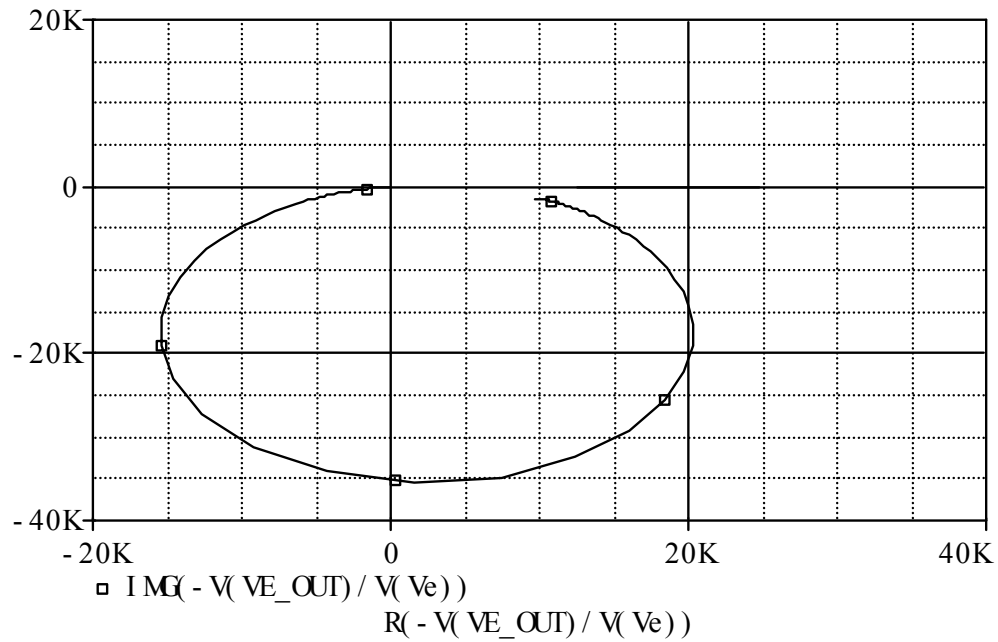


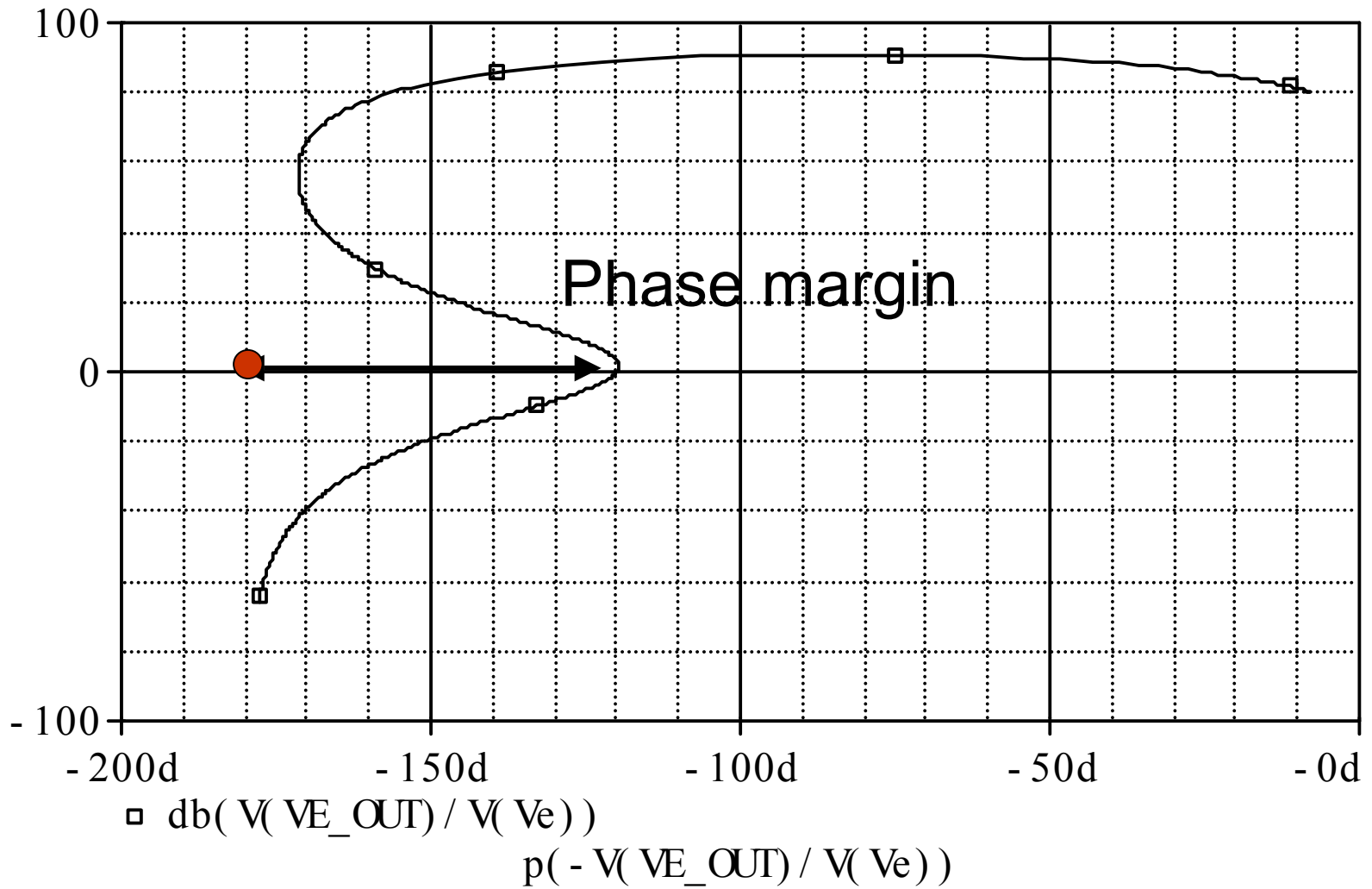
$V_{ac} = 1V$; $V_c = \text{Constant (operating point)}$; $K_S = 1/20$

LoopGain

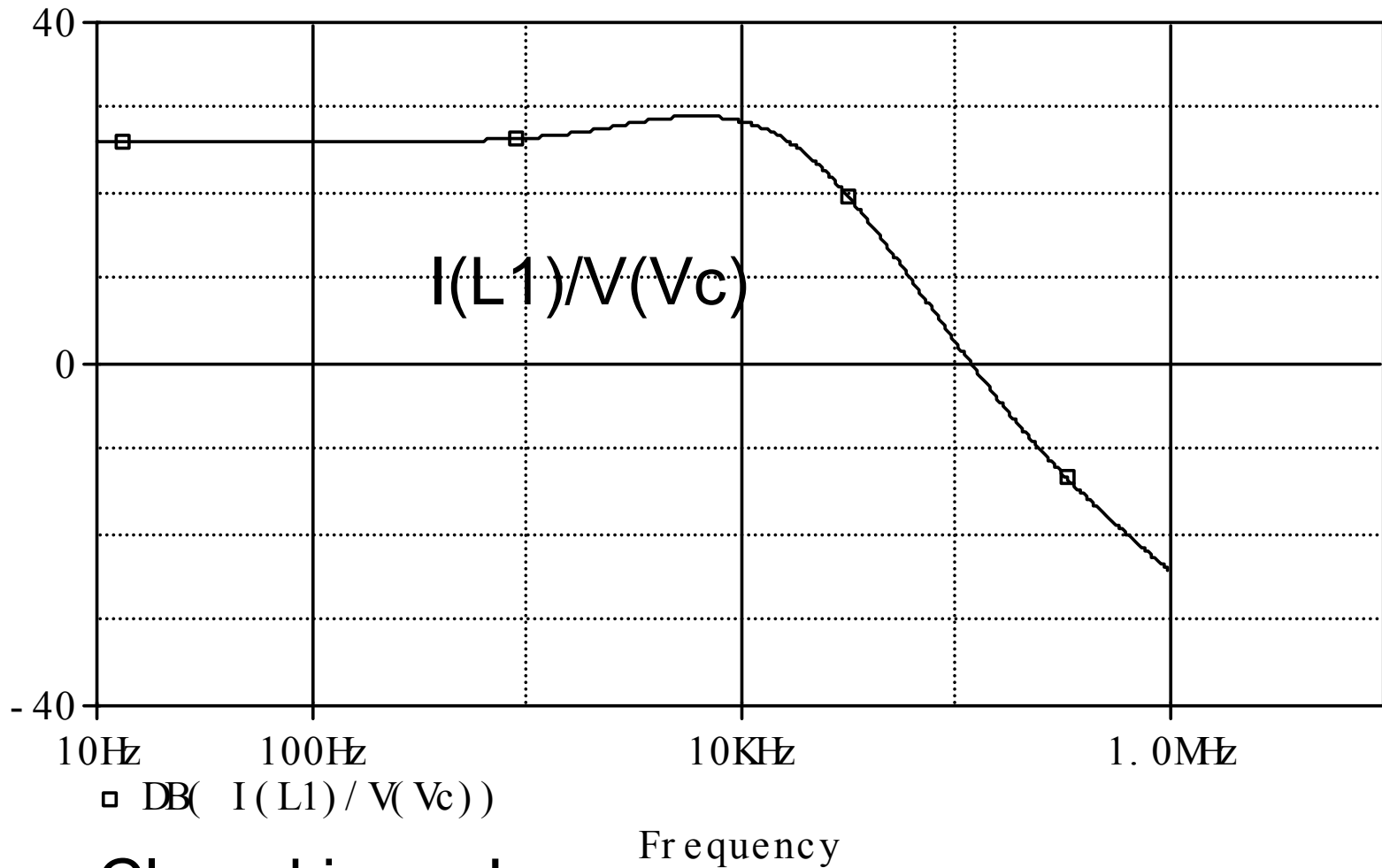


Phase margin 60°

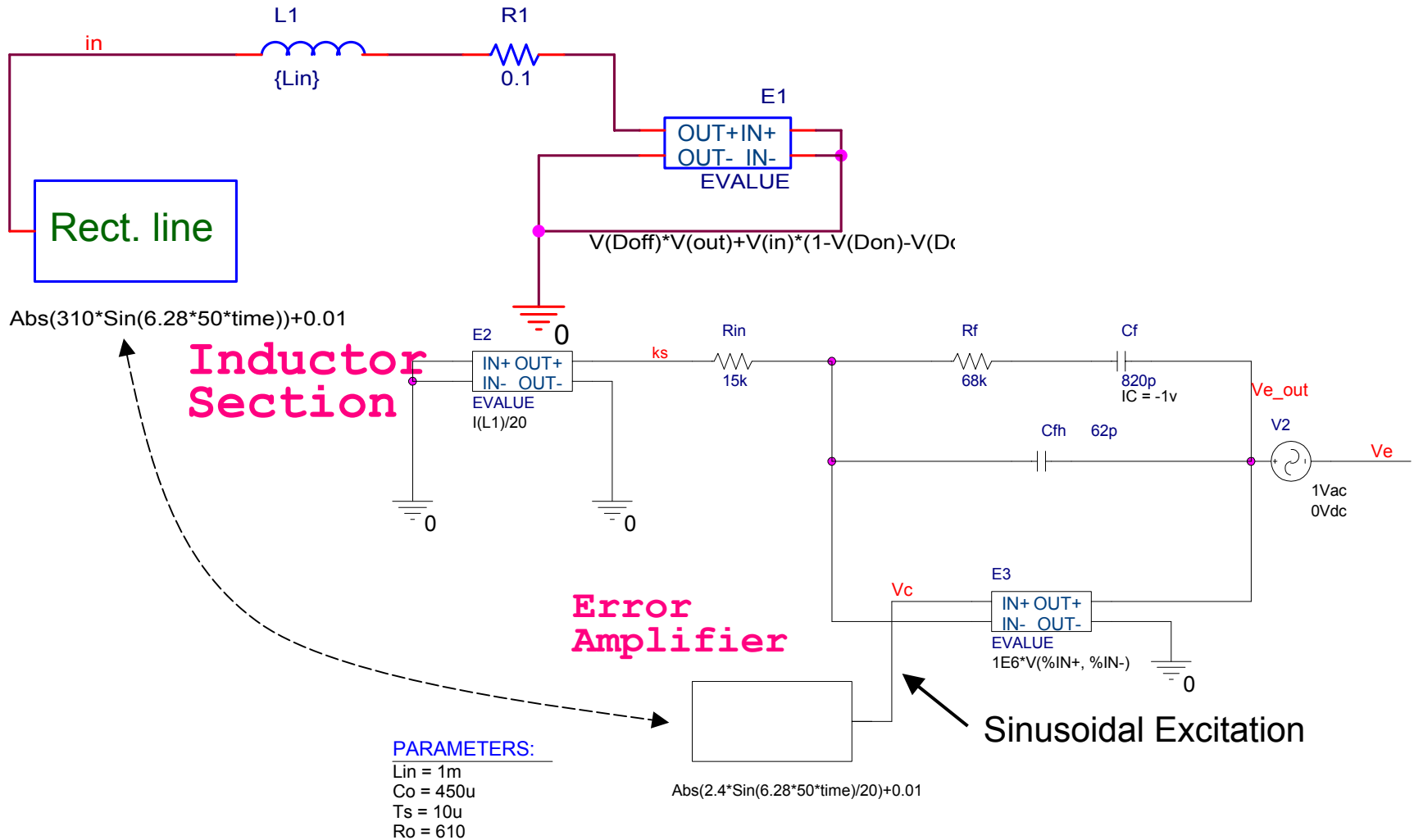




Nichols

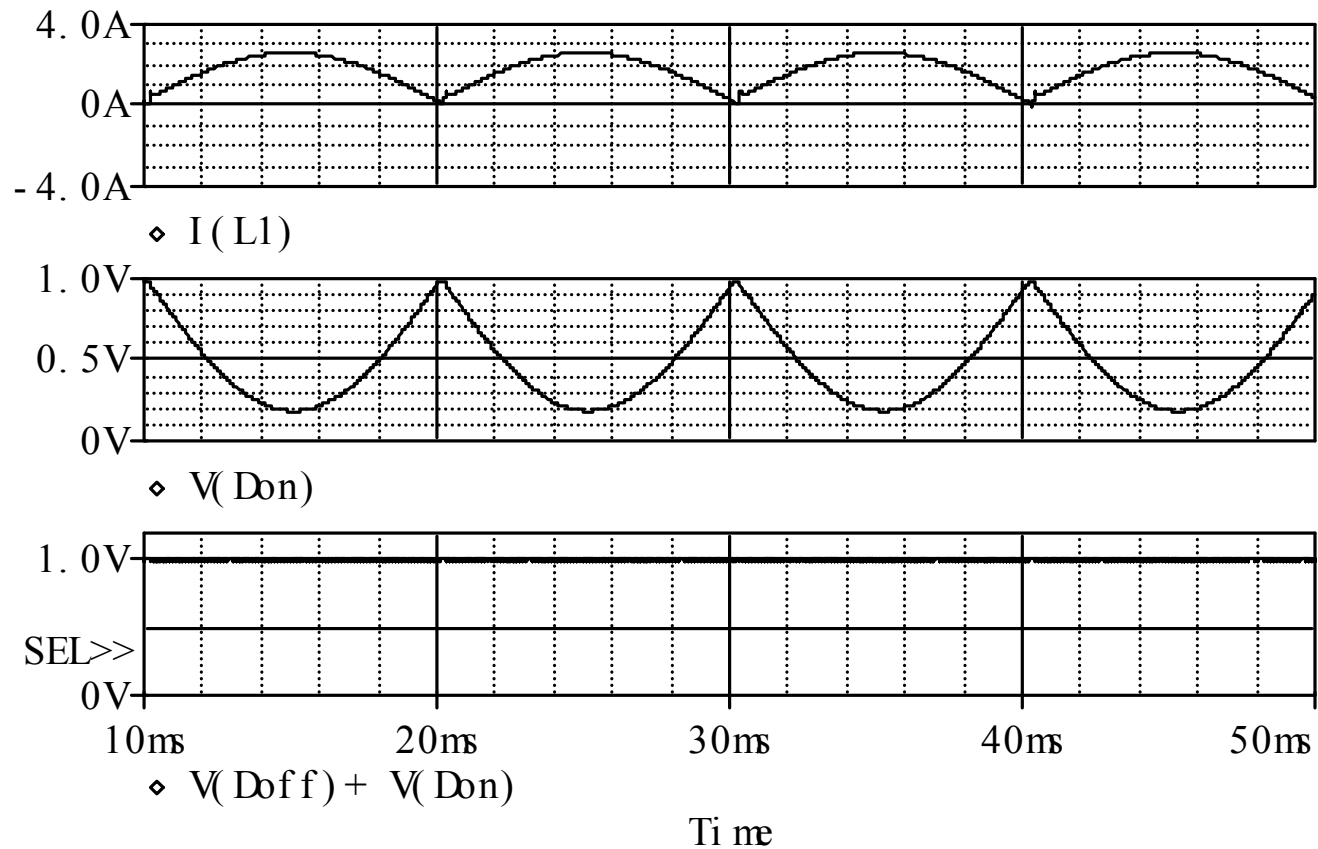


Closed inner Loop

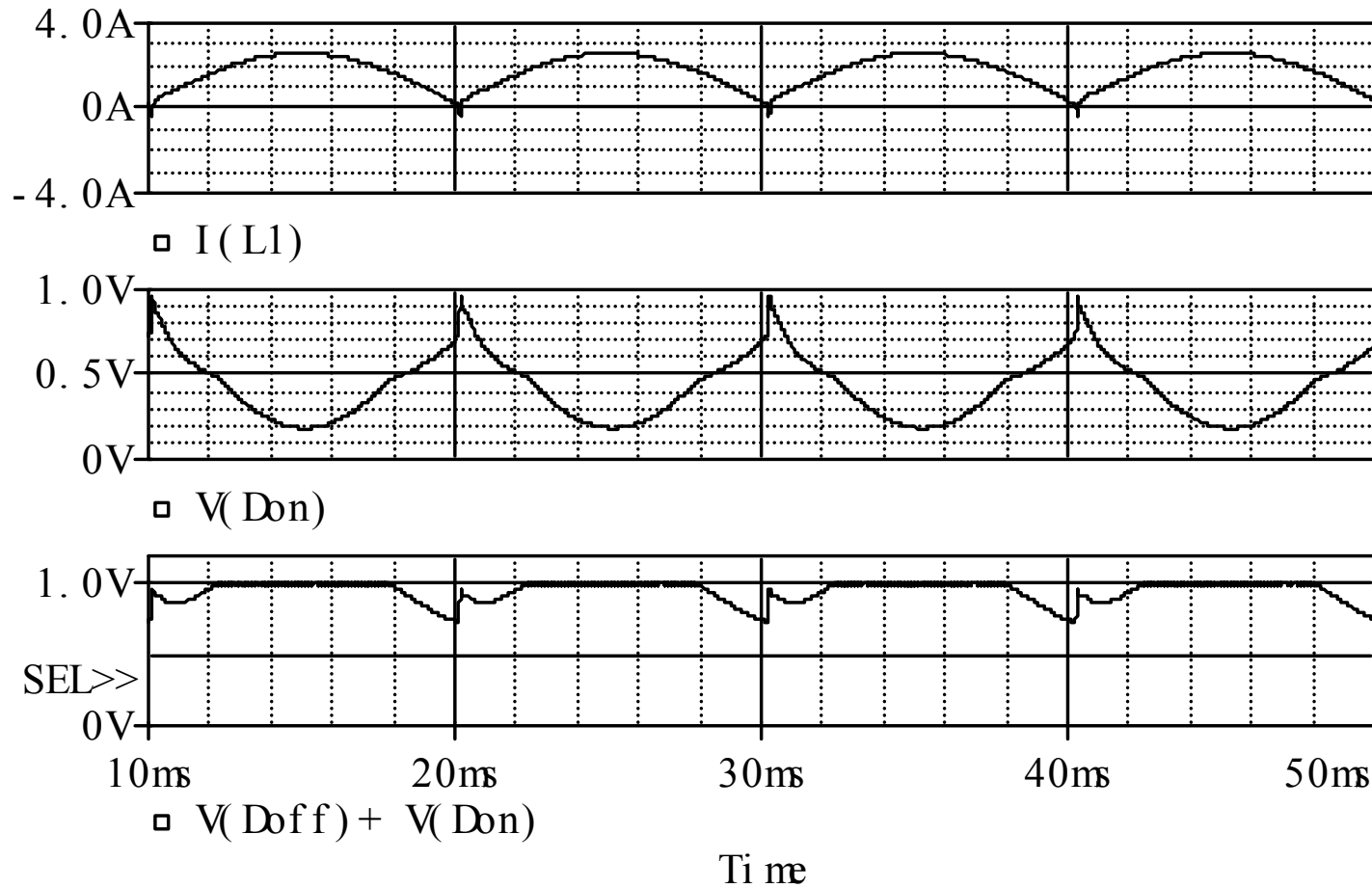


- Toward Power factor Correction (open loop)





In CCM: $D_{on} + D_{off} = 1$



After changing L_m to $300\mu H$

FOURIER ANALYSIS

Transient Output File Options [X]

Print values in the output file every: seconds

Perform Fourier Analysis

Center Frequency: hz

Number of Harmonics:

Output Variables:

Include detailed bias point information for nonlinear controlled sources and semiconductors (/OP)

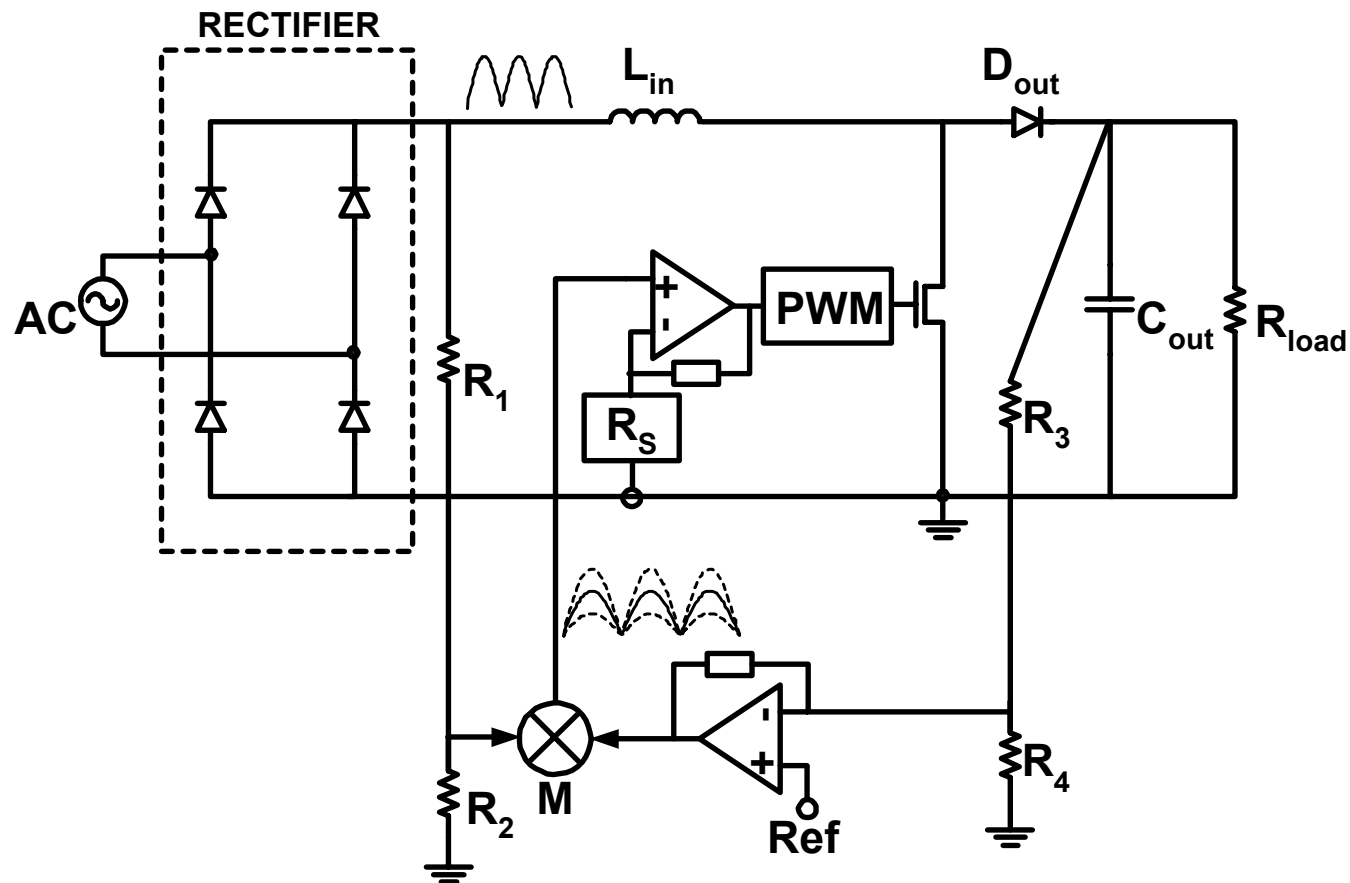
OK
Cancel

DC COMPONENT = 1.367887E-04

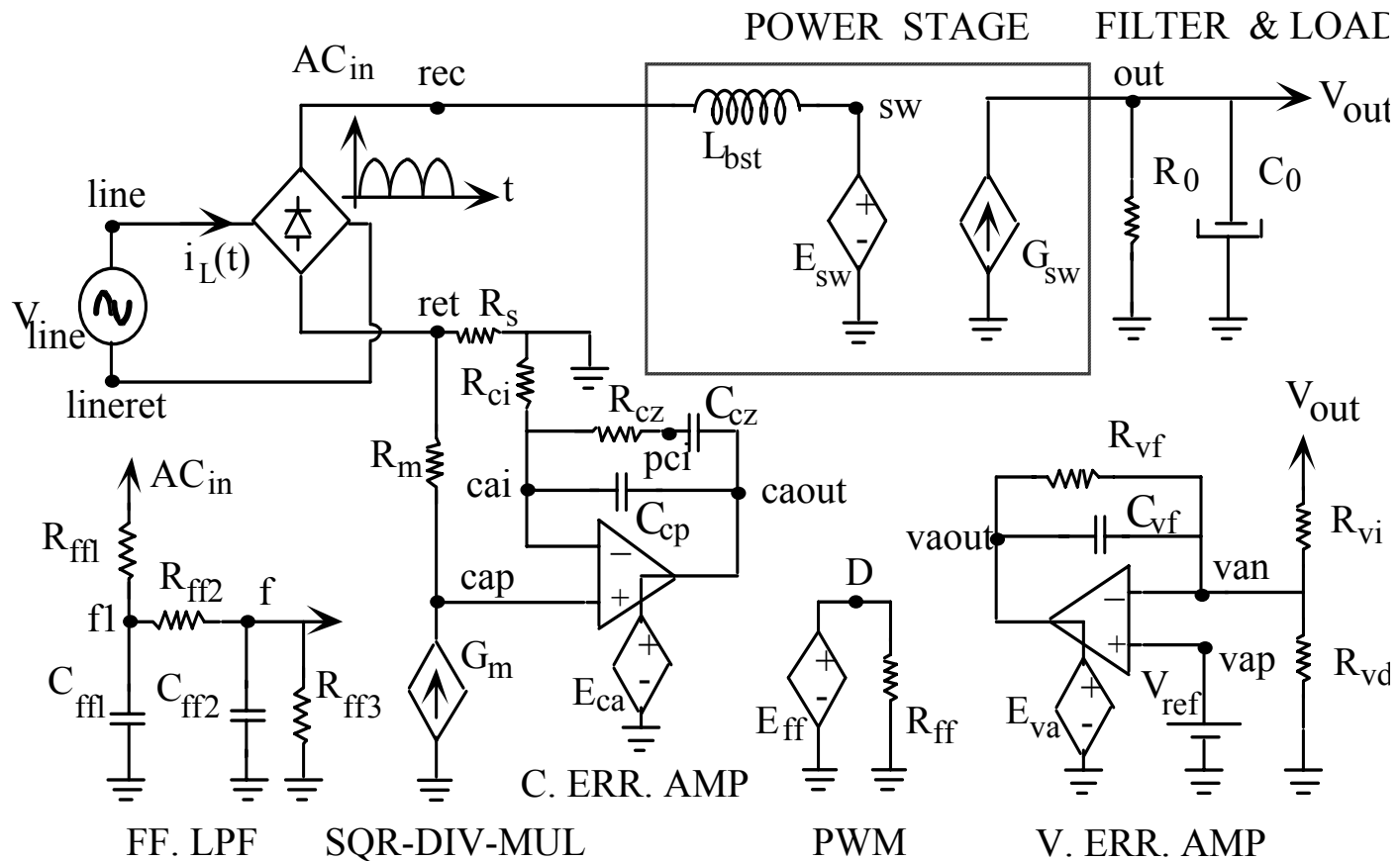
HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	5.000E+01	2.659E+00	1.000E+00	2.973E-01	0.000E+00
2	1.000E+02	1.659E-03	6.240E-04	1.077E+01	1.017E+01
3	1.500E+02	9.142E-02	3.438E-02	-1.001E+01	-1.090E+01
4	2.000E+02	7.244E-04	2.724E-04	2.227E+01	2.108E+01
5	2.500E+02	5.763E-02	2.167E-02	-3.483E+00	-4.969E+00
6	3.000E+02	5.572E-04	2.096E-04	3.296E+01	3.118E+01
7	3.500E+02	4.254E-02	1.600E-02	-4.976E+00	-7.057E+00
8	4.000E+02	5.337E-04	2.007E-04	4.146E+01	3.908E+01
9	4.500E+02	3.389E-02	1.274E-02	-2.130E+01	-2.397E+01
10	5.000E+02	5.120E-04	1.926E-04	4.309E+01	4.012E+01

TOTAL HARMONIC DISTORTION = 4.550535E+00 PERCENT

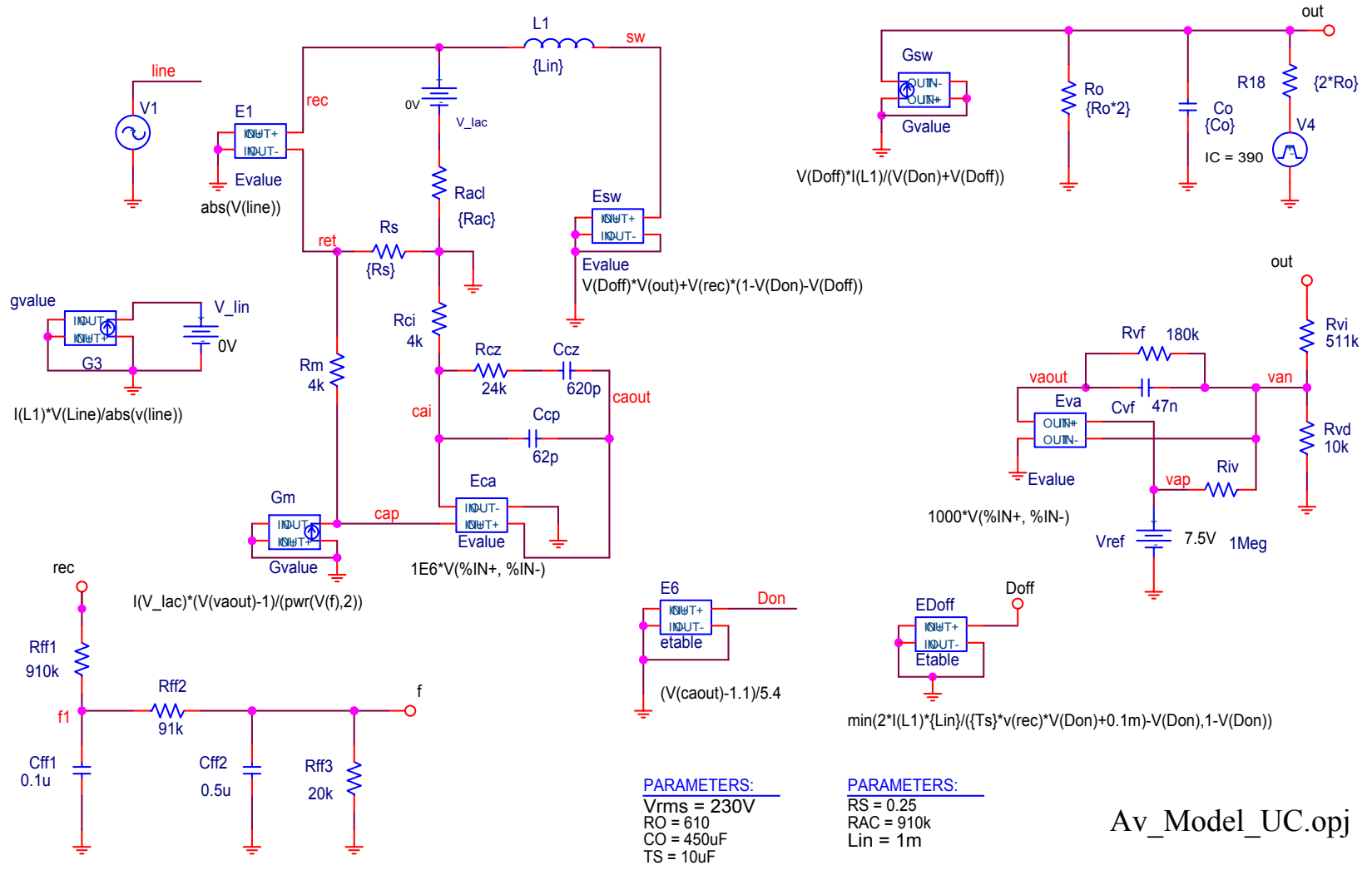
Three Loops Feedback PFC System (Conventional CCM)



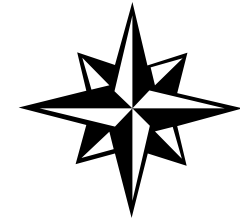
UC3854 Based Average Model



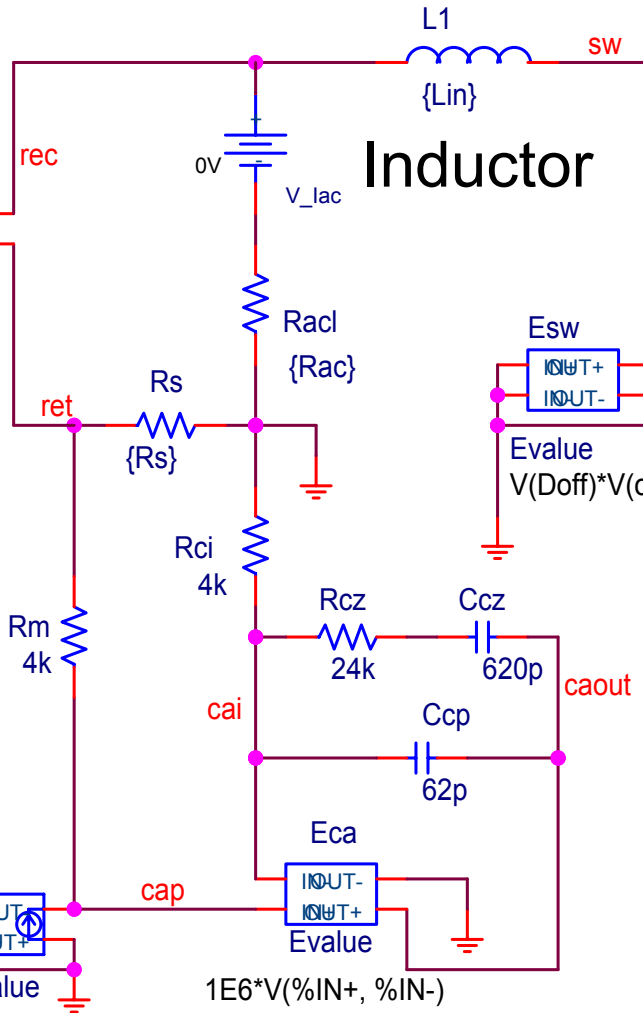
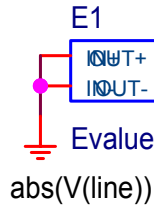
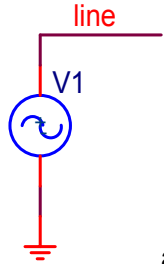
CCM - Based on UC3854



Av_Model_UC.opj



Input

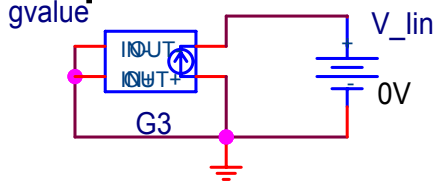


Inductor



$$Evalue = V(Doff) * V(out) + V(rec) * (1 - V(Don) - V(Doff))$$

Input current

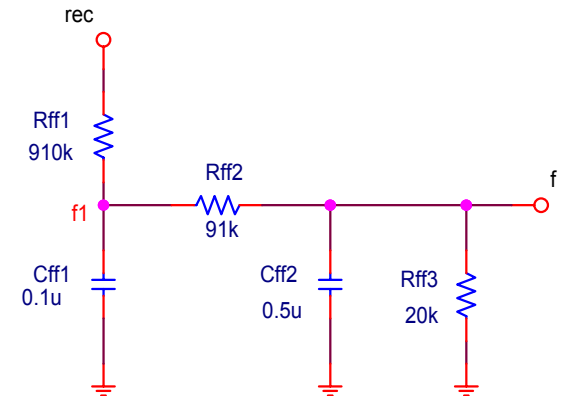


$$I(L1) * V(Line) / abs(v(line))$$

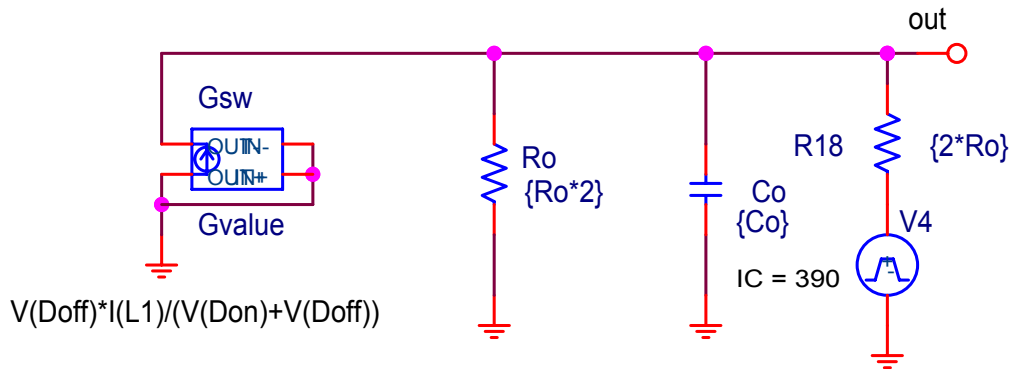
$$I(V_lac) * (V(vaout) - 1) / (pwr(V(f), 2))$$

Multiplier

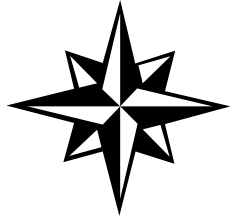
Current Amp



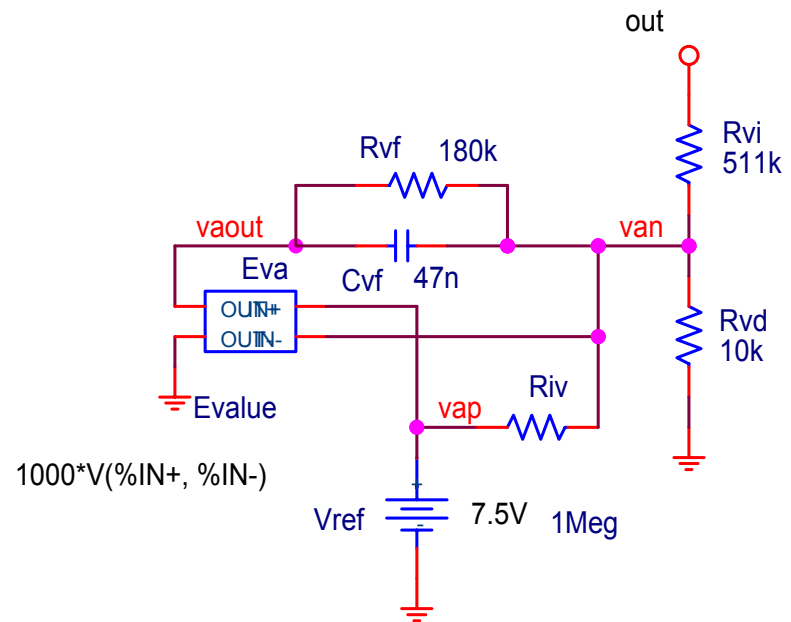
Feedforward



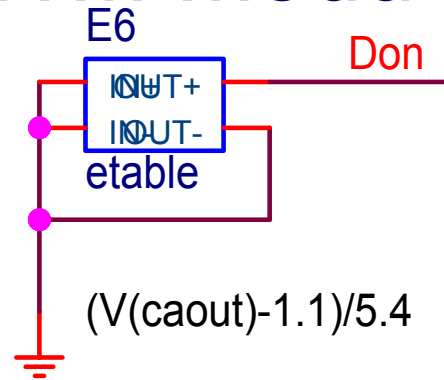
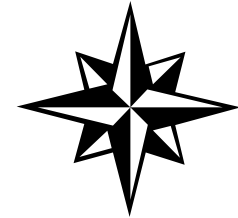
Output Section plus Load Change



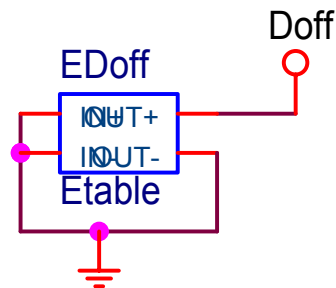
Voltage Amplifier



Duty Cycle Generator (PWM Modulator)



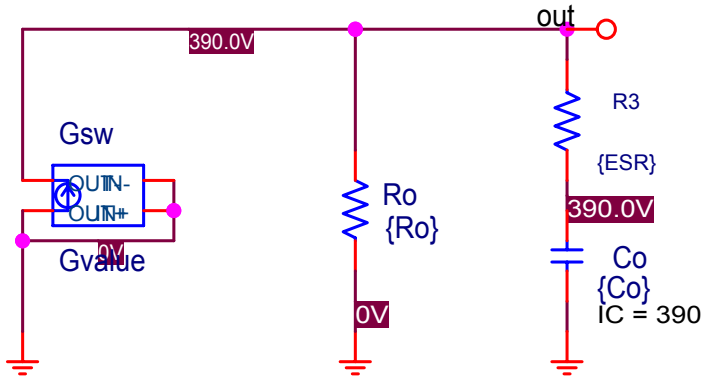
Doff Generator (CCM-DCM)



$$\min(2 * I(L1) * \{Lin\} / (\{Ts\} * v(rec) * V(Don) + 0.1m) - V(Don), 1 - V(Don))$$

Voltage Control Loop

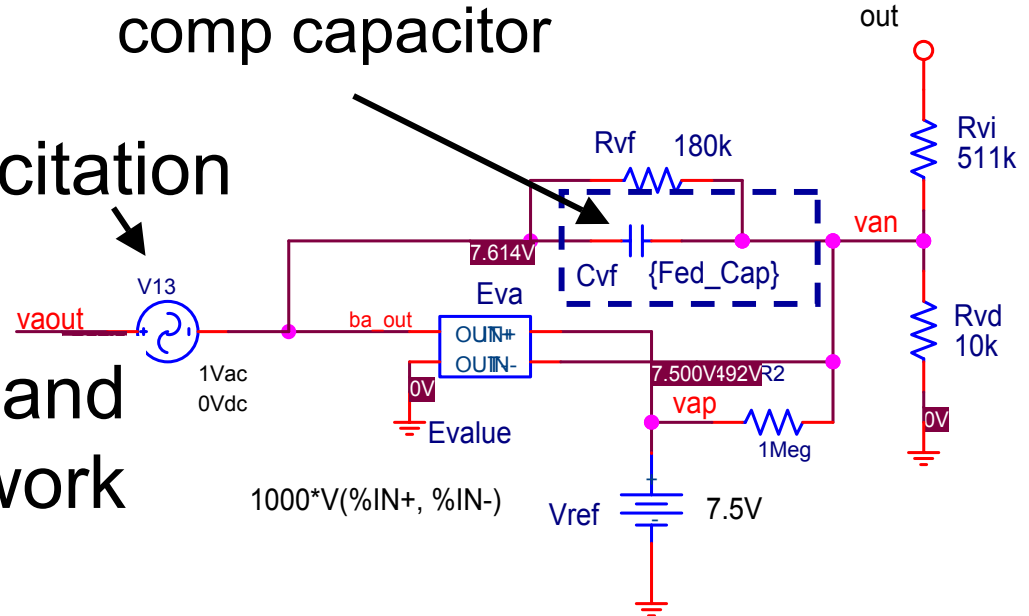
Output Section



$$V(Doff) \cdot I(L1) / (V(Don) + V(Doff))$$

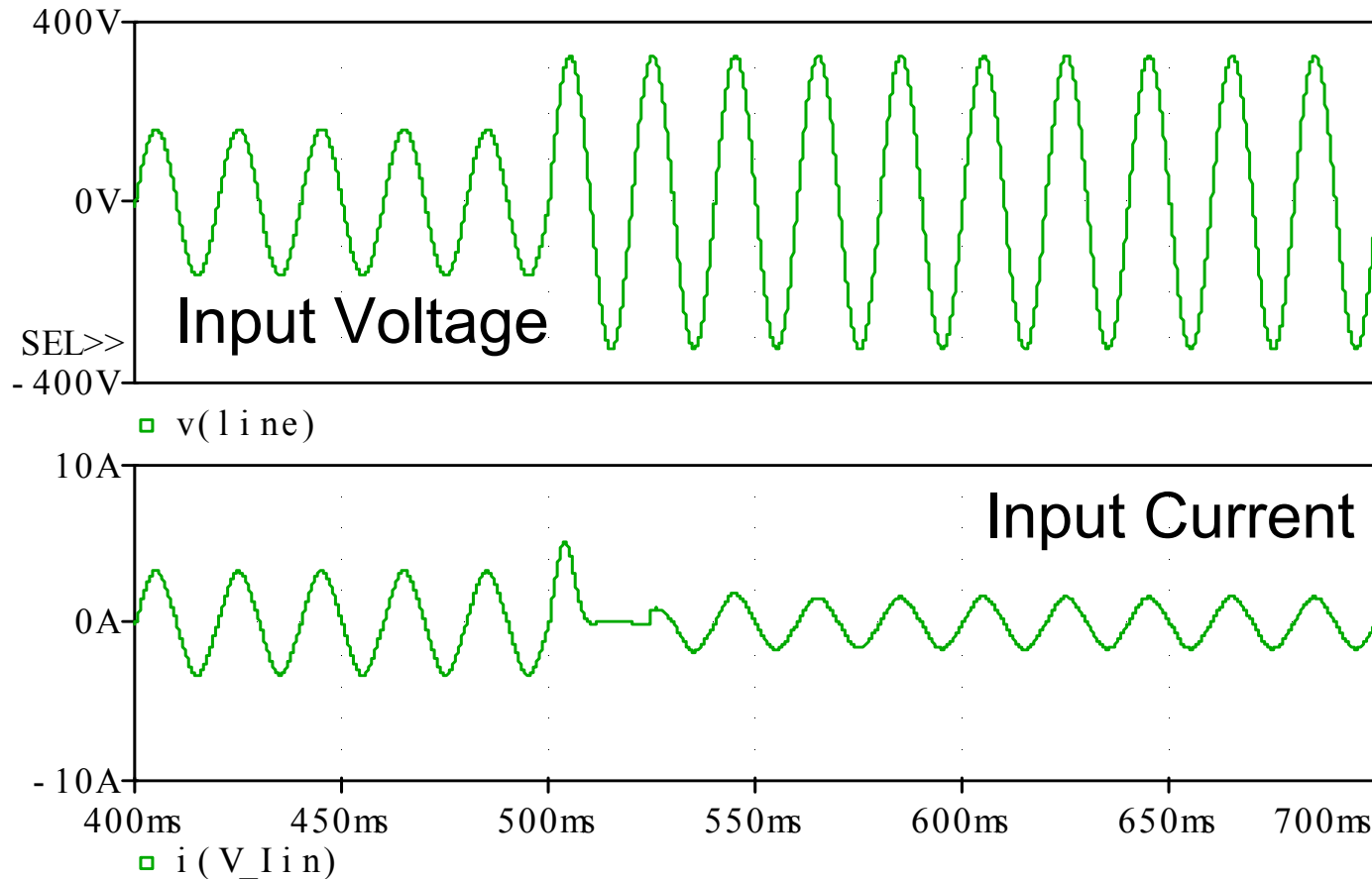
V feedback
comp capacitor

Excitation



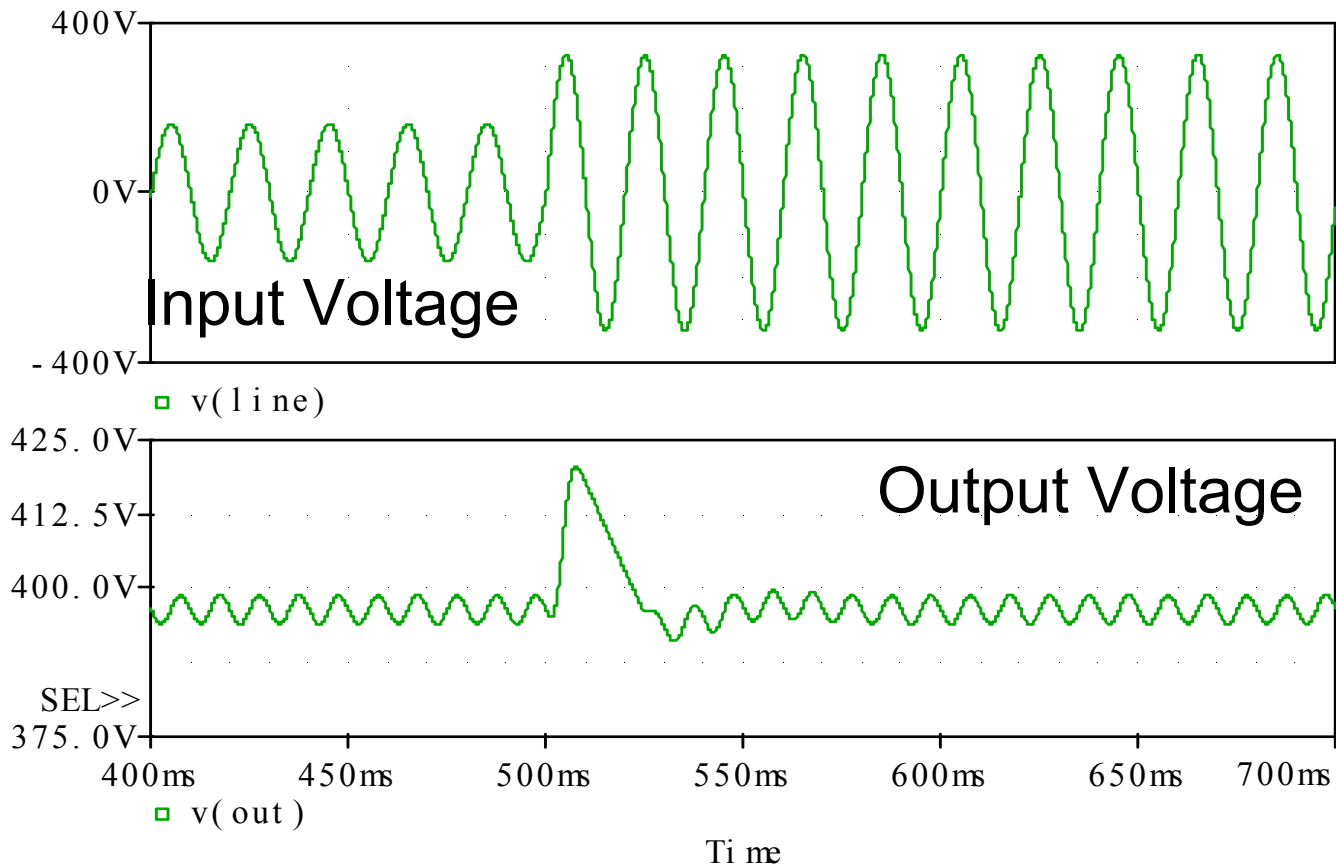
Error Amplifier and Compensation Network

Input Voltage Step Response: 115Vrms to 230Vrms



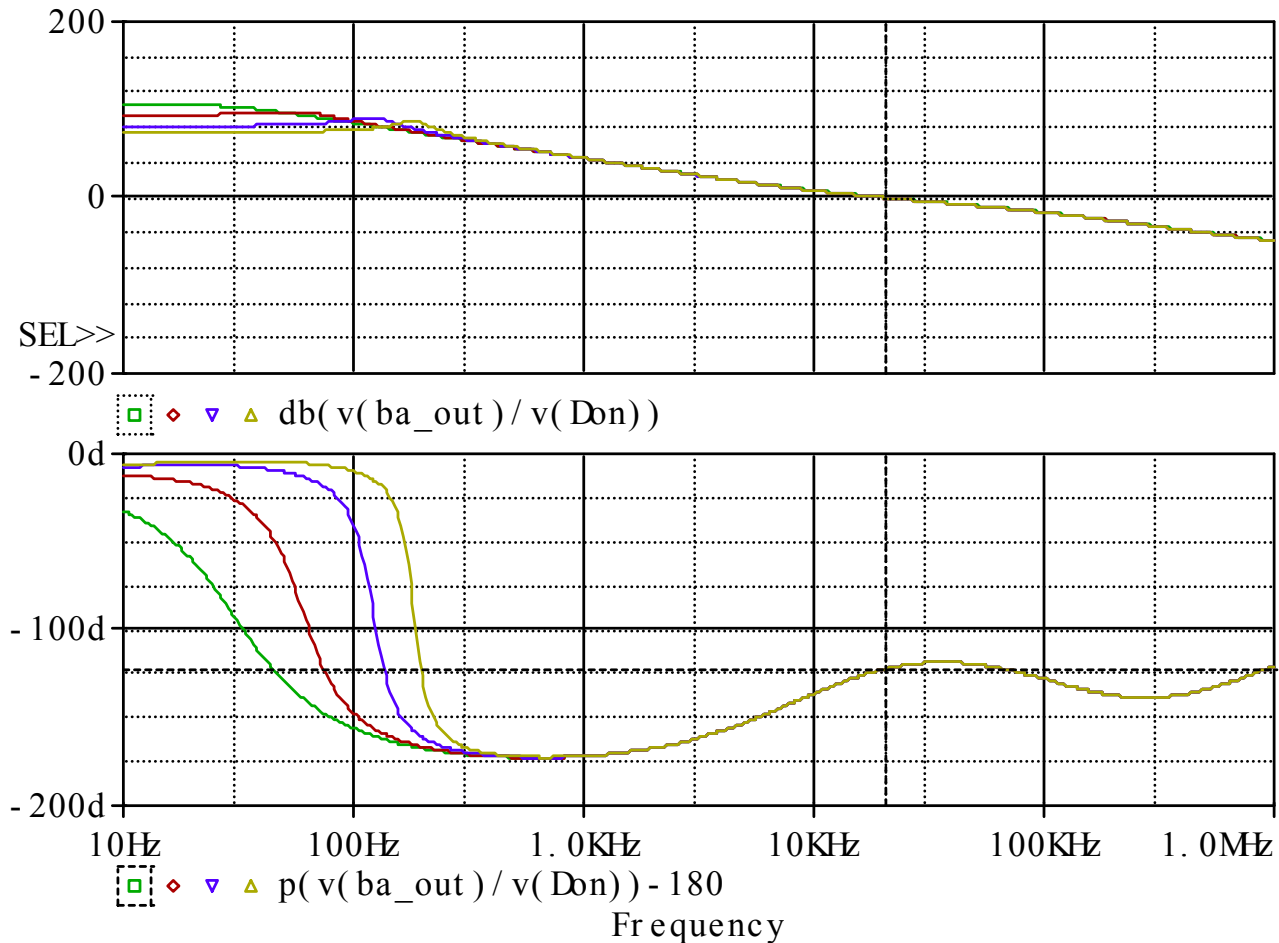
$P_{out}=250W$, Slew Rate= $160V/mS$

Input Voltage Step Response: 115Vrms to 230Vrms



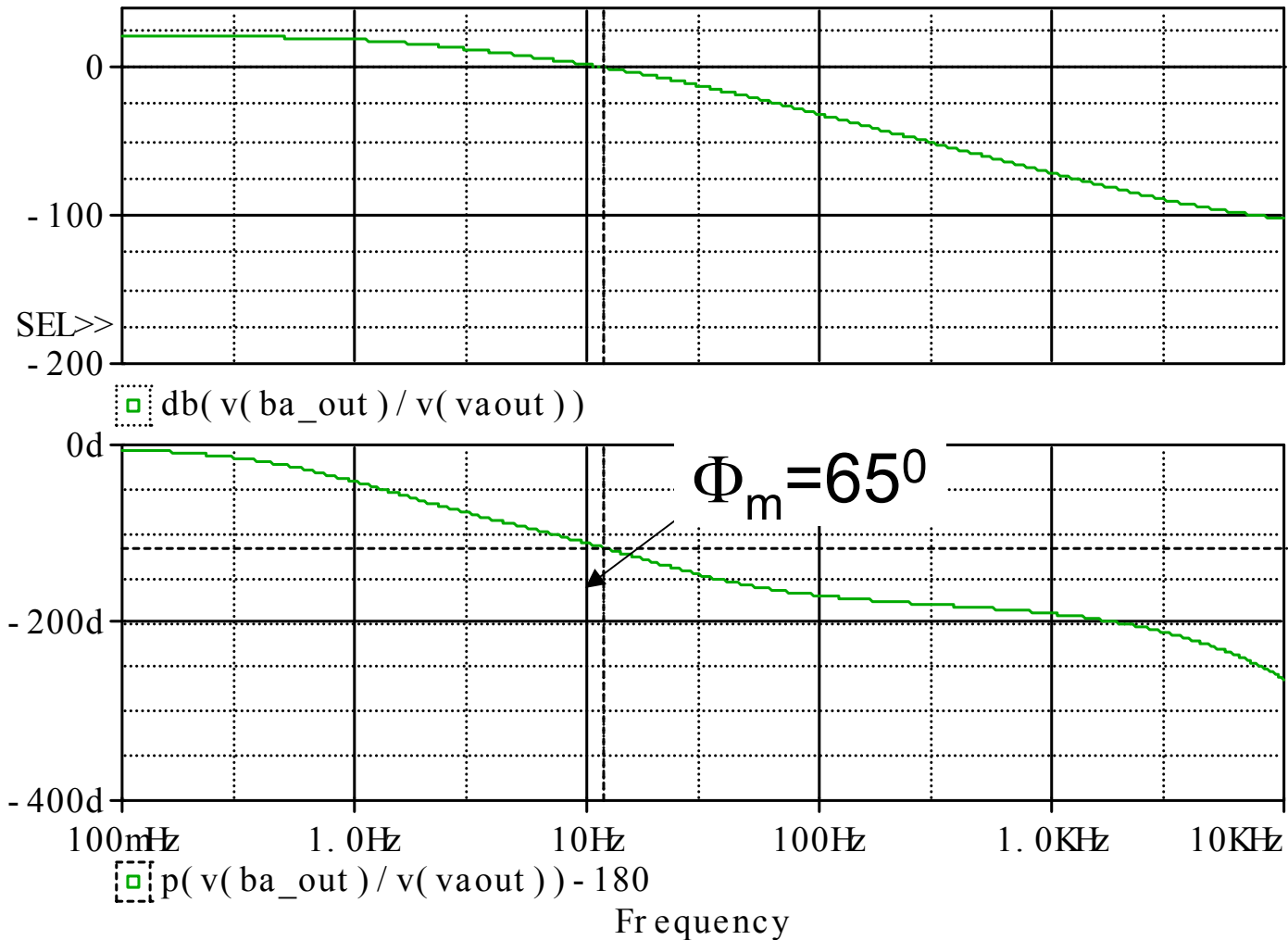
Pout=250W, Slew Rate=160V/mS

Current Loop Gain at Different Input Voltages

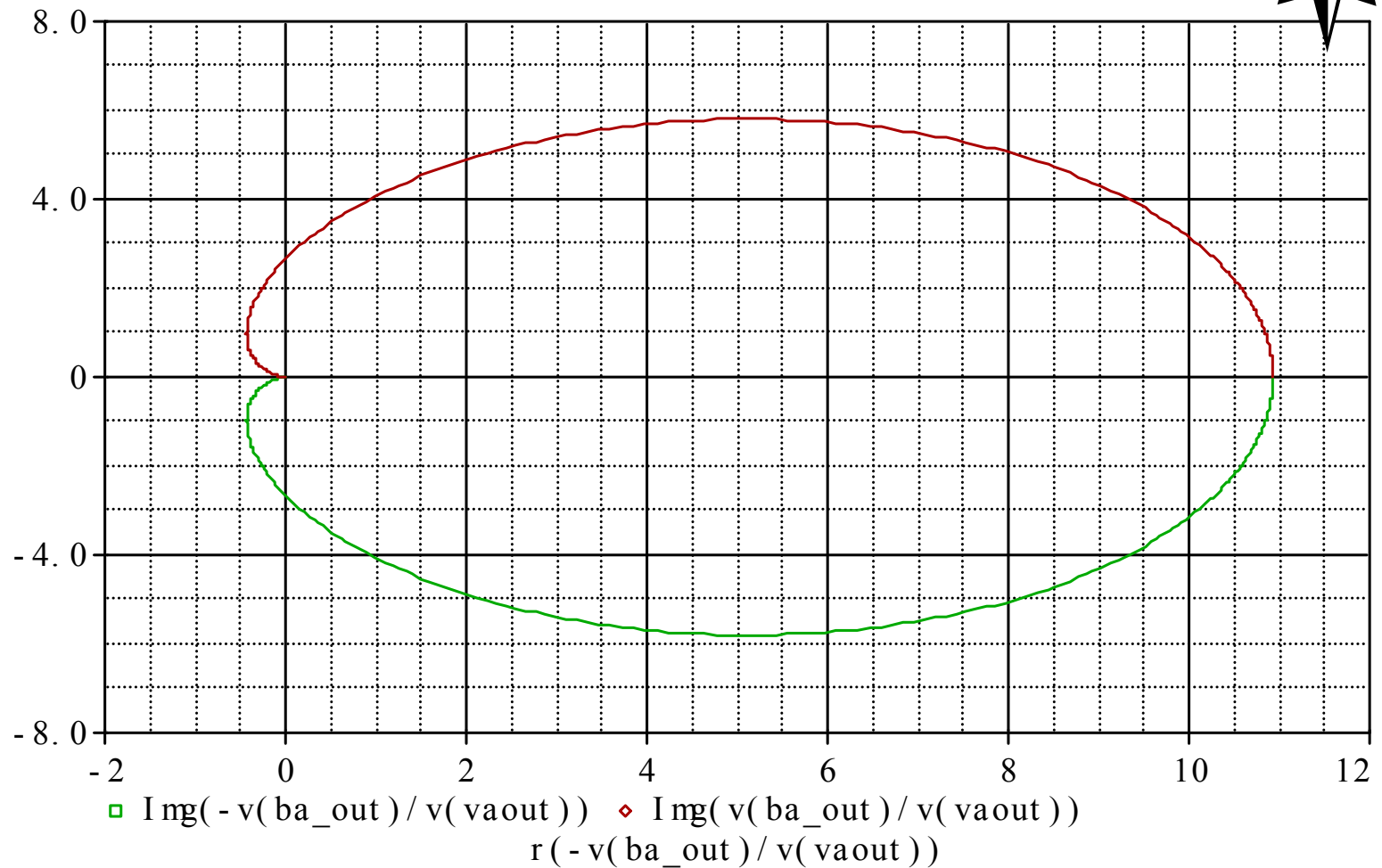
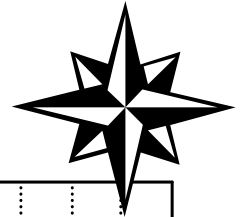


$V_{in} = 50V, 100V, 200V, 300V$

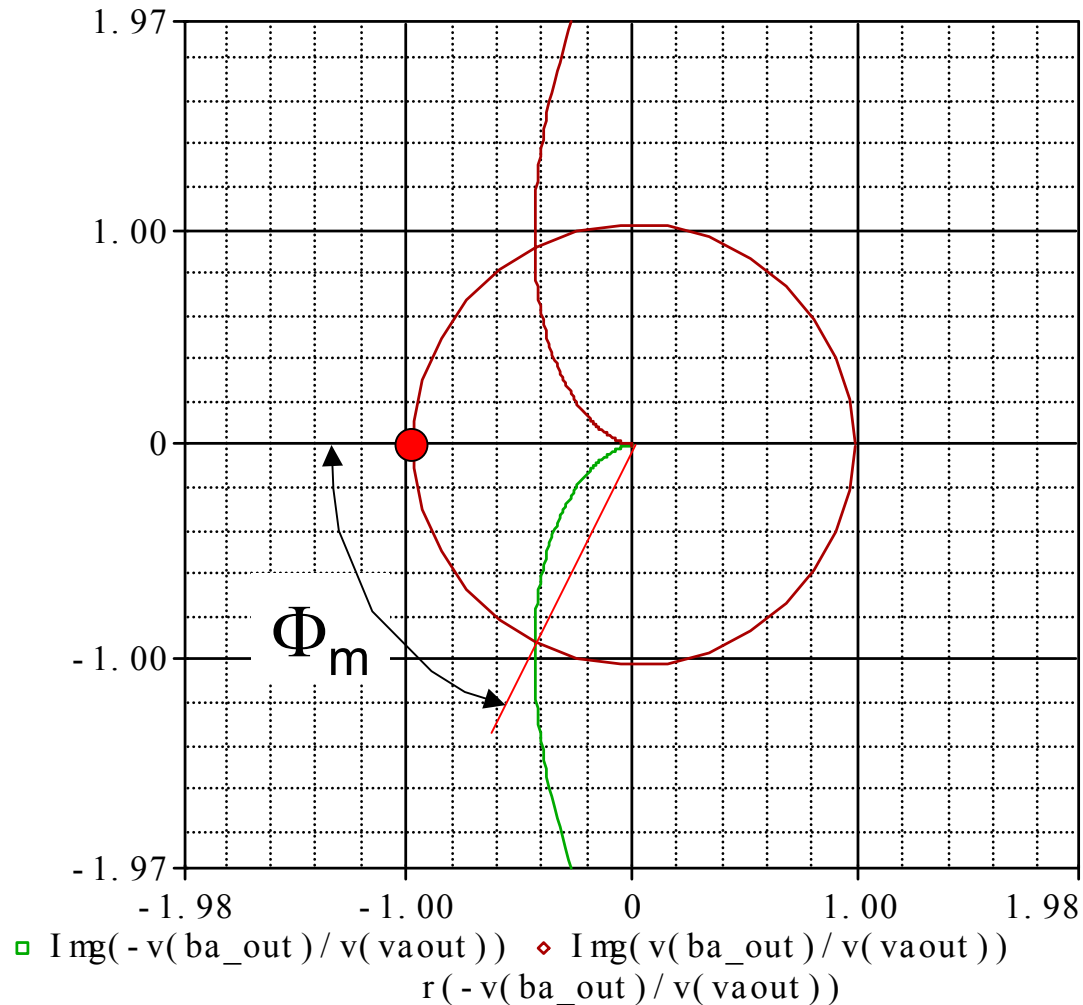
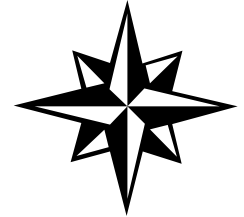
Loop Gain of Voltage Control Loop



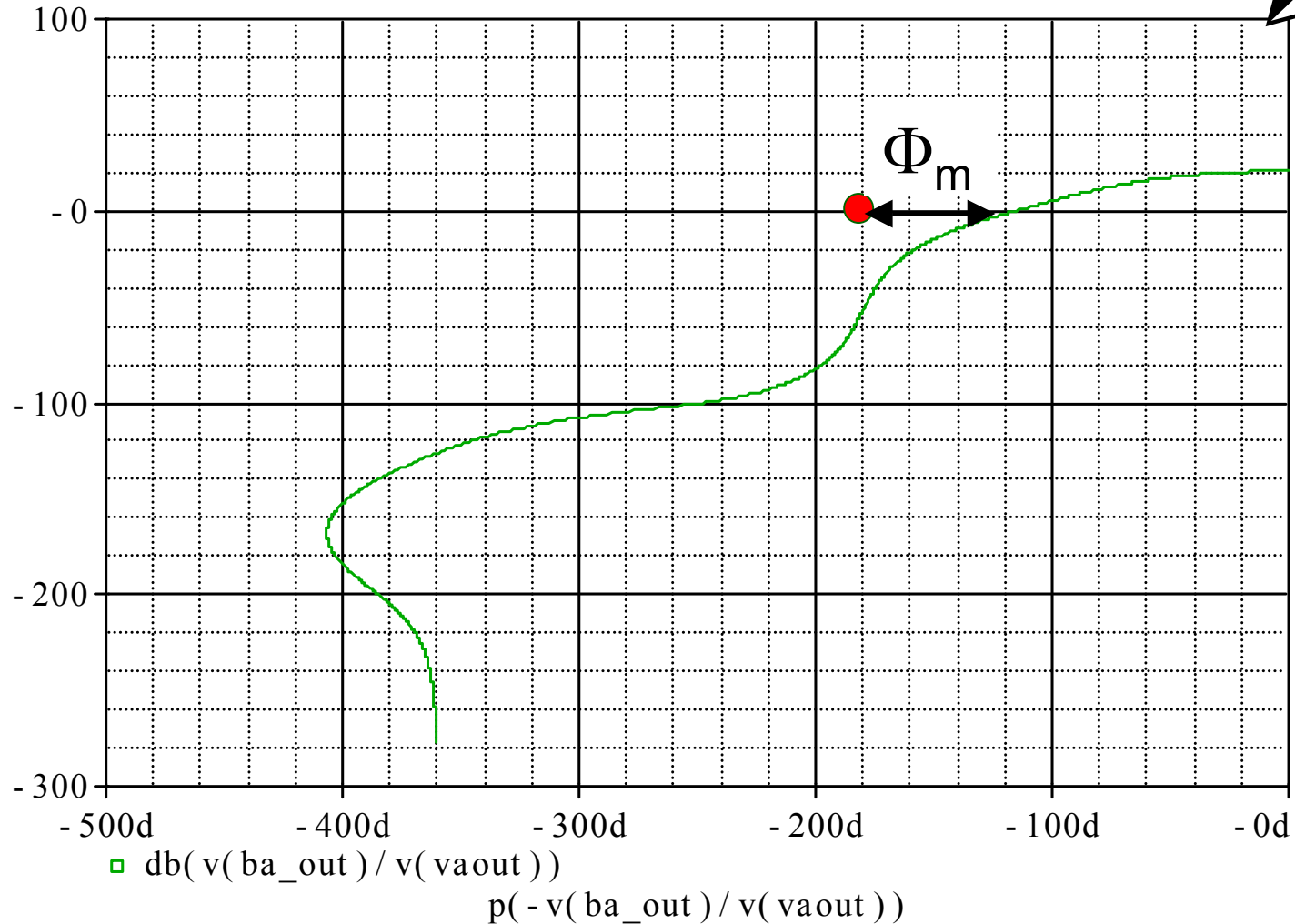
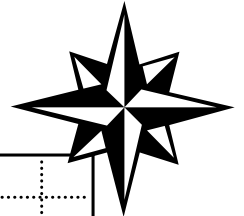
Nyquist Plot



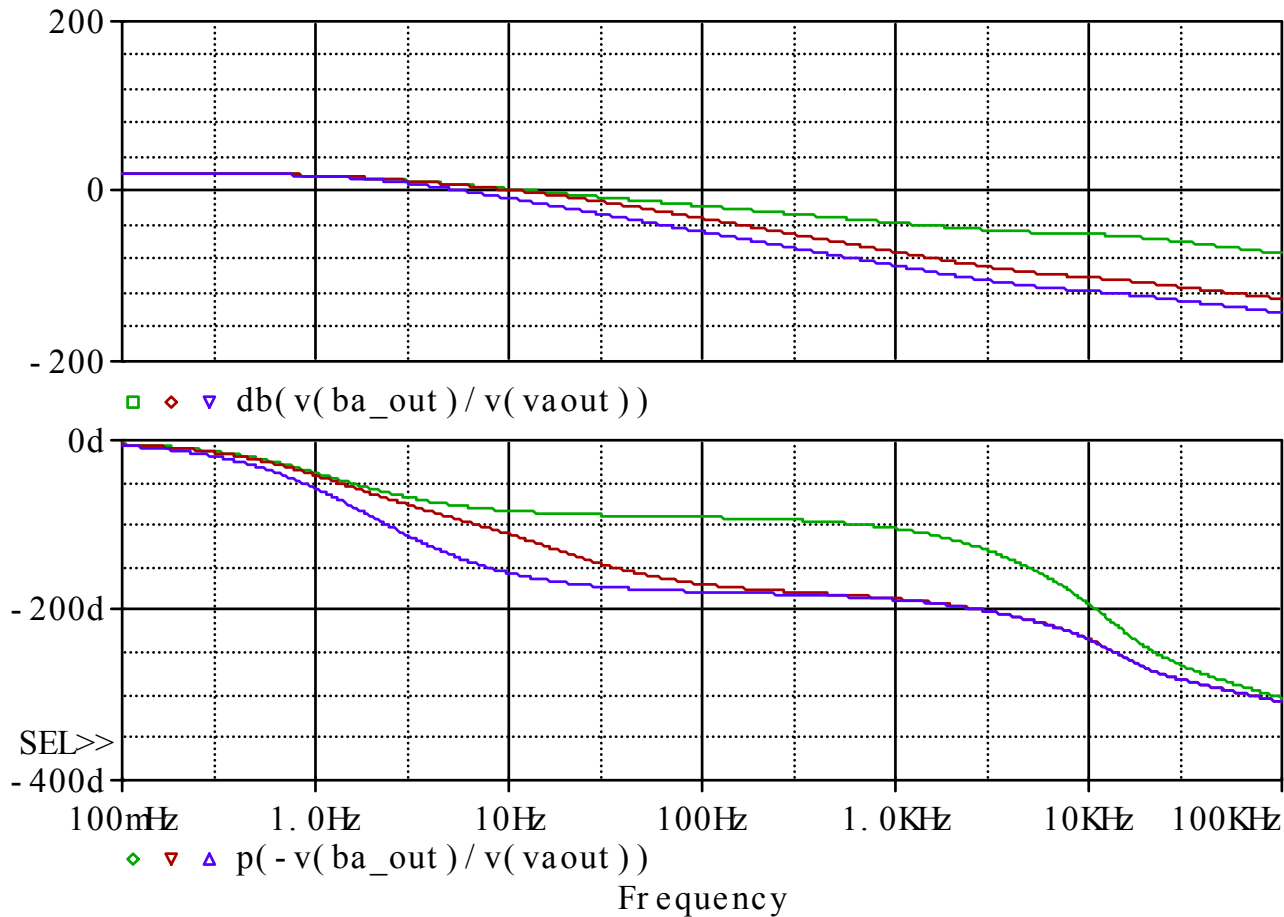
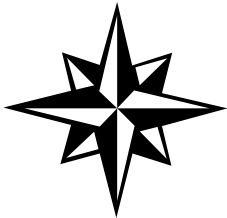
Nyquist Plot (zoom in)



Nichols Chart

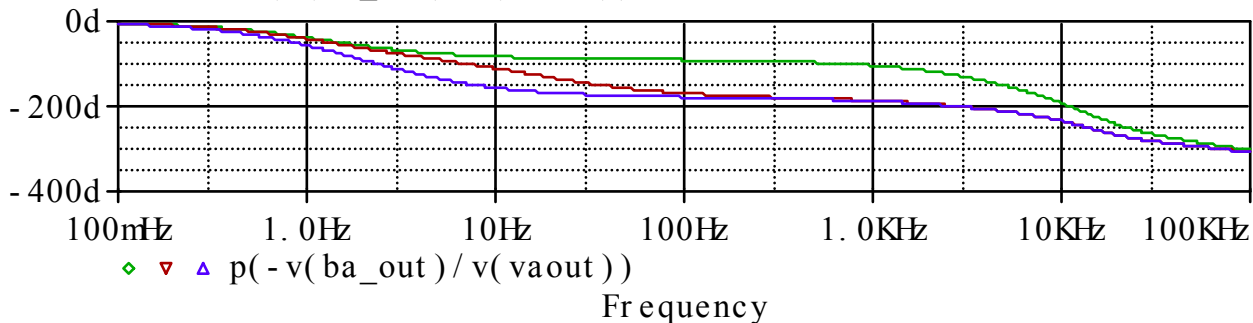
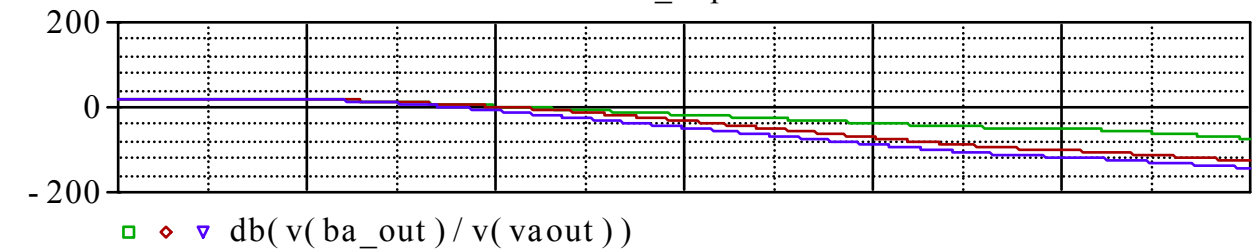
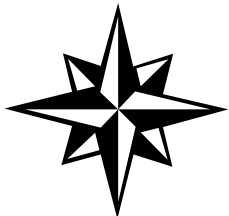
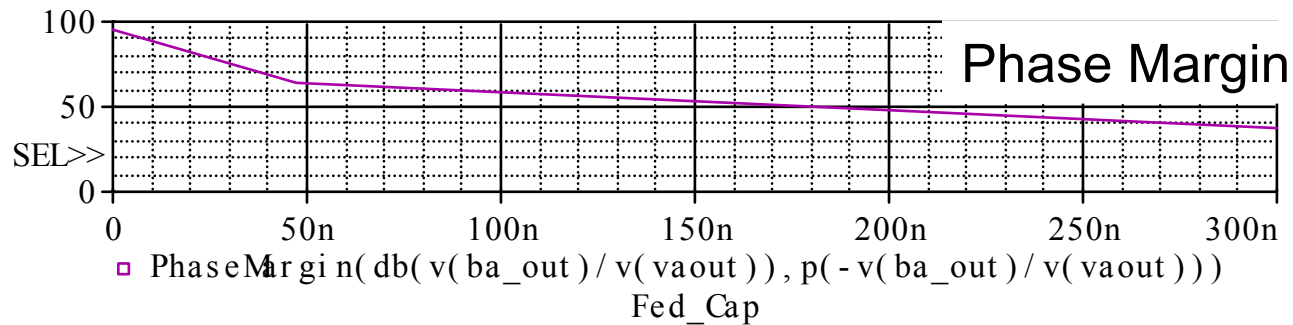


Implications of Compensation Capacitor



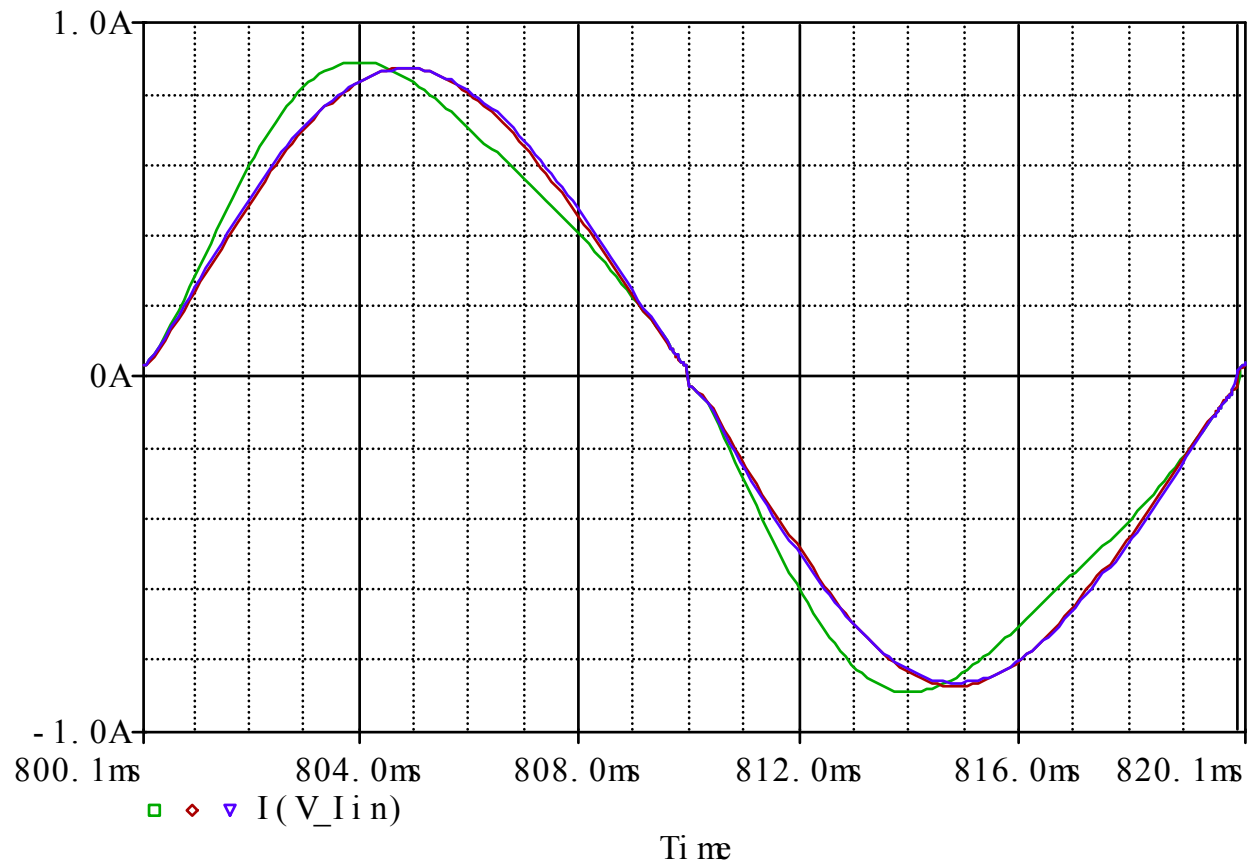
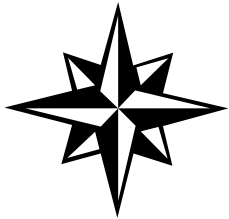
$C_v = 0.1nF, 47nF, 300nF$

Implications of Compensation Capacitor



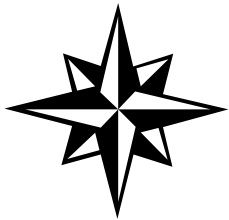
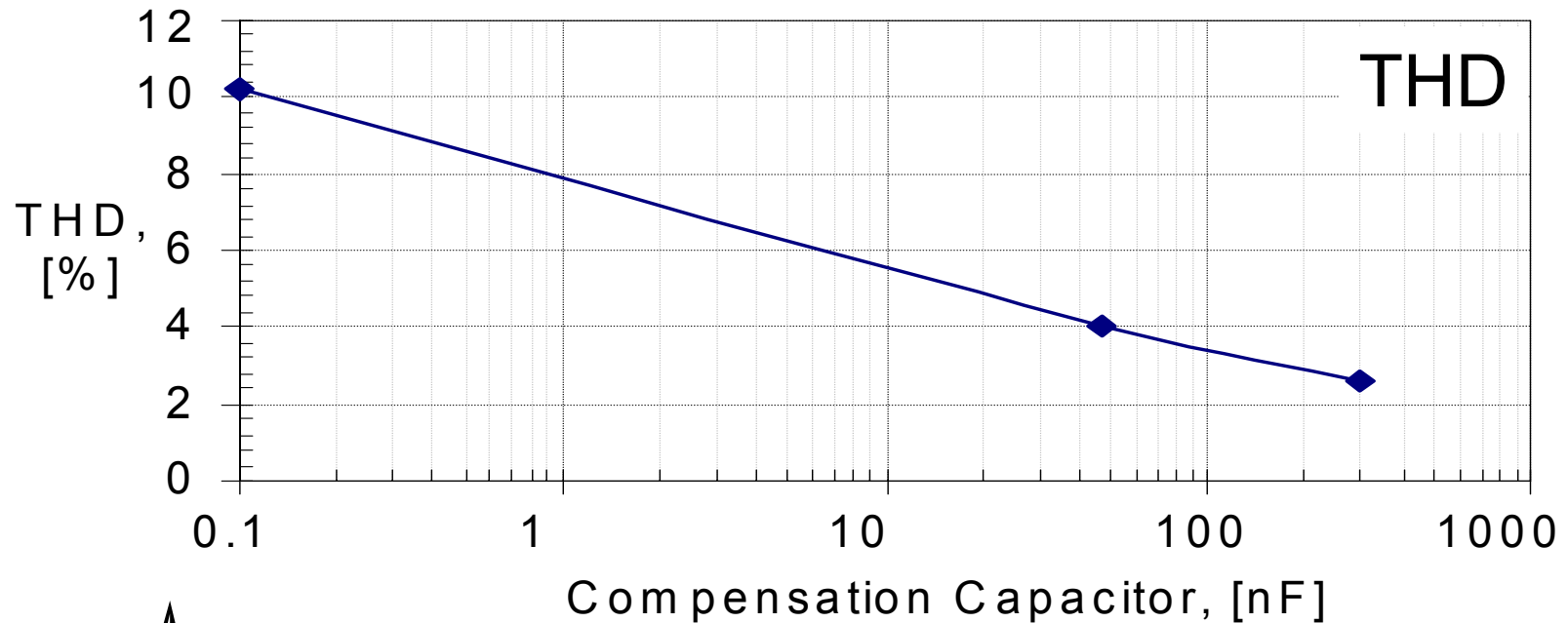
$C_vf = 0.1\text{nF}, 47\text{nF}, 300\text{nF}$

Implications of Compensation Capacitor



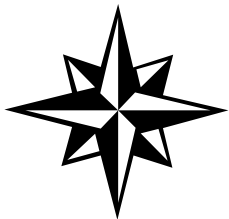
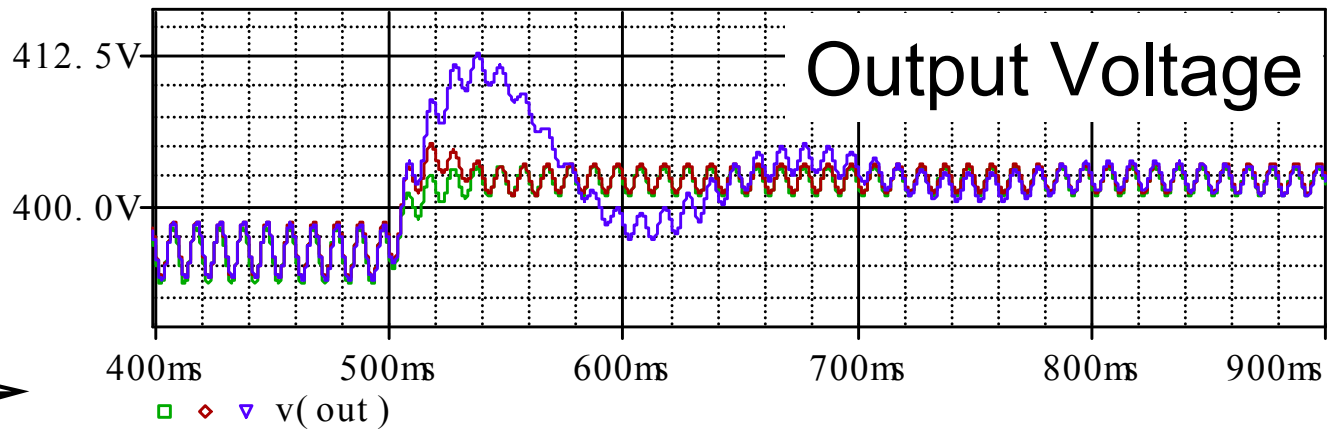
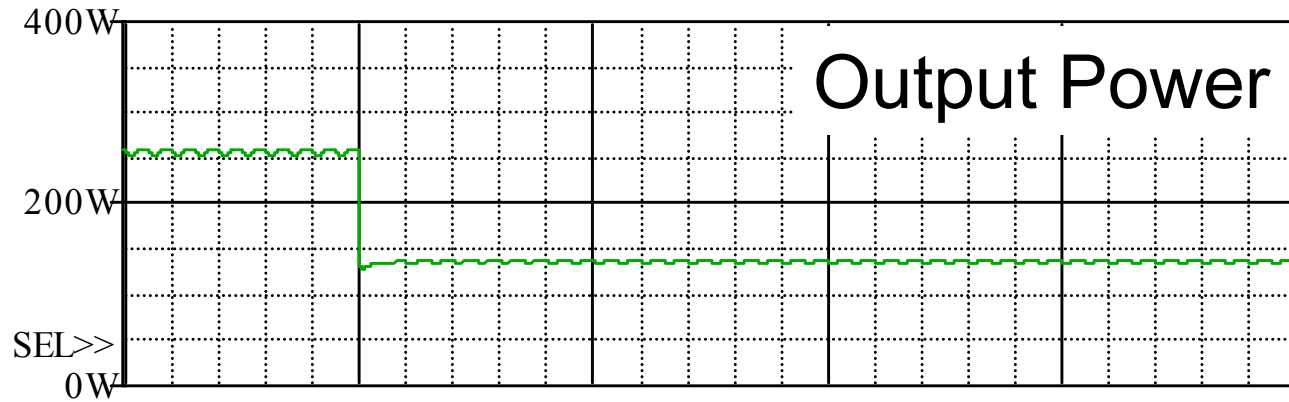
$C_v f = 0.1\text{nF}, 47\text{nF}, 300\text{nF}$

Implications of Compensation Capacitor



$C_v = 0.1\text{nF}, 47\text{nF}, 300\text{nF}$

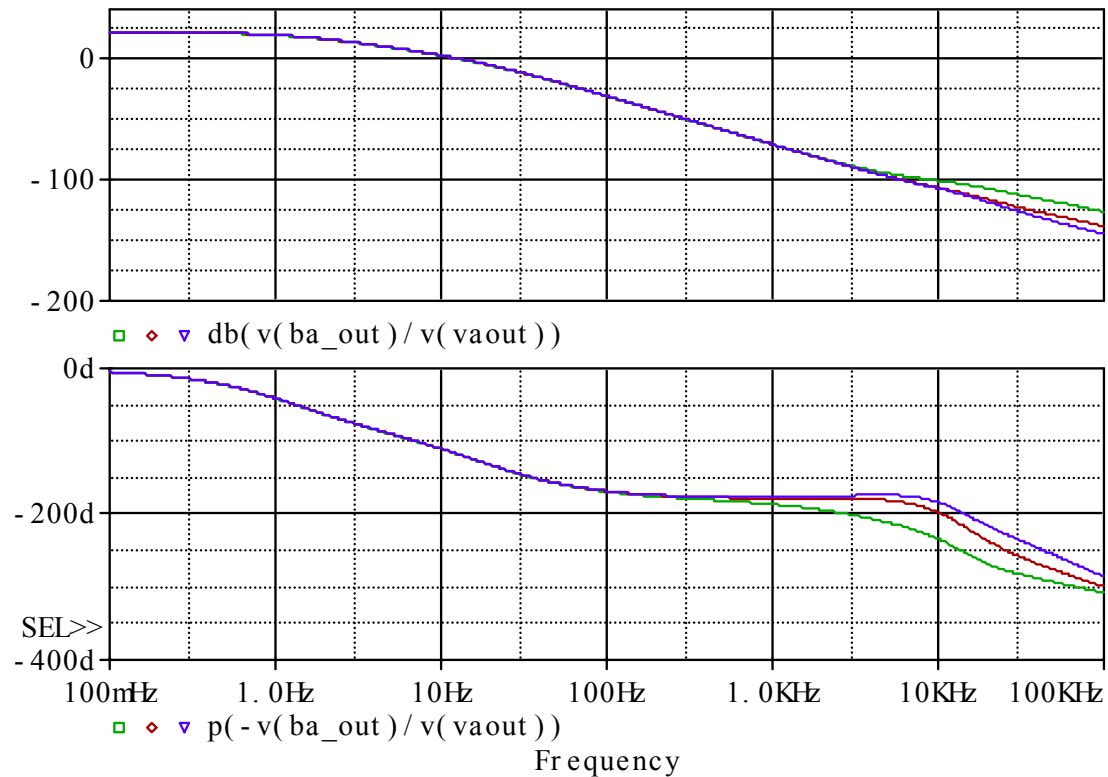
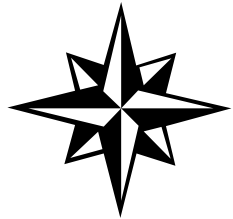
Implications of Compensation Capacitor



Time

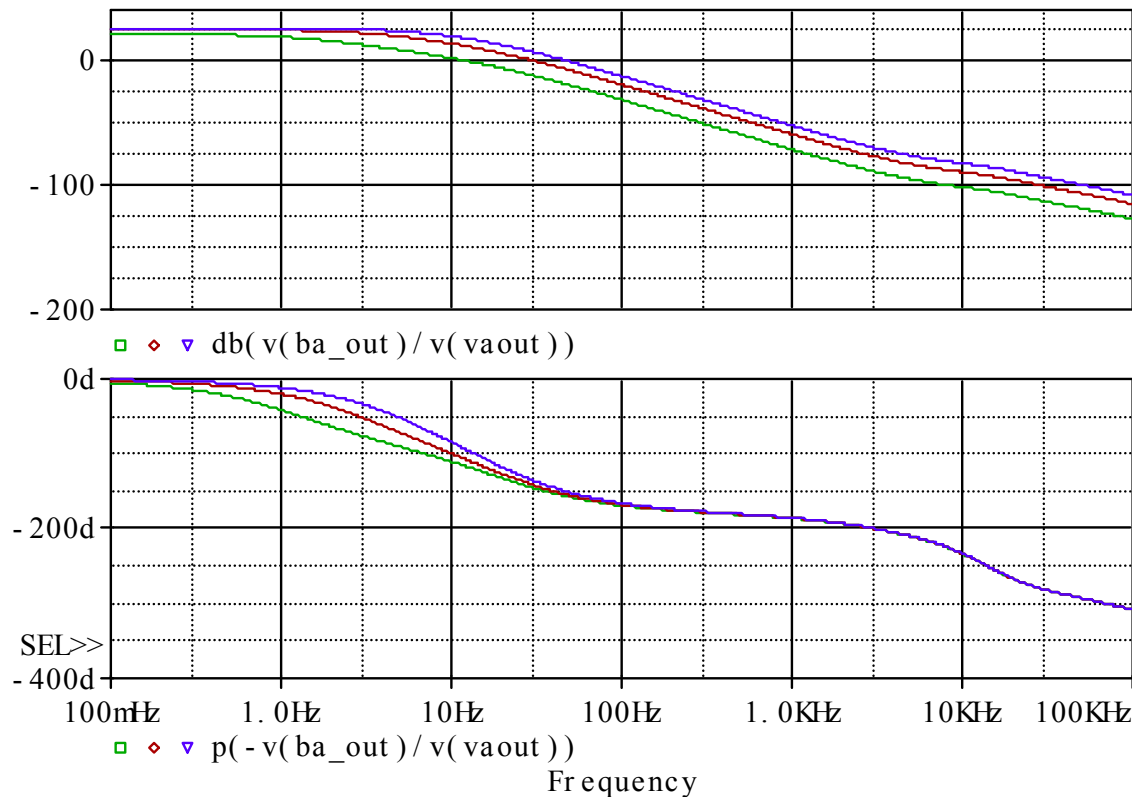
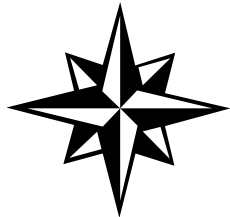
$C_v = 0.1\text{nF}, 47\text{nF}, 300\text{nF}$

Voltage Loop Gain at Different Input Voltages



$V_{in}=100V, 200V, 300V$ with feedforward

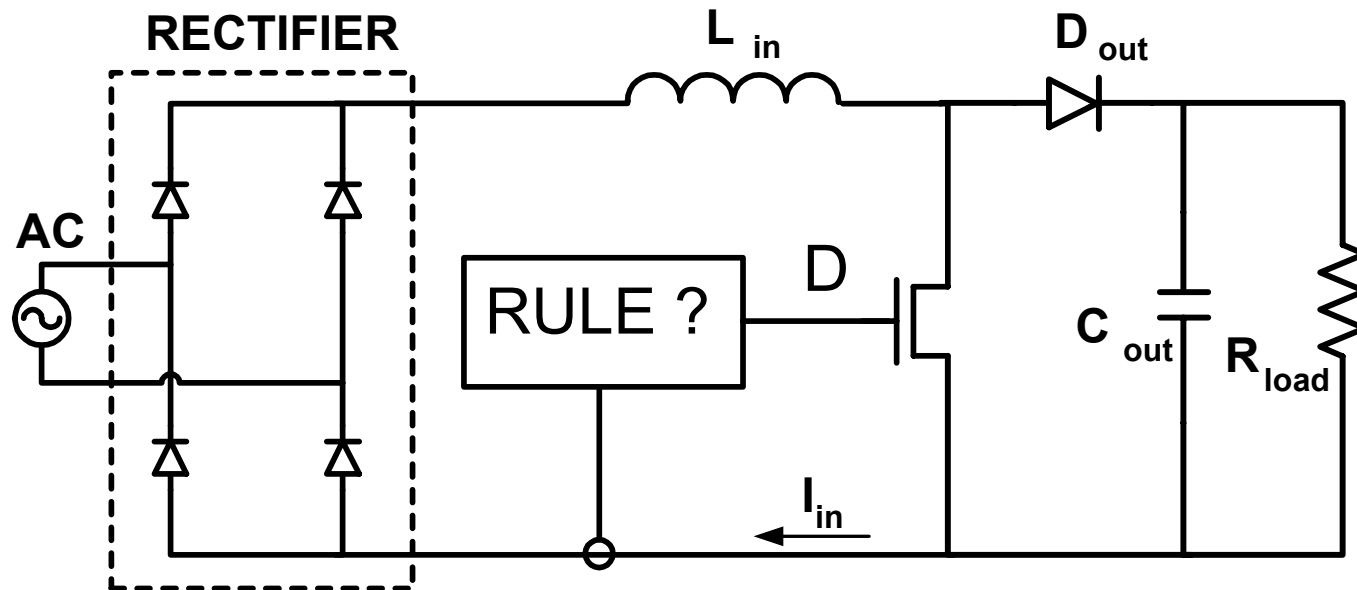
Voltage Loop Gain at Different Input Voltages



$V_{in} = 100V, 200V, 300V$ without feedforward

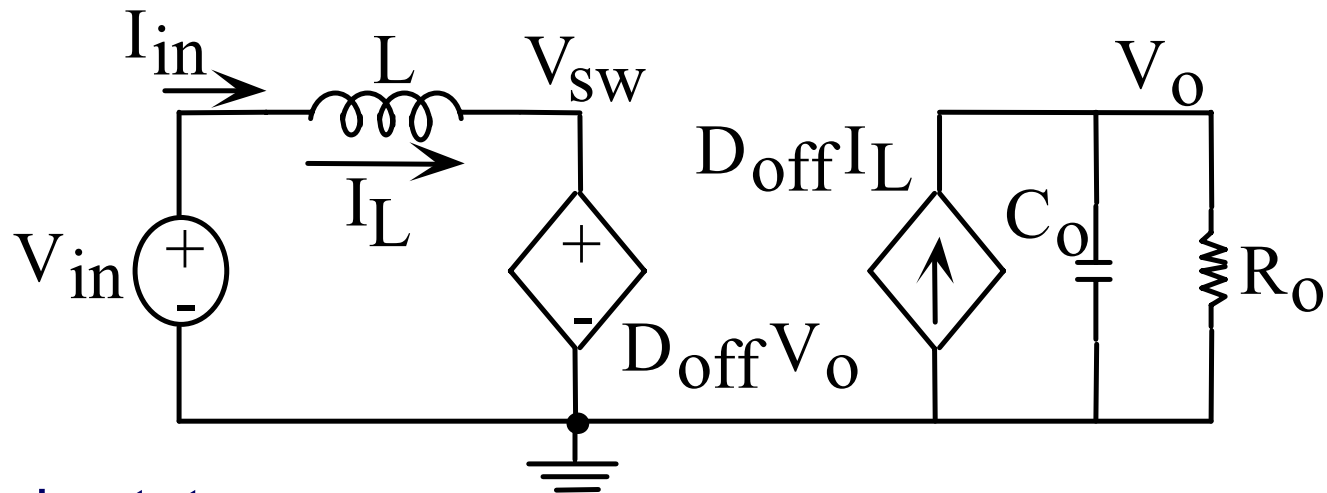
CCM APFC Control with no Sensing of Input Voltage

The Concept



Programming Rule Derivation

Average Model



In steady state,
the average voltage across the inductor is zero:

$$\langle V_{in} \rangle = \langle V_{SW} \rangle = D_{off} \langle V_o \rangle$$

$\langle S \rangle$ – low frequency component (average over one switching cycle)

Programming Rule Derivation

In steady state,
the average voltage across the inductor is zero:

$$\langle V_{in} \rangle = D_{off} \langle V_o \rangle$$

$$\frac{\langle V_{in} \rangle}{\langle I_{in} \rangle} = R_e = \frac{D_{off} \langle V_o \rangle}{\langle I_L \rangle}$$

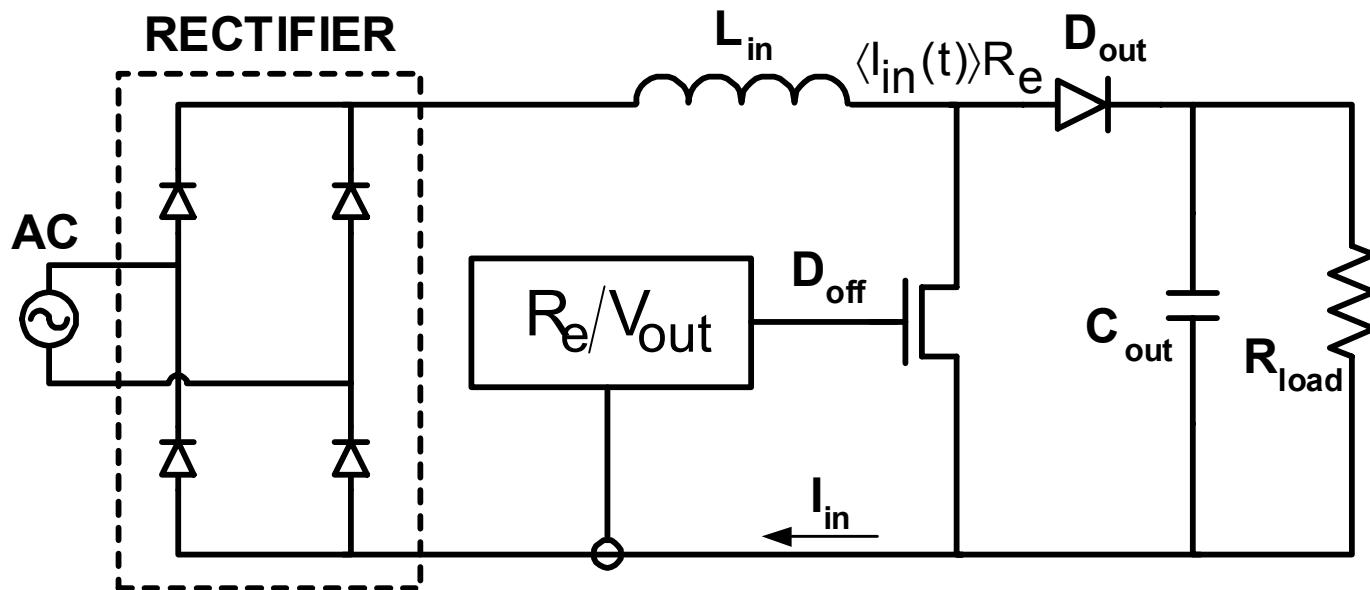
A resistive input will be observed if D_{off} is programmed according to the rule

$$D_{off} = \left(\frac{R_e}{\langle V_o \rangle} \right) \langle I_L \rangle, \quad 0 < D_{off} < 1$$

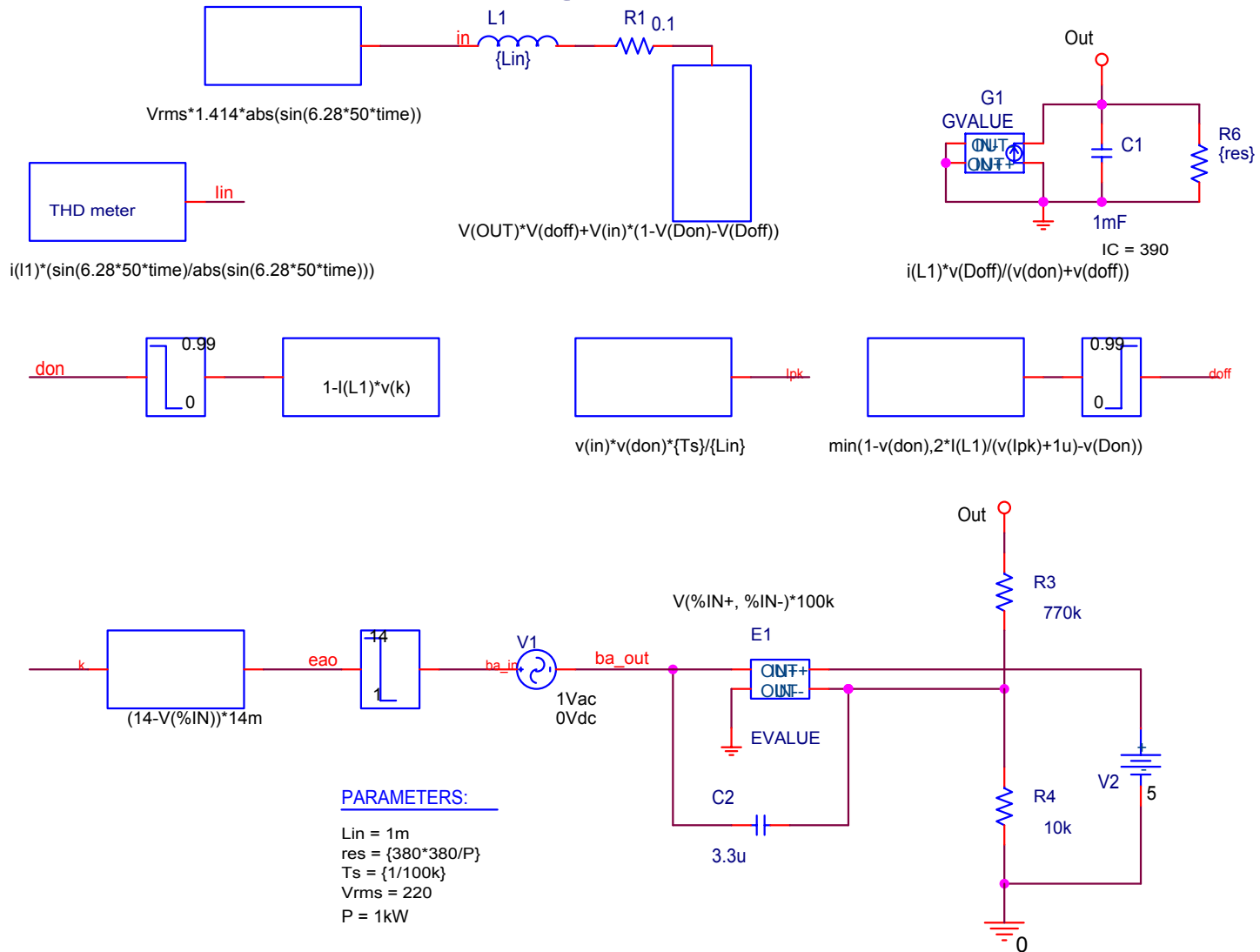
Loop Gain Derivation

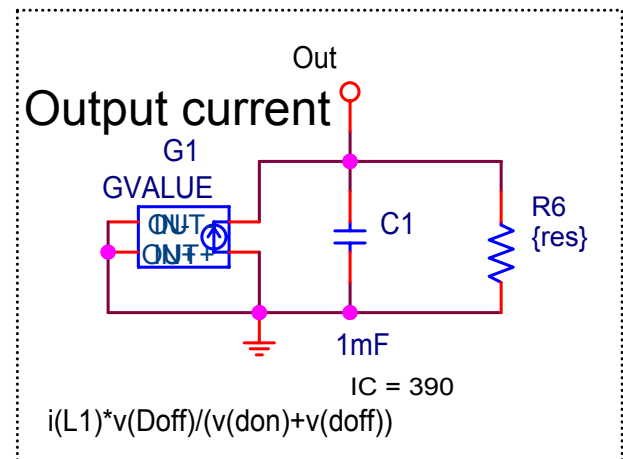
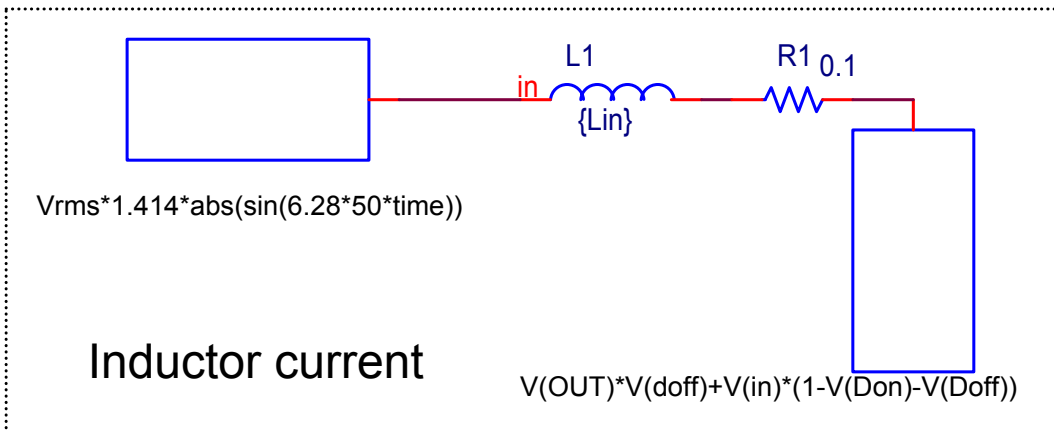
Control Law Implementation

$$D_{\text{off}}(t) = \left(\frac{R_e}{V_{\text{out}}} \right) \langle I_{\text{in}}(t) \rangle$$

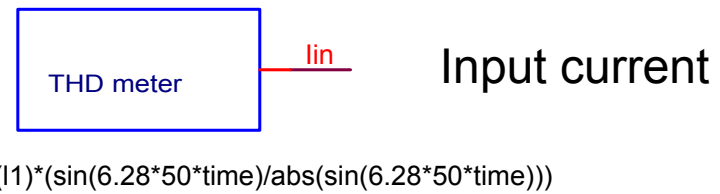
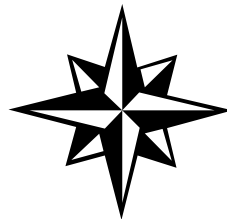
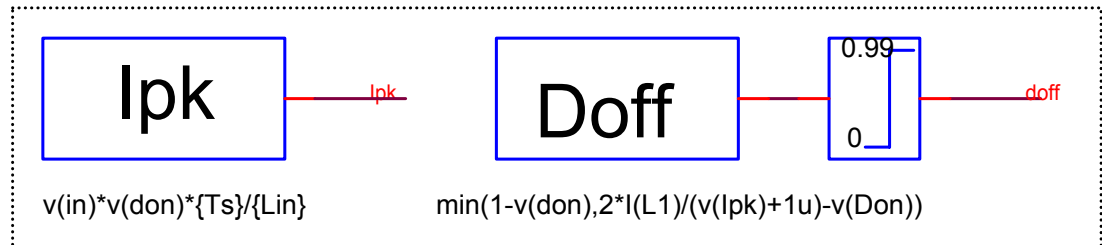
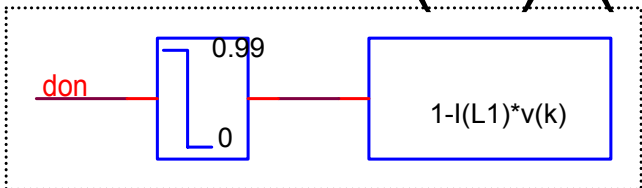


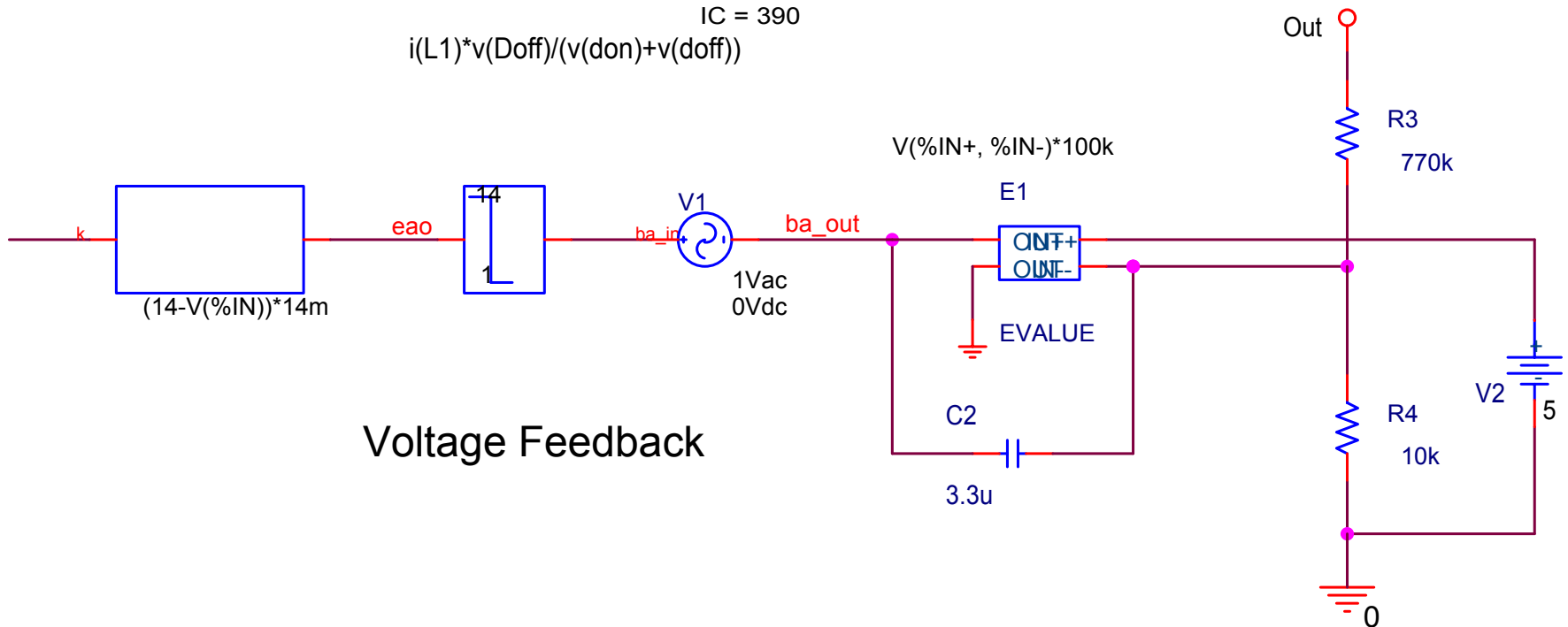
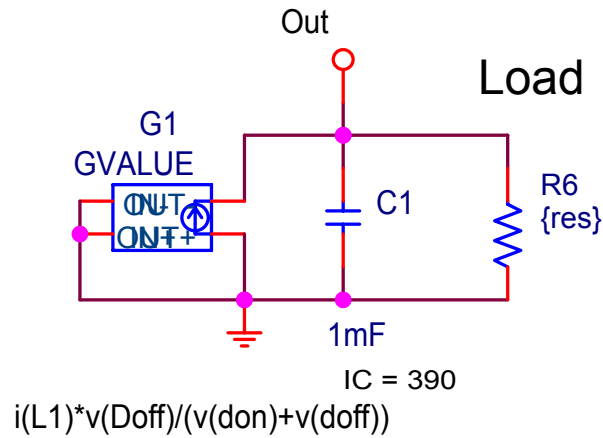
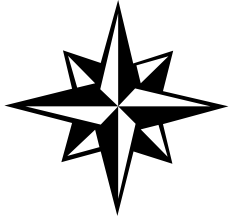
Average Model



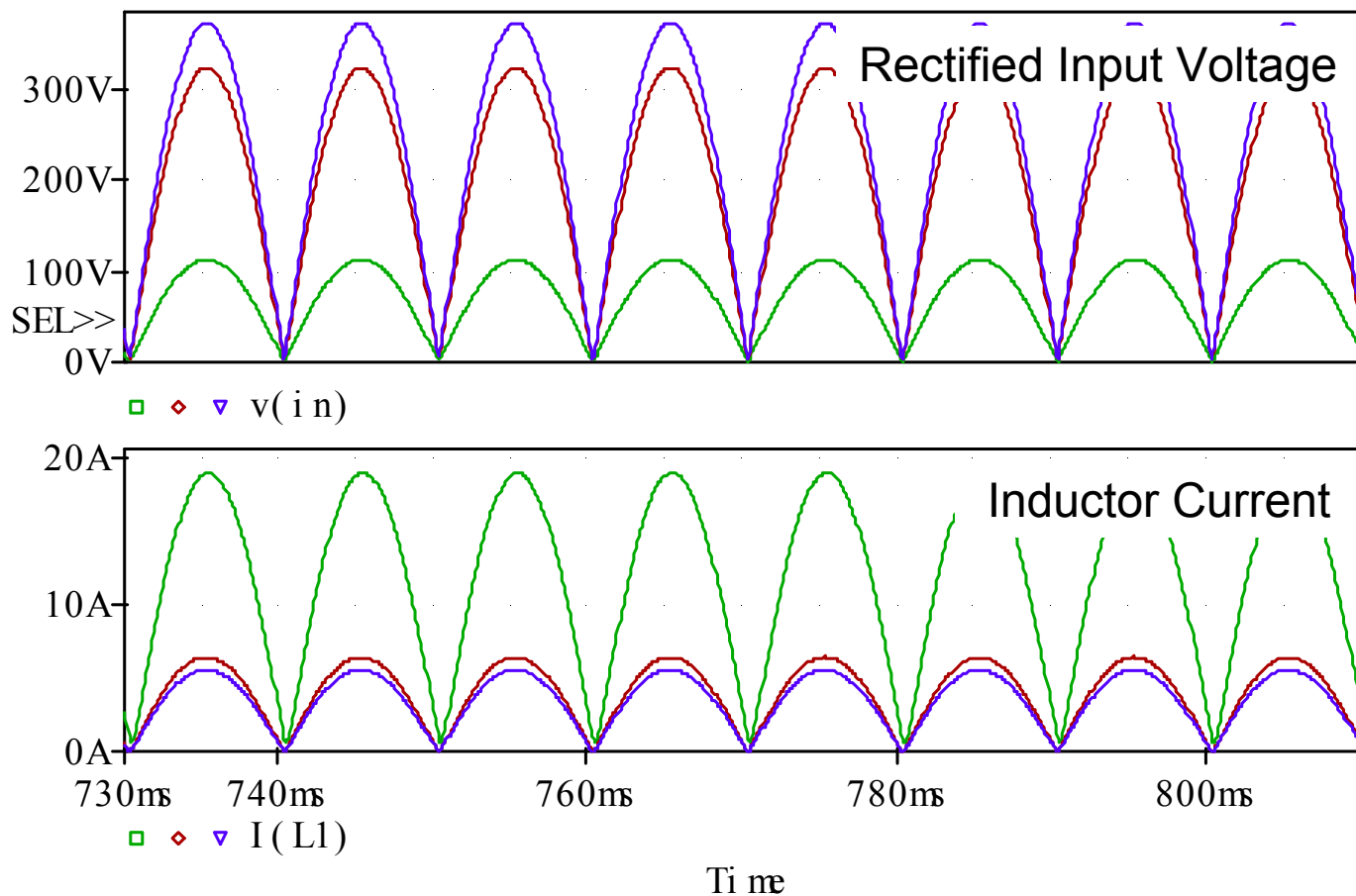


$D_{on} = 1 - I(L1)V(k)$



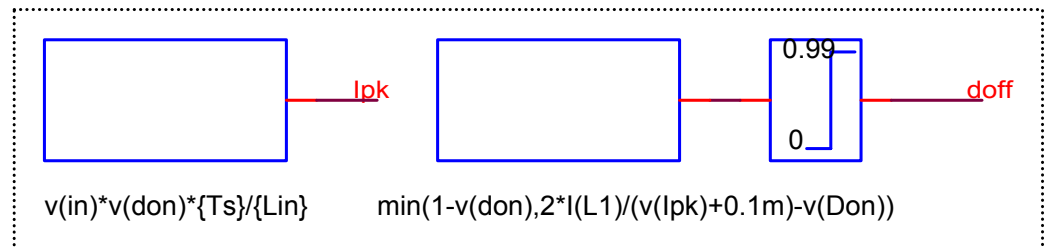
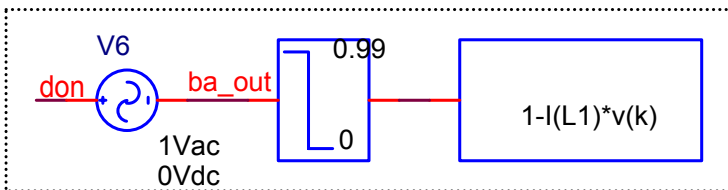
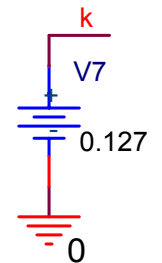
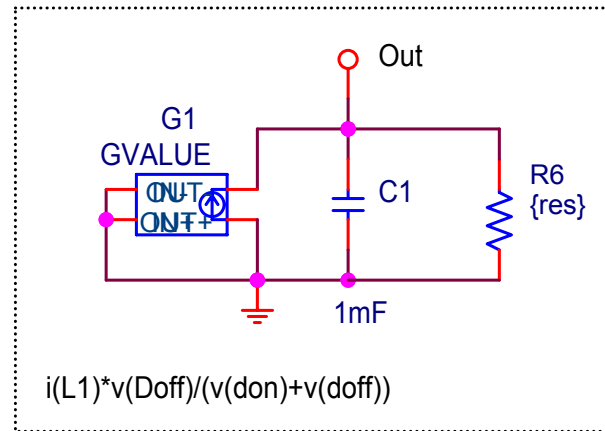
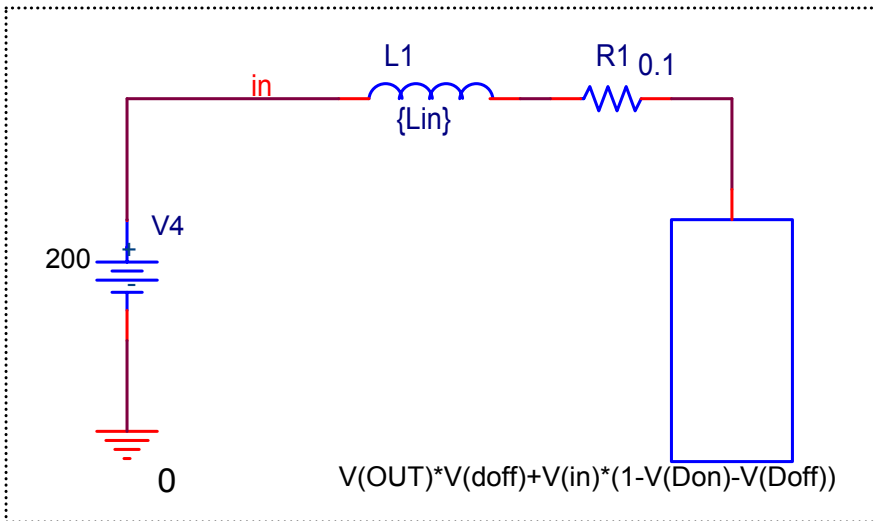
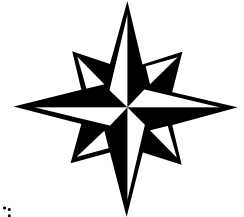


Input Behavior at Different Line Voltages

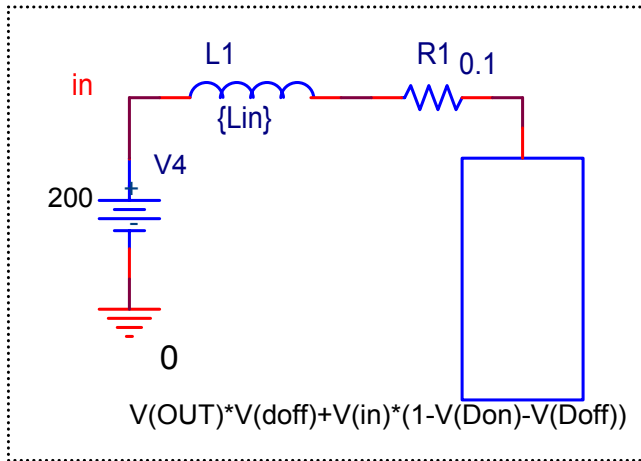


$P_{out}=1kW$, $V_{in}=80V_{rms}$, $230V_{rms}$, $265V_{rms}$

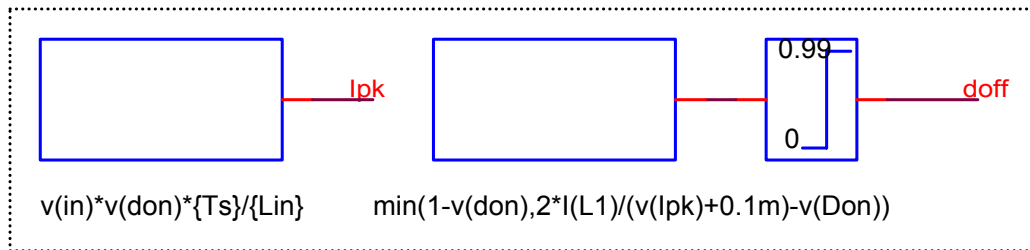
Current Loop



Current Loop

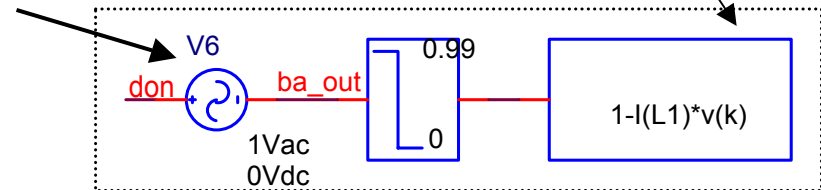


Input Inductor Section



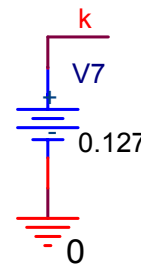
Doff Generator

Excitation

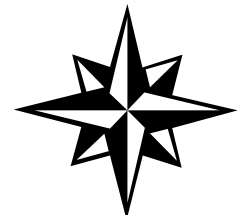


Multiplier

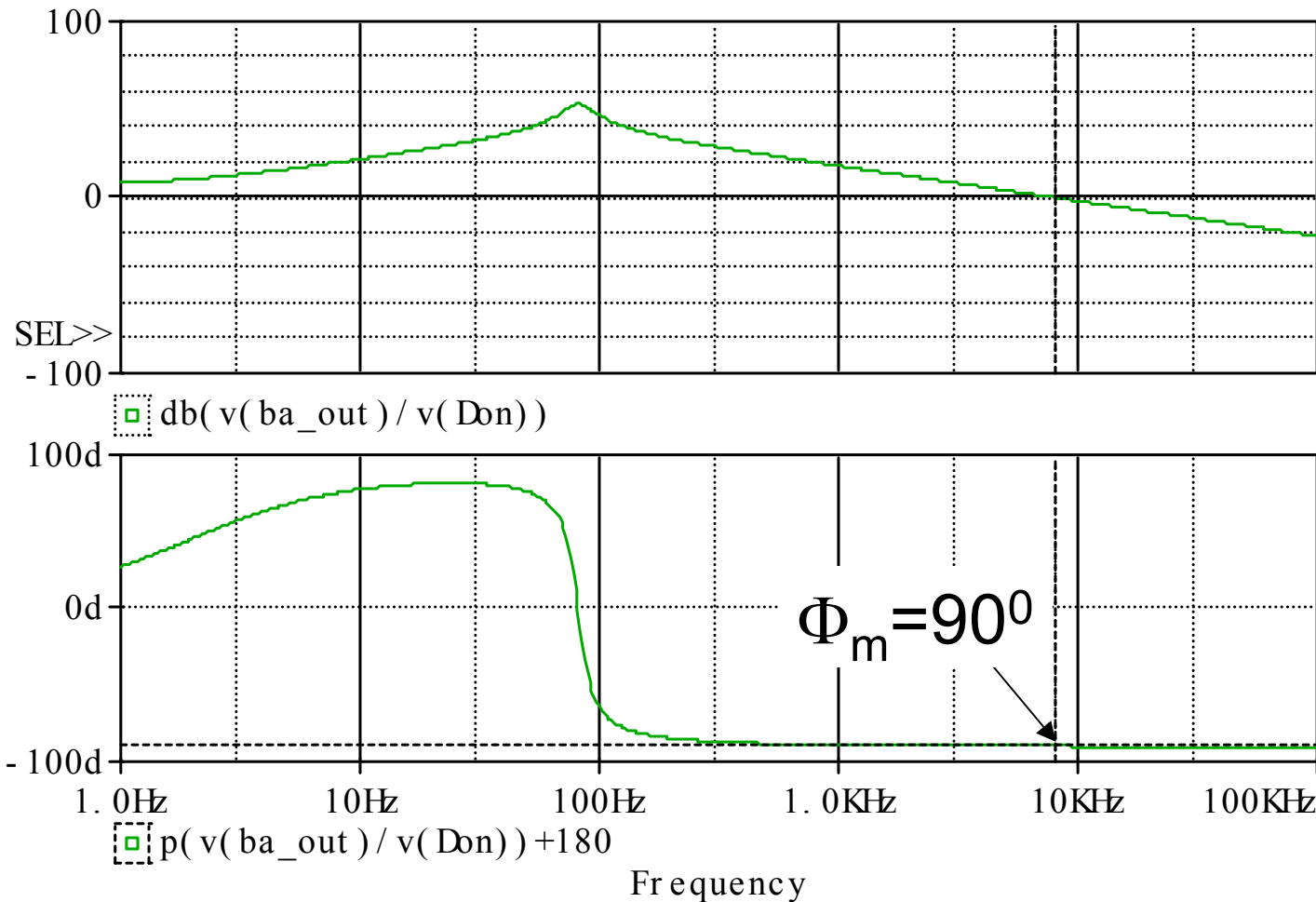
Don Generator



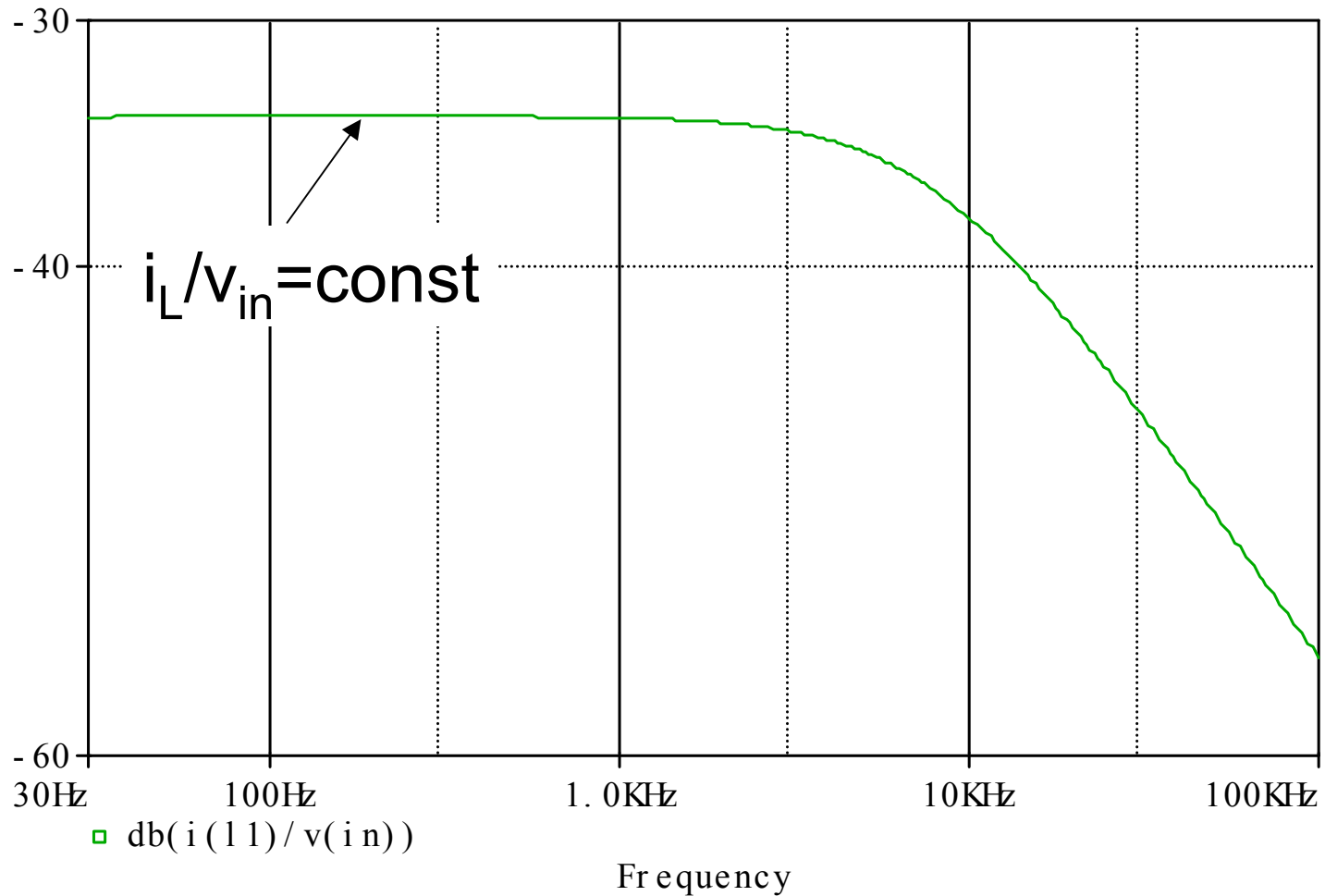
← Voltage error amplifier output is constant (open voltage loop)



Loop Gain of Current Control Loop



Current Loop Transfer Function



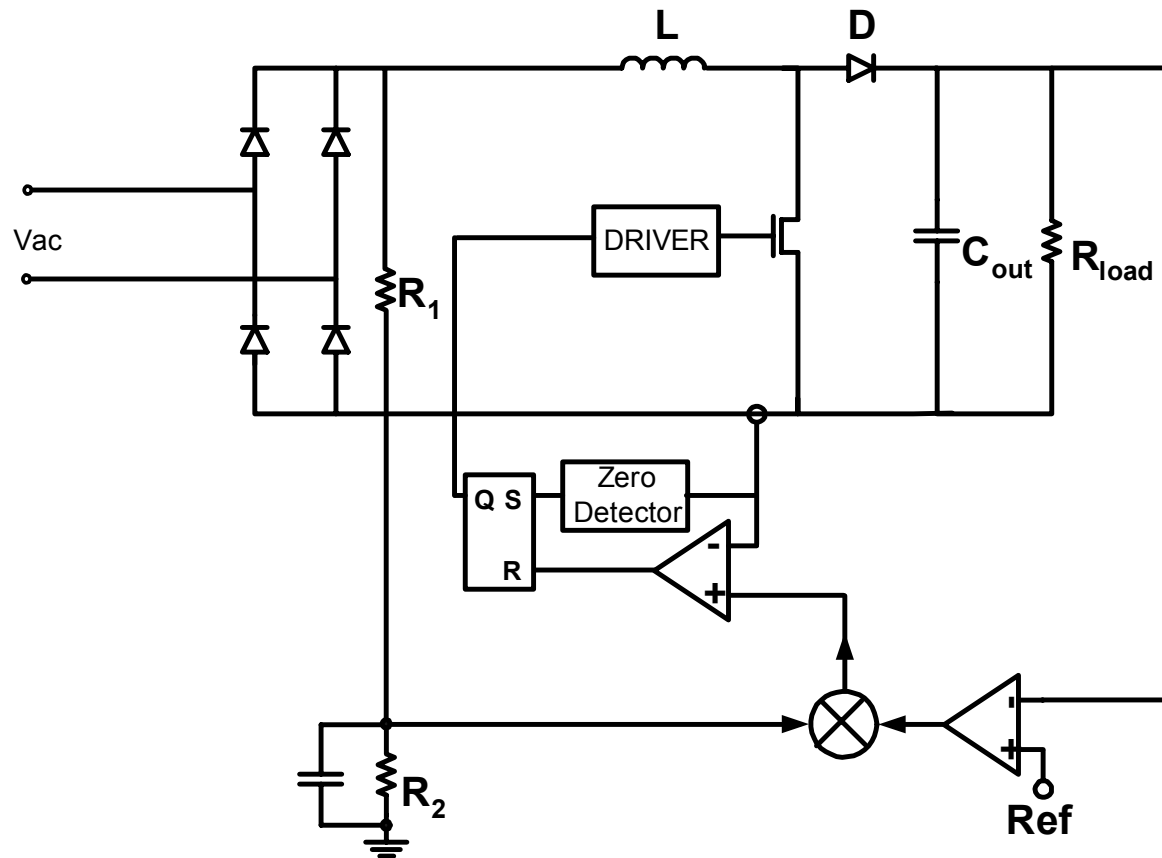
Live Simulation 2

- CCM APFC No sensing of input Voltage

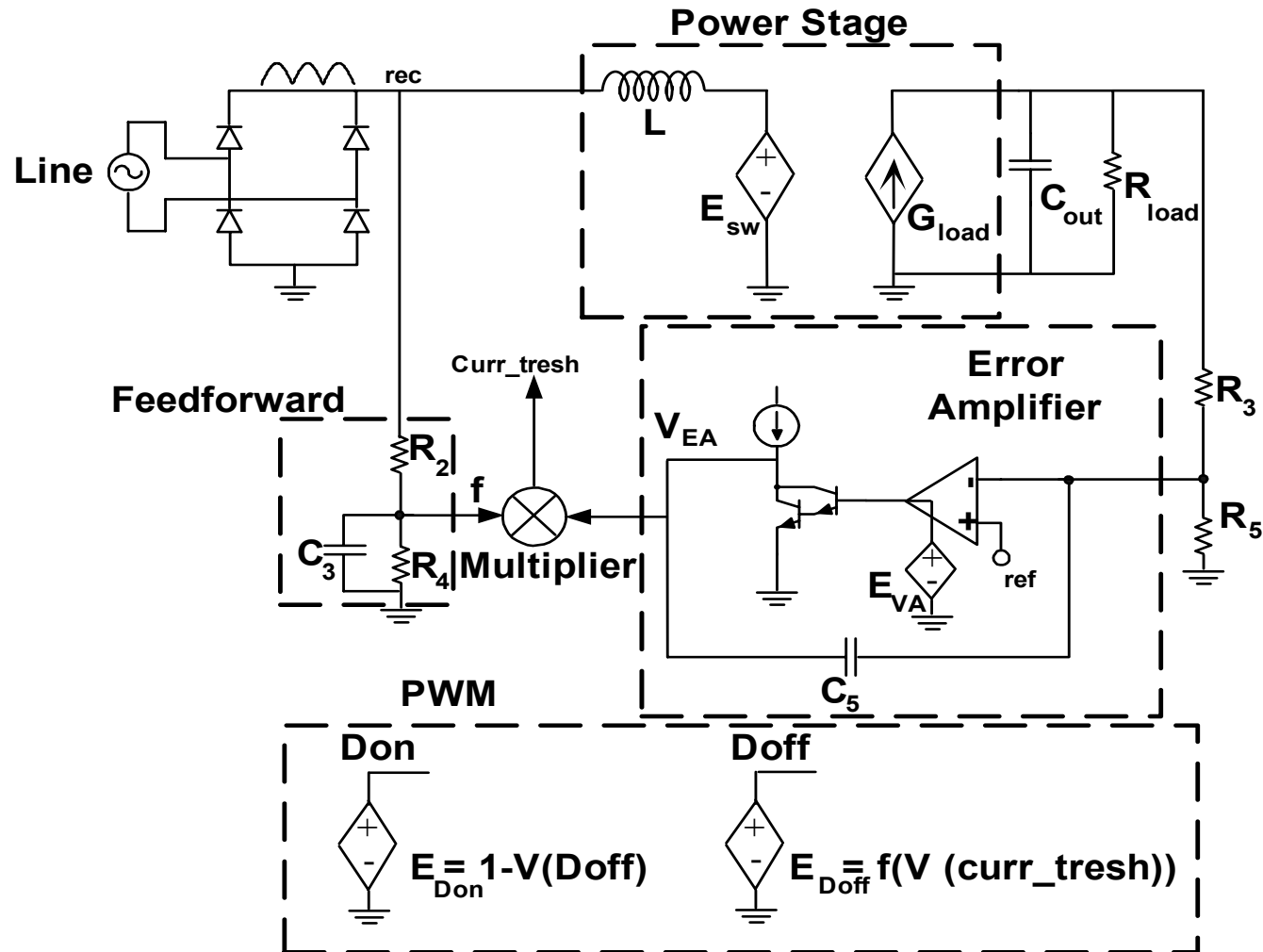


Critical Conduction Mode of Operation

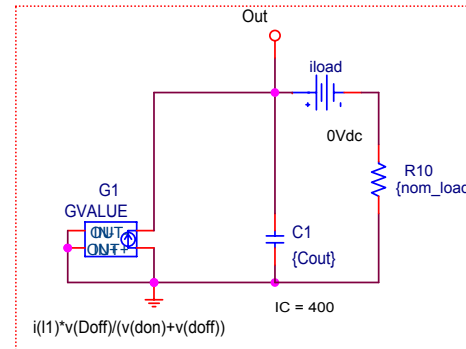
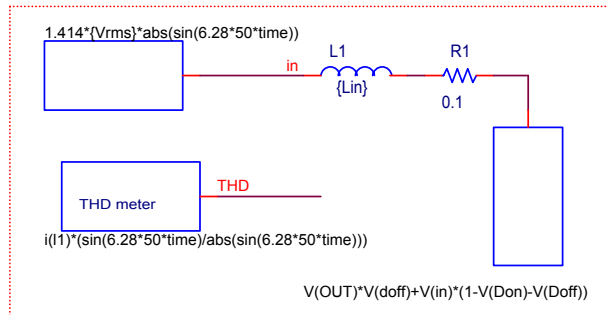
Conventional Border Line Control Method



MC34261 Based Average Model

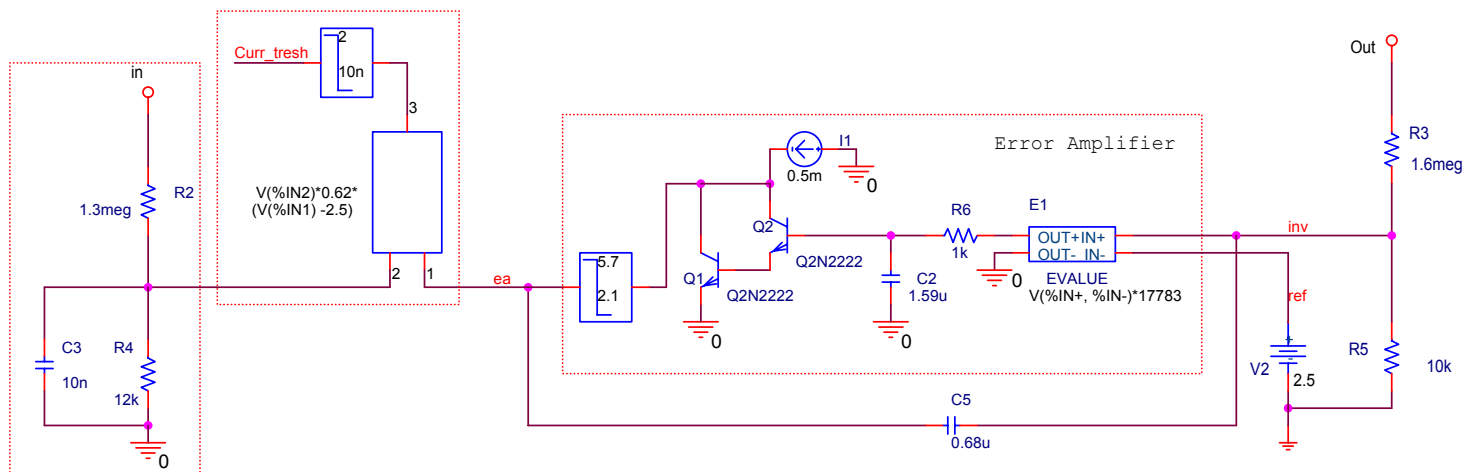


MC34261 Based Average Model

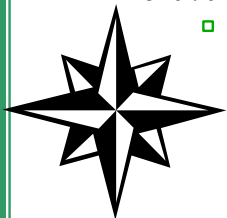
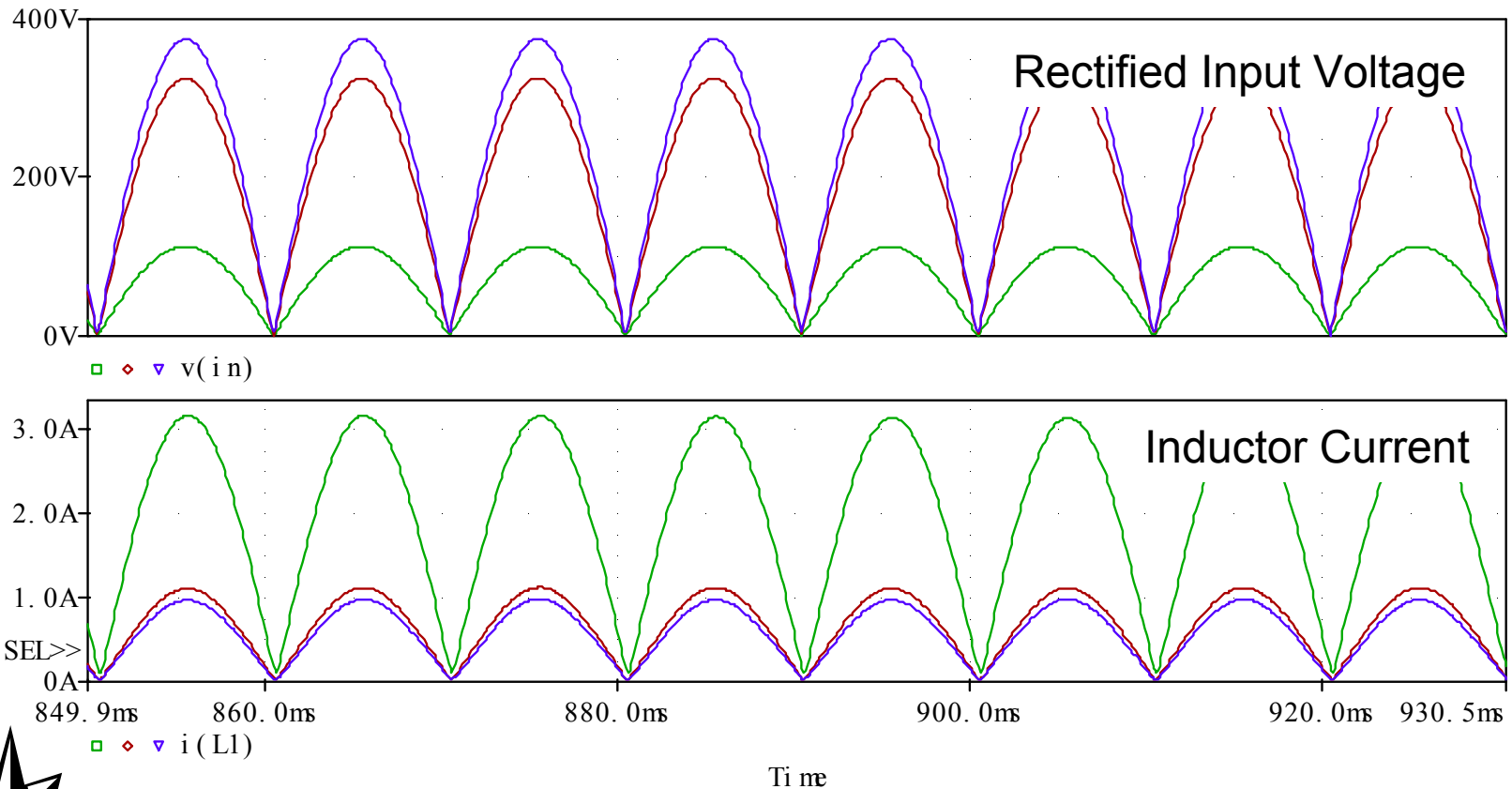


PARAMETERS:

$Lin = 0.87m$
 $V_{rms} = 220$
 $P = 175W$
 $Nom_load = \{Vo \cdot Vo / P\}$
 $R_{sense} = 0.1$
 $Cout = 180u$
 $Vo = 400$

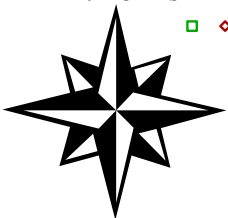
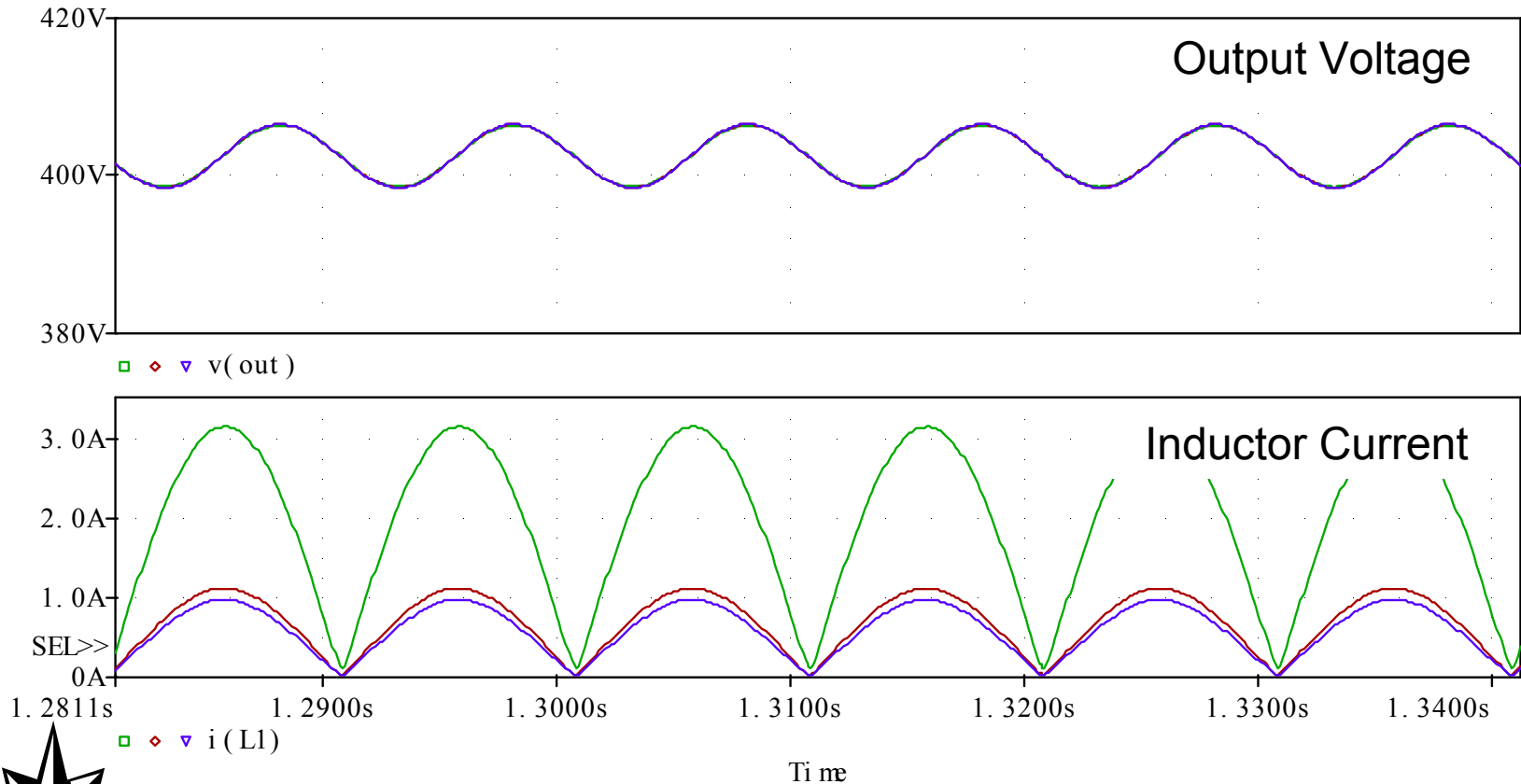


Input Behavior at Different Line Voltages



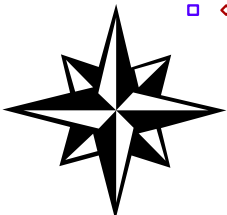
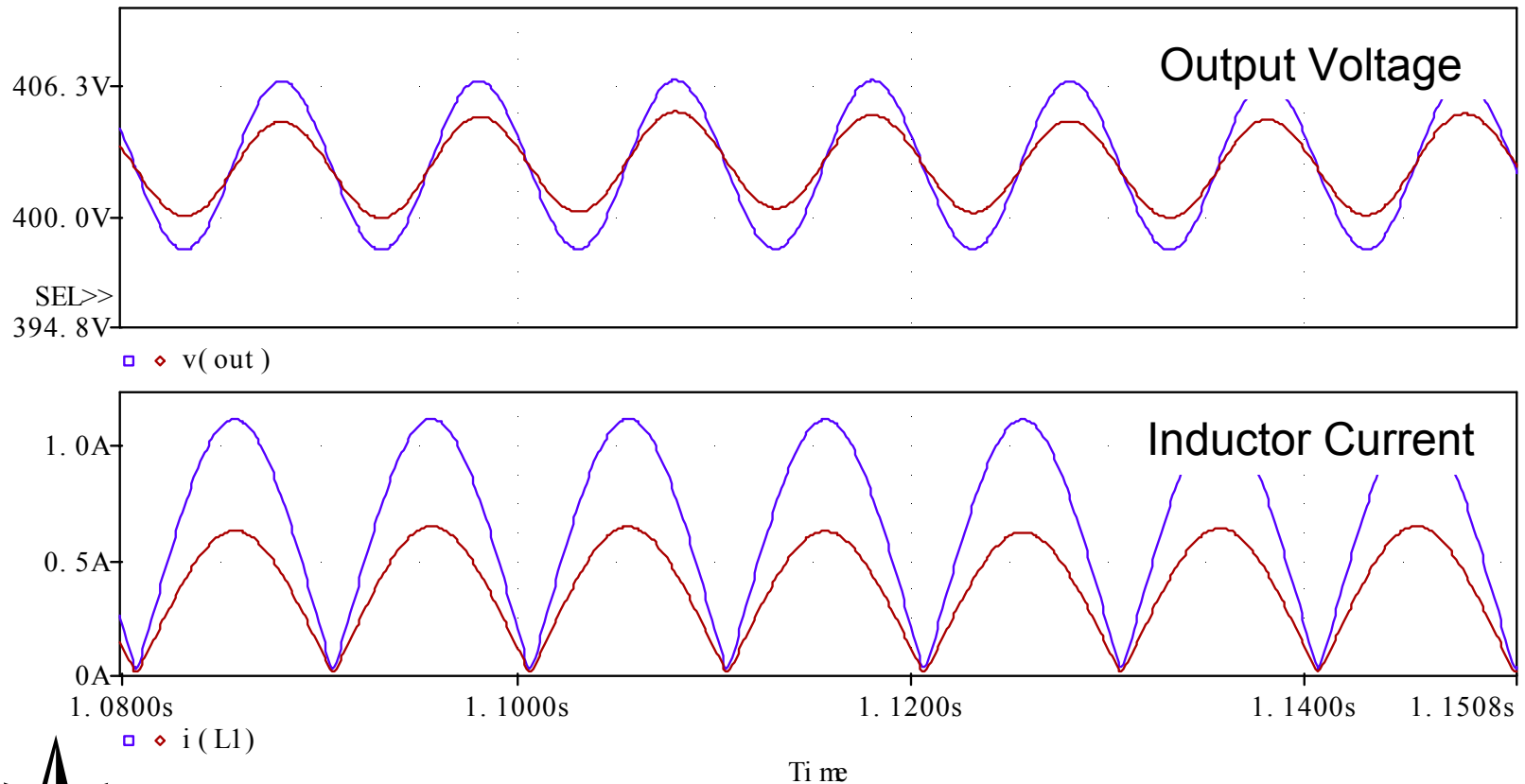
$P_{out}=175W$, $V_{in}=80V_{rms}$, $230V_{rms}$, $265V_{rms}$

Behavior at Different Line Voltages



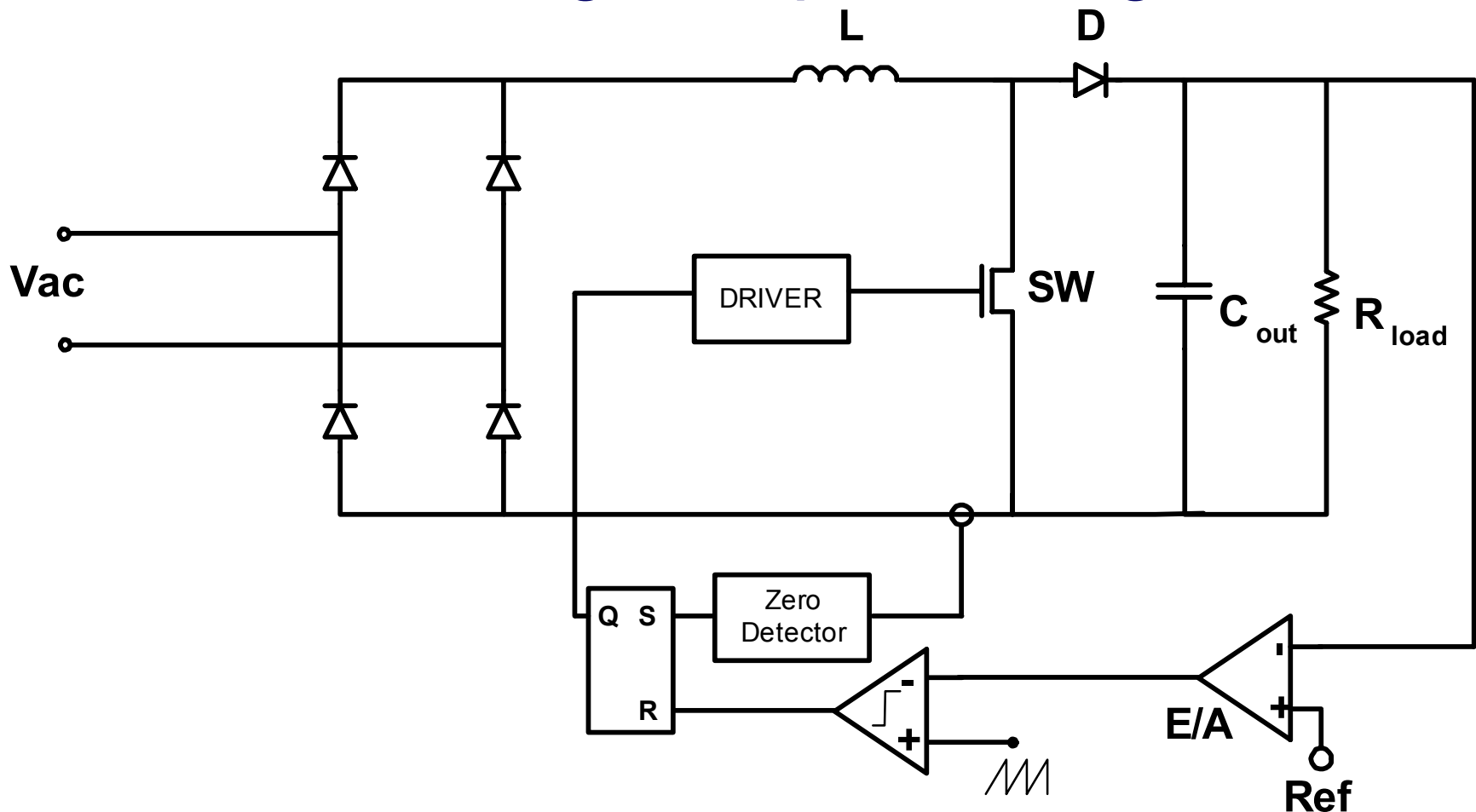
$P_{out}=175W$, $V_{in}=80V_{rms}$, $230V_{rms}$, $265V_{rms}$

Behavior at Different Power Levels

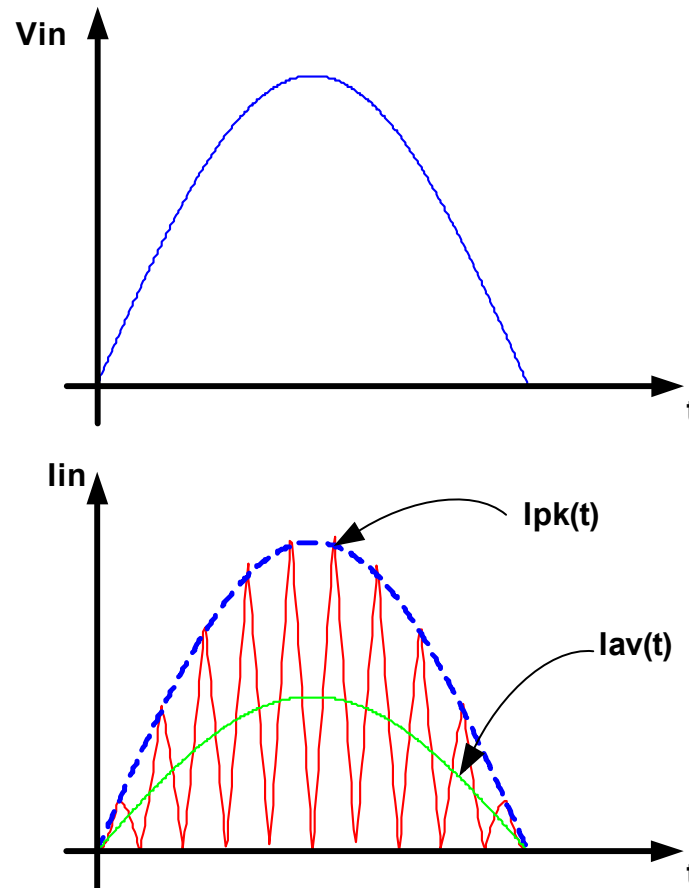


$V_{in}=230V_{rms}$, $P_{out}=175W$, $100W$

Border Line Control Concept with no Sensing of Input Voltage

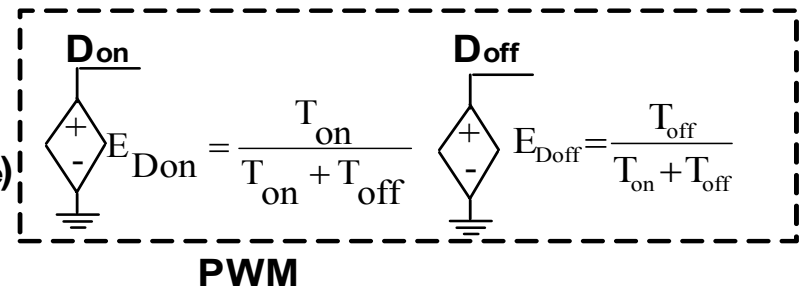
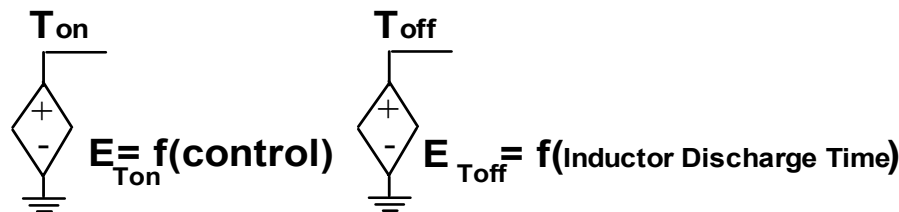
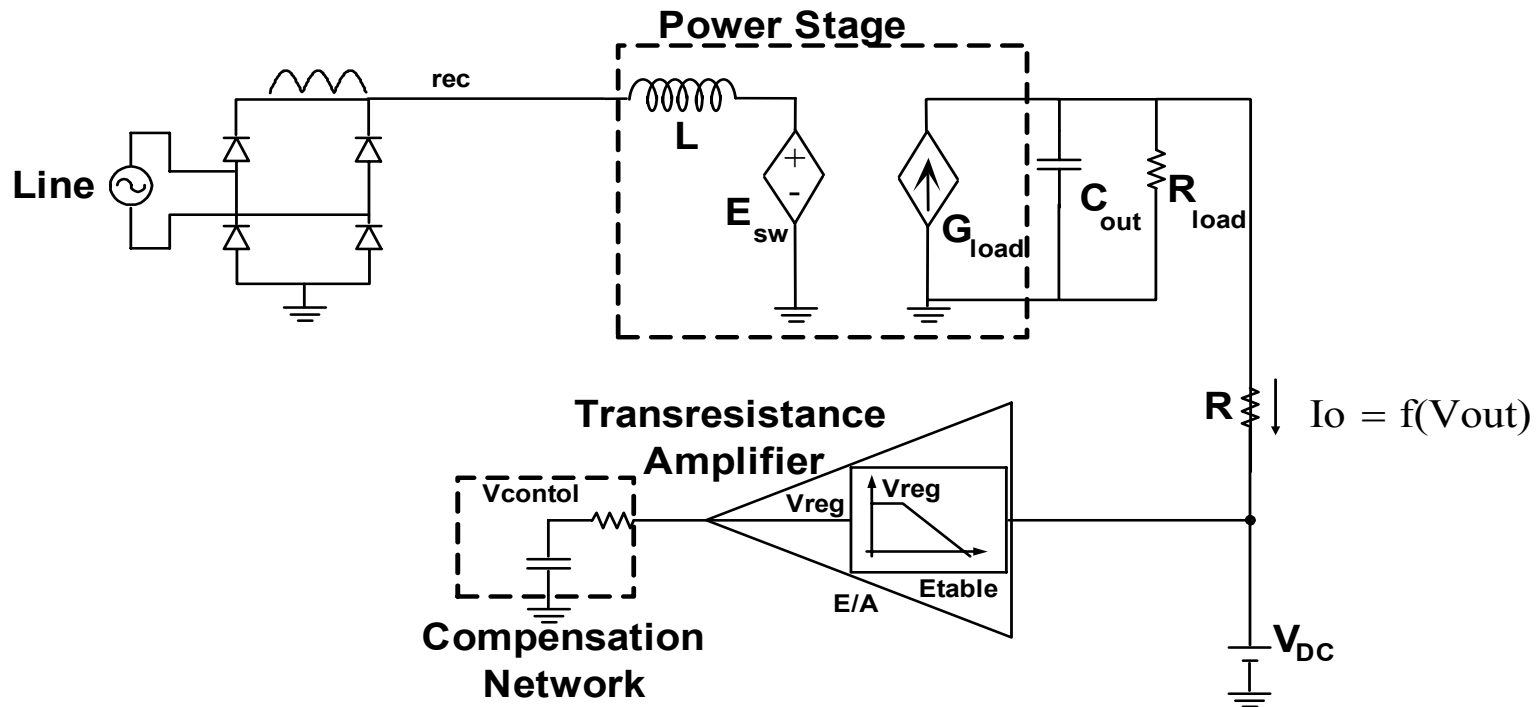


Principle of Operation

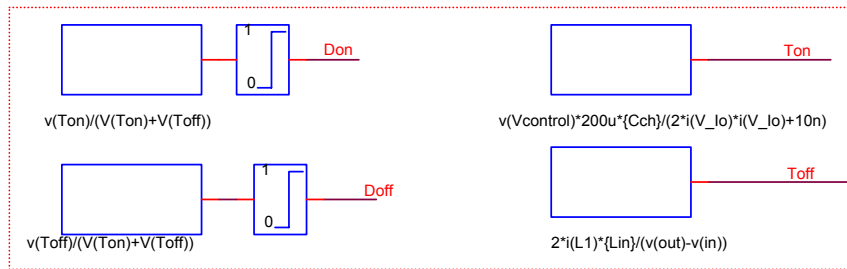
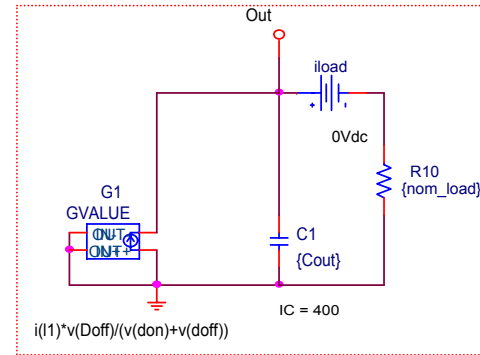
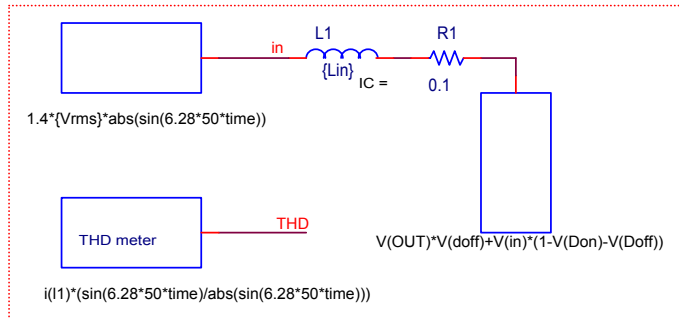


$$i_{pk}(t) = 2i_{av}(t) = \frac{V_{in}}{L} T_{on} \quad \frac{V_{in}(t)}{i_{av}(t)} = \text{const. if } T_{on} = \text{const.}$$

MC33260 Based Average Model

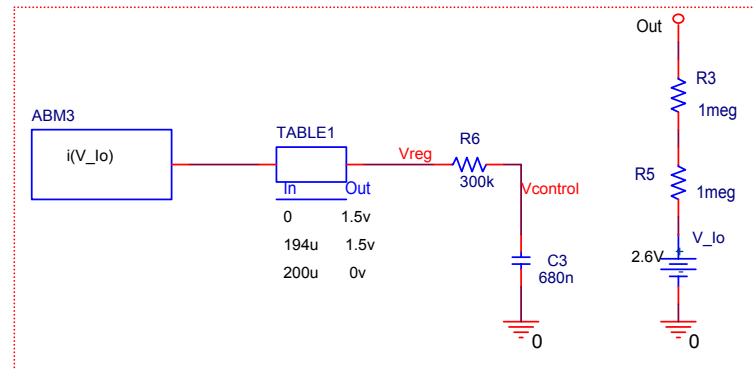


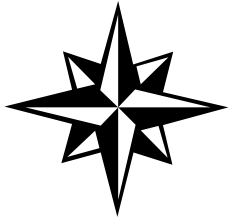
MC33260 Based Average Model



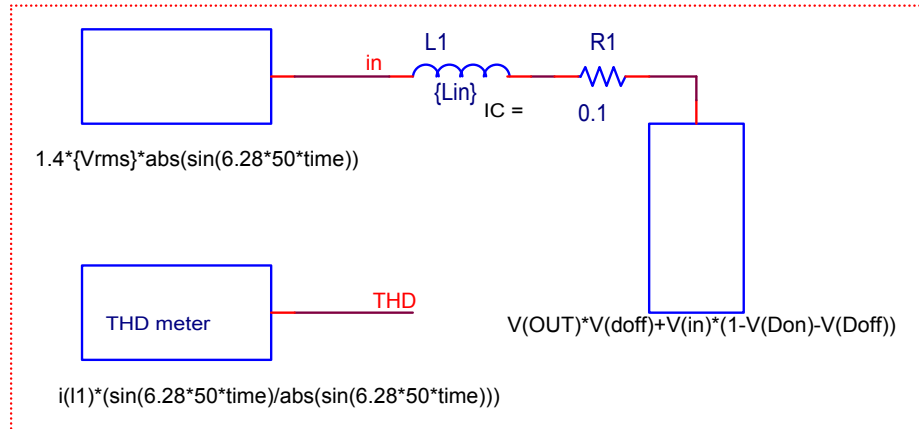
PARAMETERS:

- Lin = 320u
- CT = 2.7n
- Vrms = 220
- P = 80
- Norm_load = {Vo*Vo/f
- Rsense = 1
- Cout = 47u
- Vo = 400
- Cch = {15p+CT}

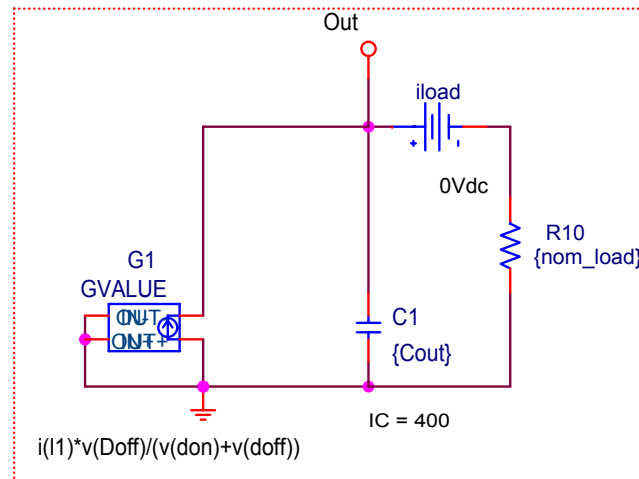


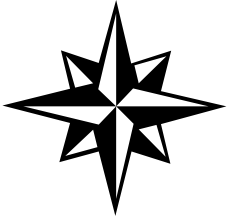


Inductor Current

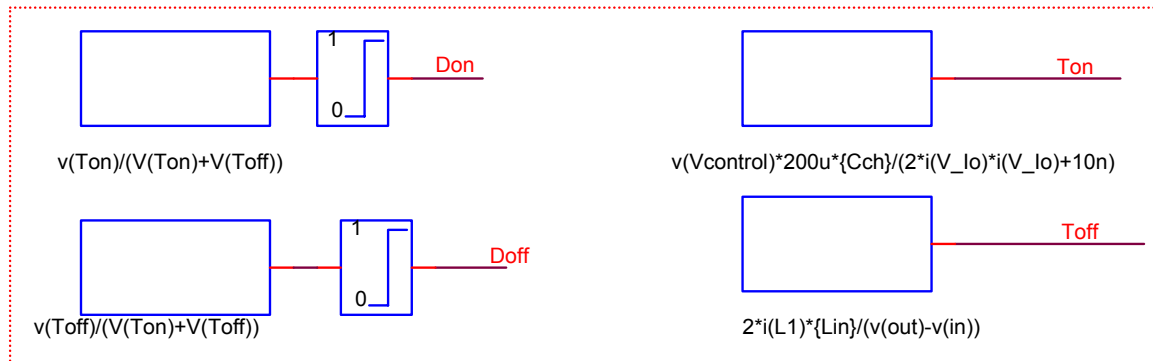


Output Current and Load

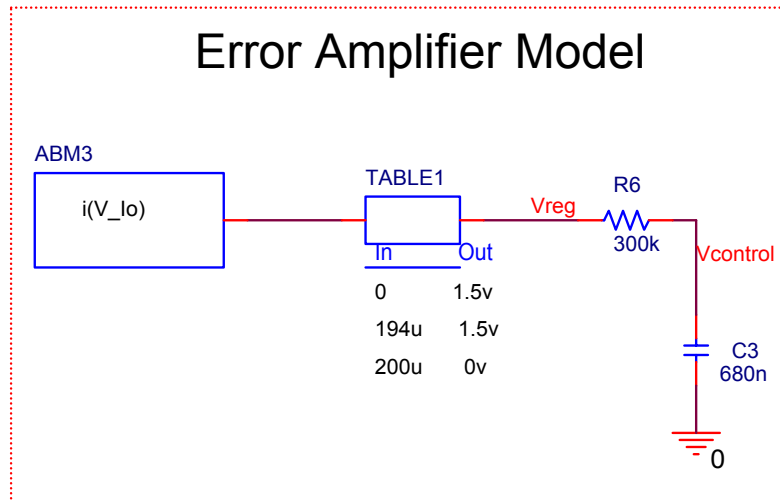




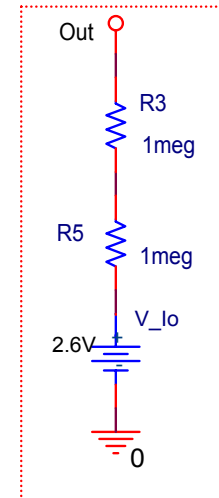
Don and Doff Generator



Error Amplifier Model

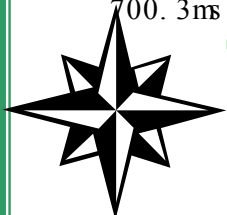
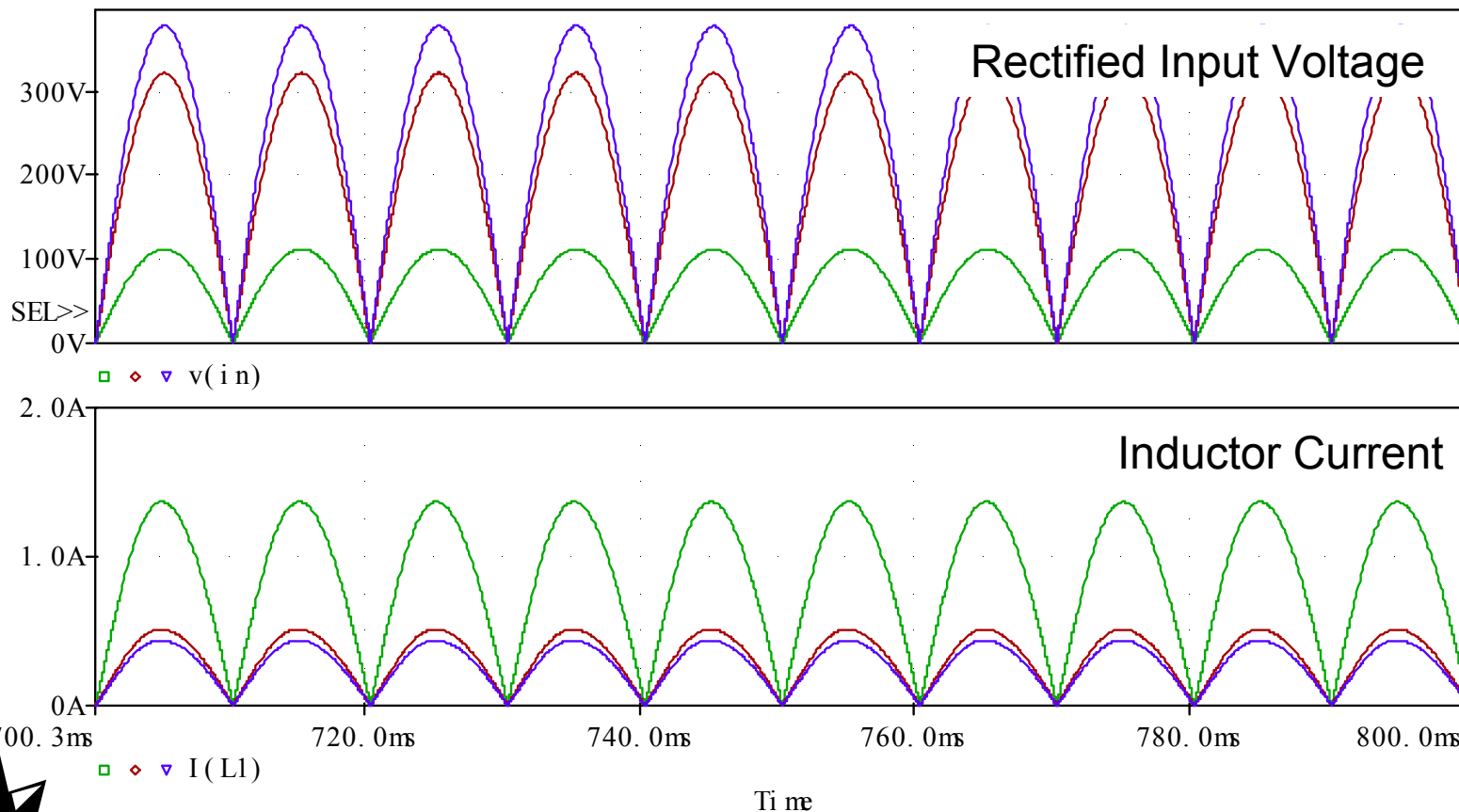


Feedback



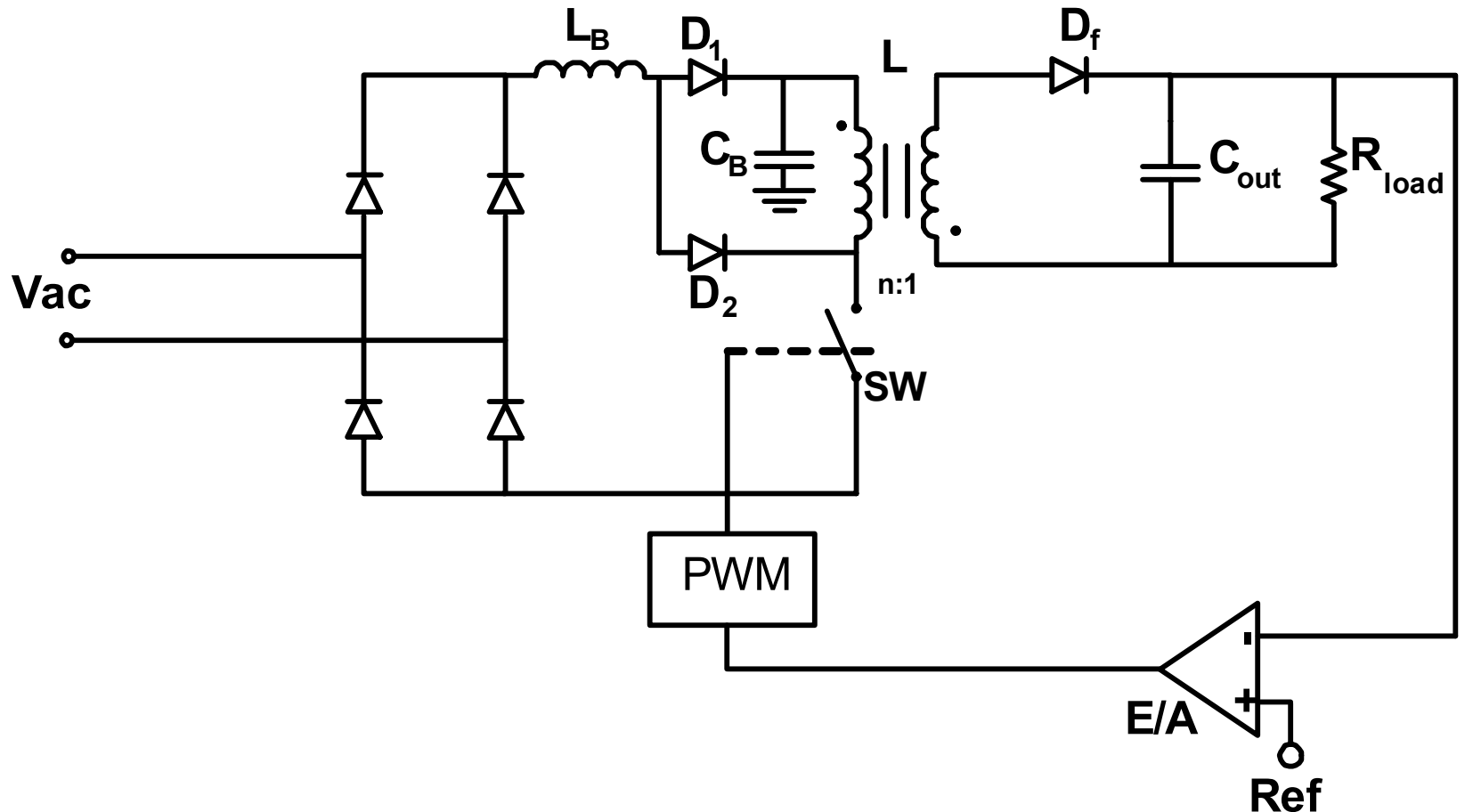
Current of V_lo reflects an output voltage level

Input Behavior at Different Line Voltages

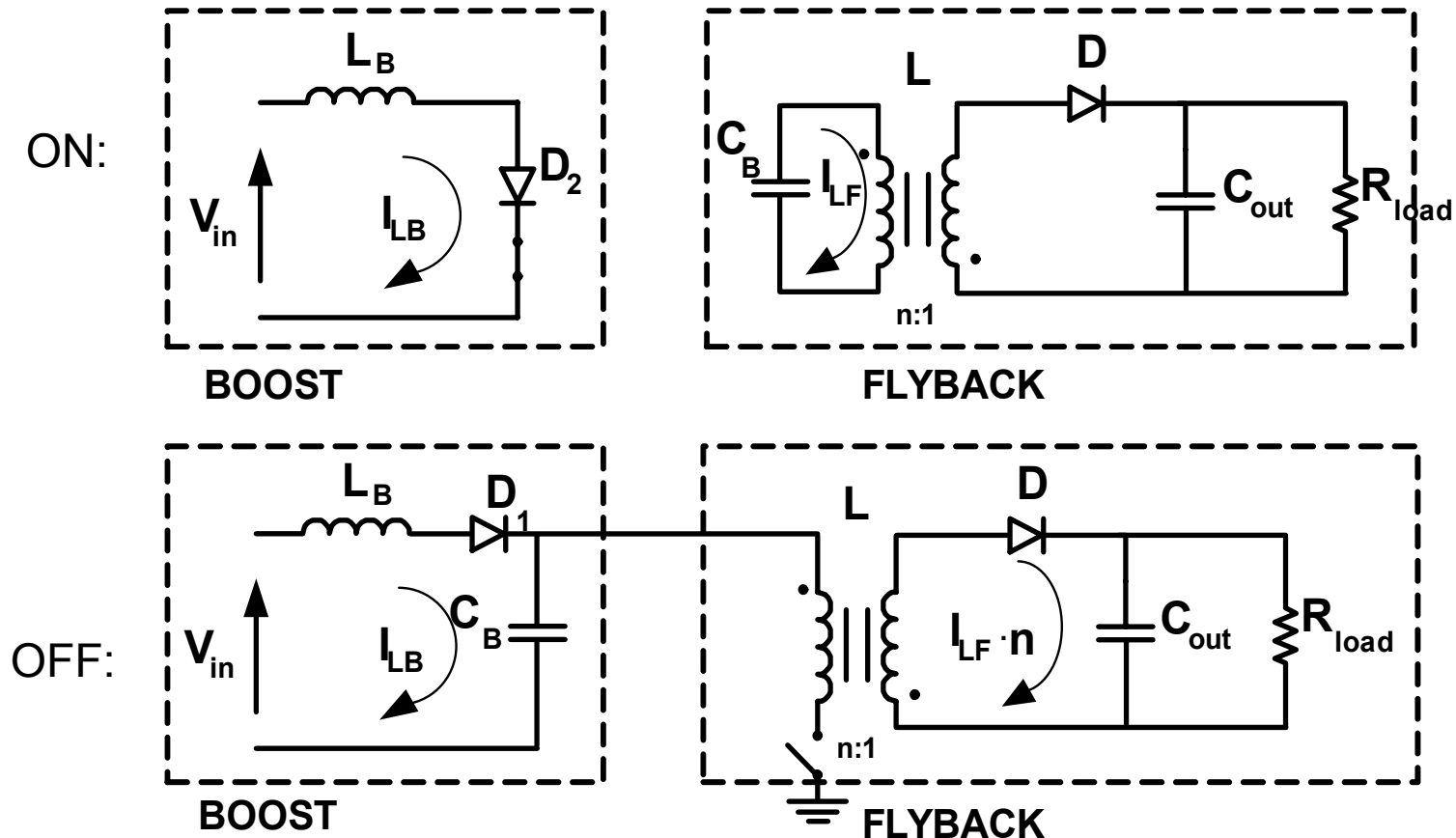


$P_{out}=80W$, $V_{in}=80V_{rms}$, $230V_{rms}$, $270V_{rms}$

Combined Stage (Boost-Flyback)



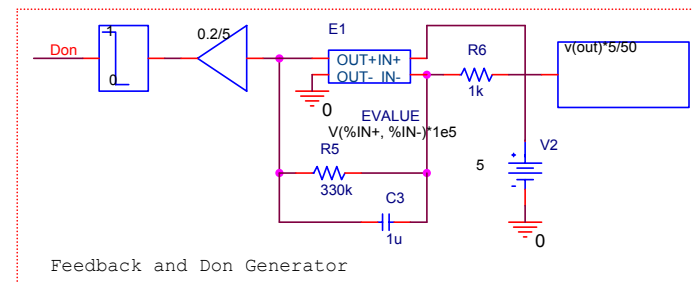
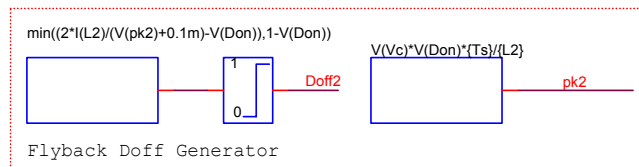
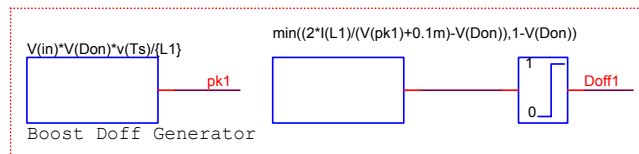
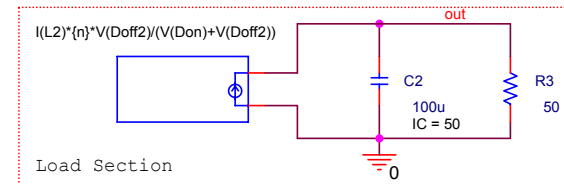
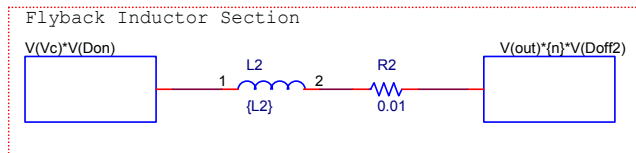
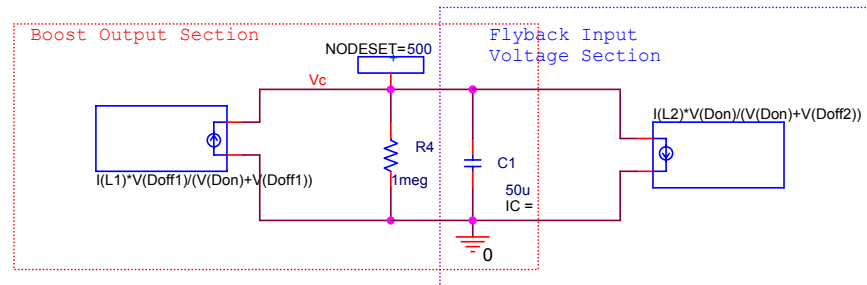
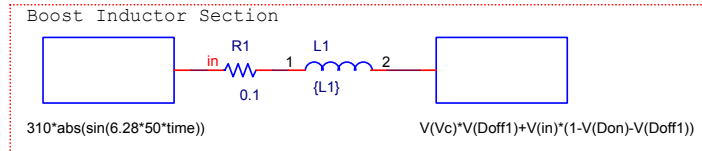
Principle of Operation

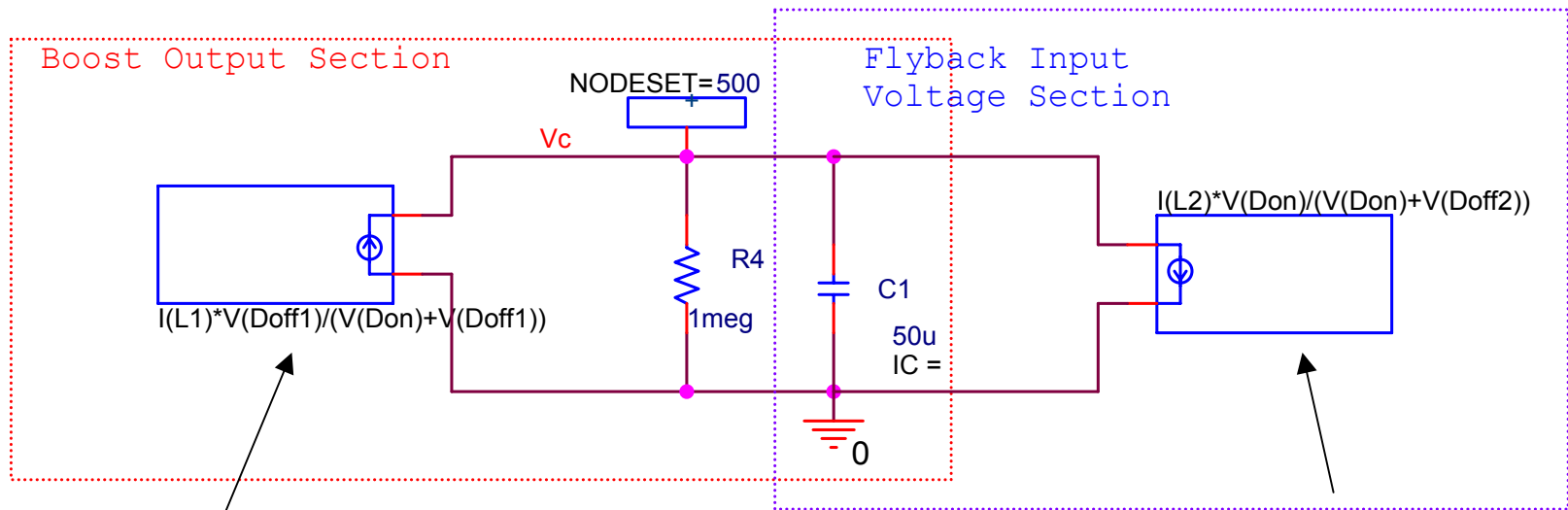
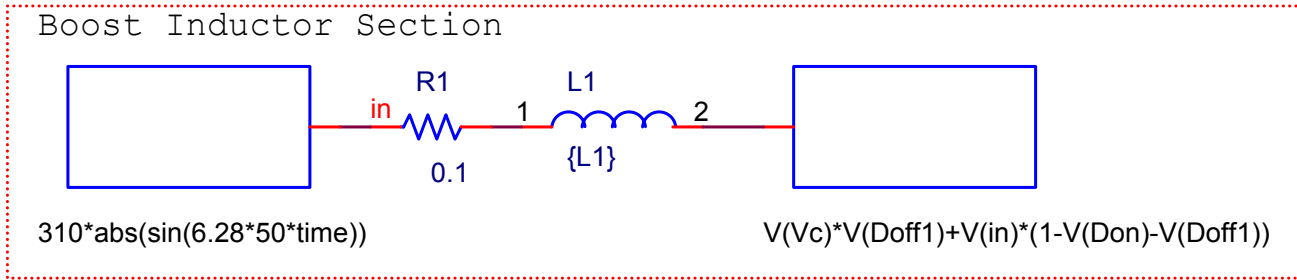


- C_B serves as output capacitor for Boost Section and as input voltage source for Flyback section.

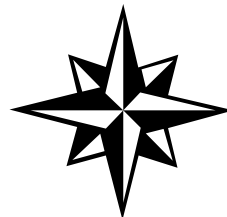


Average Model

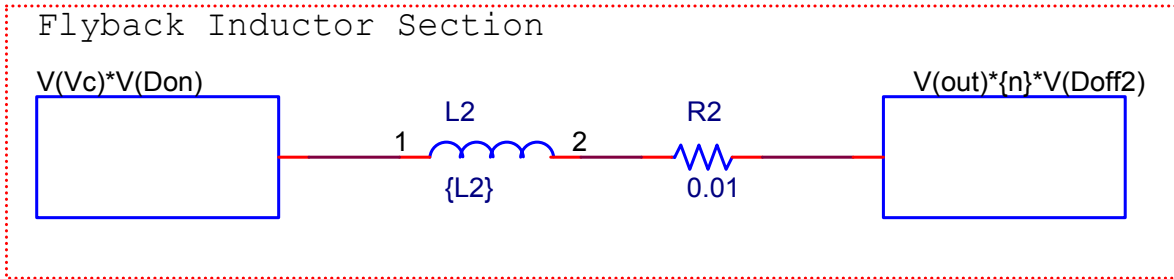




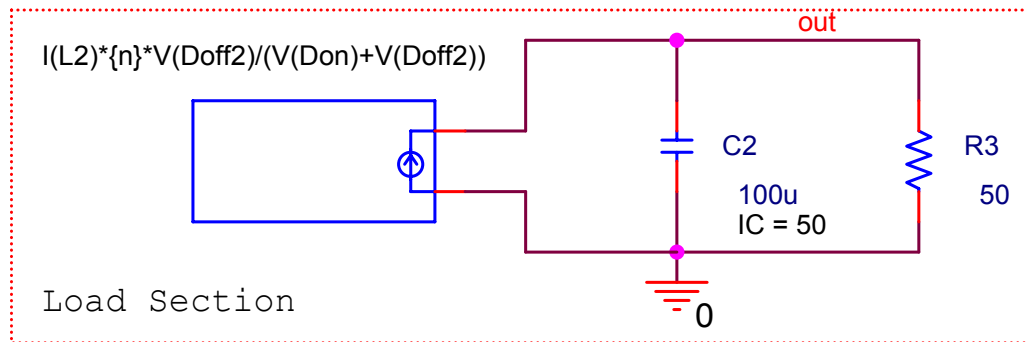
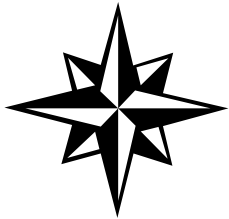
Capacitor charges by Boost inductor during $T_{off}(\text{Boost})$



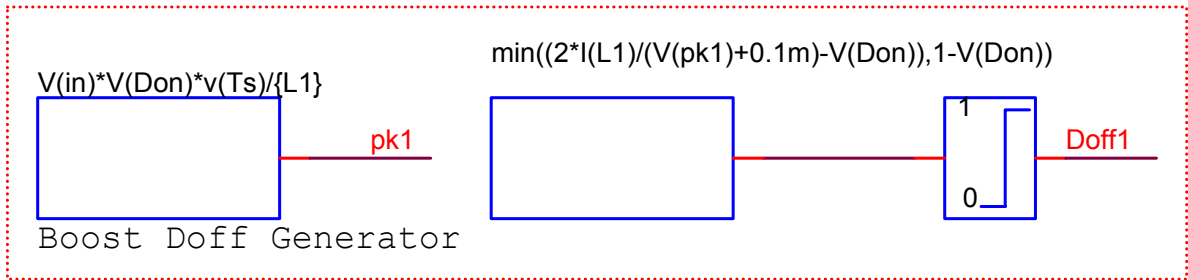
... and discharges by Flyback inductor during T_{on}



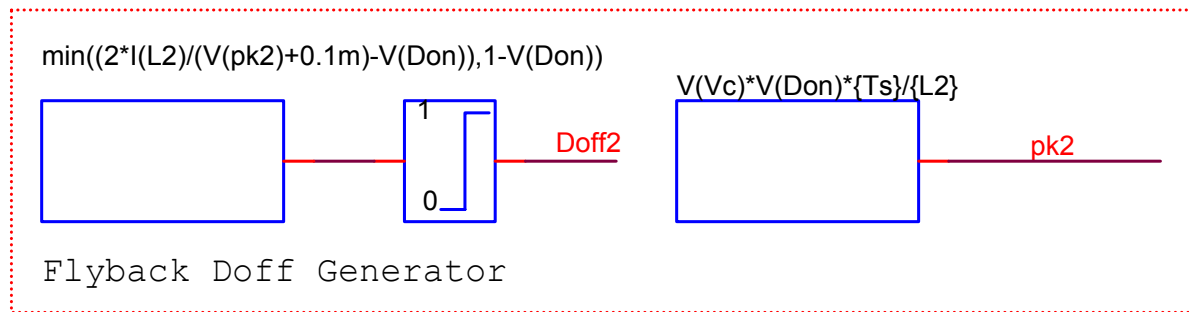
Flyback Inductor Section



Load

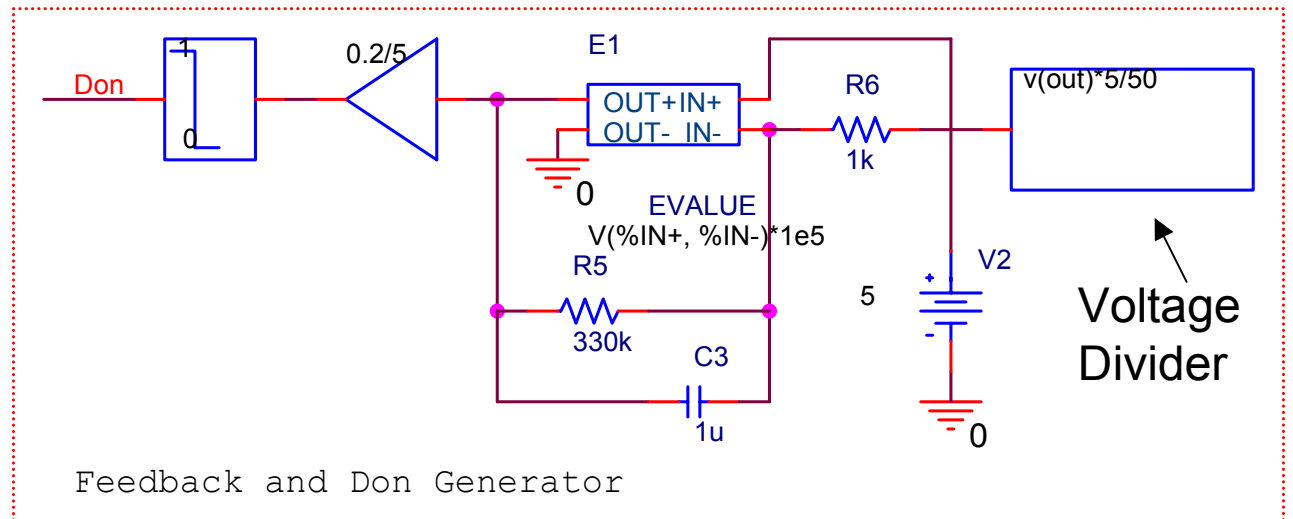


Doff Generator for Boost Section



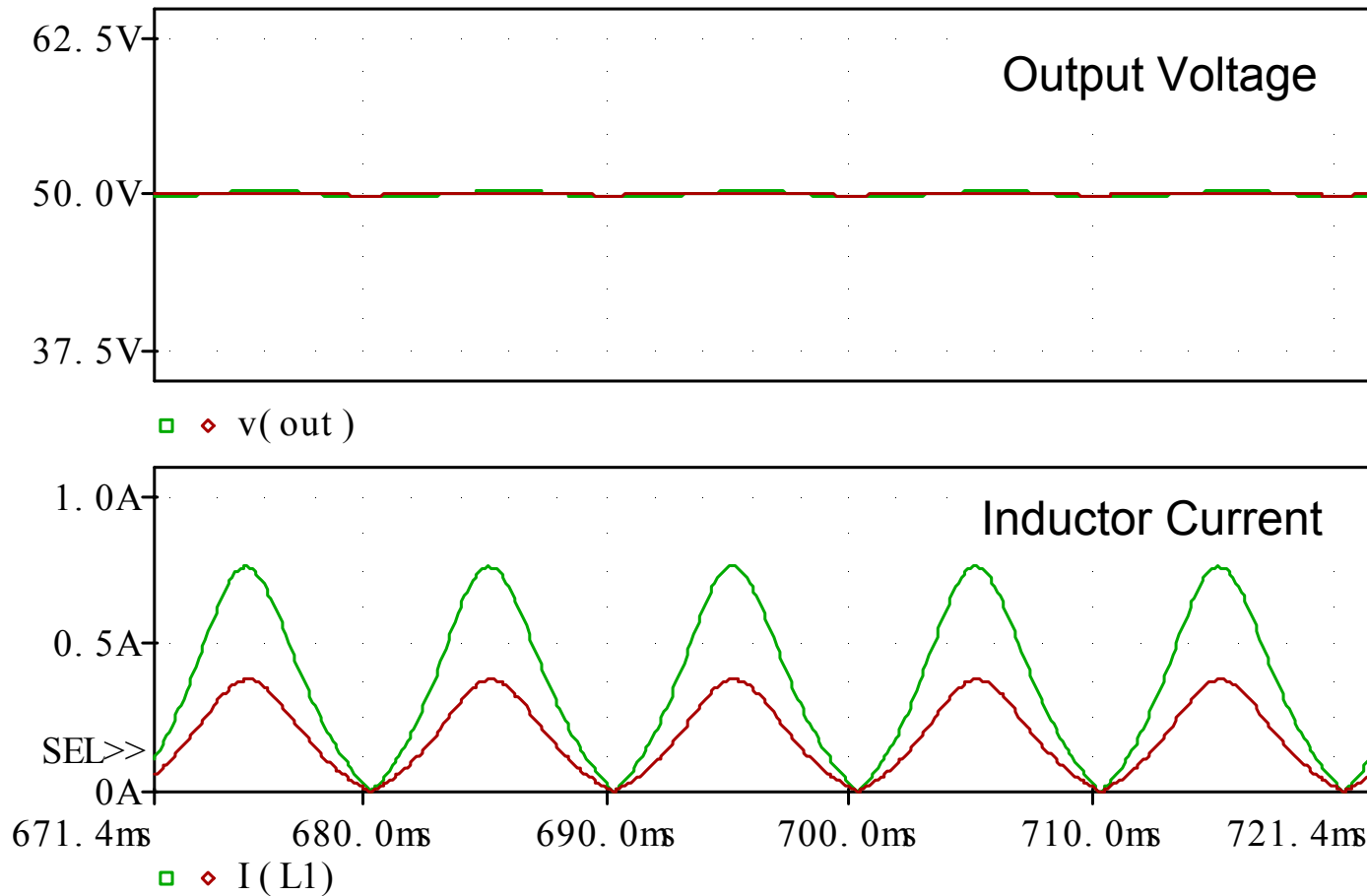
Doff Generator for Flyback Section

Error Amplifier and Don generator



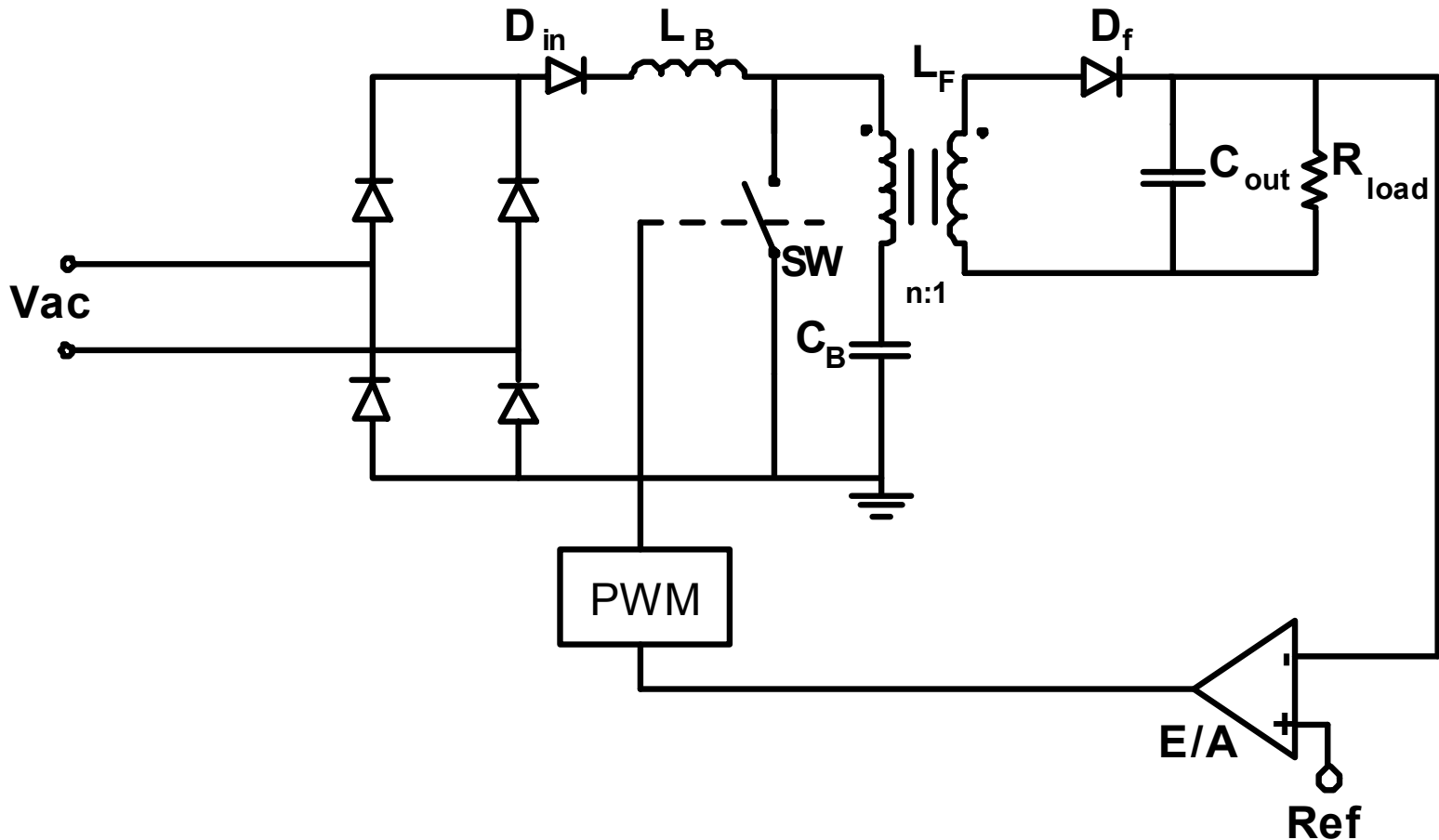
Voltage Divider

Behavior at Different Power Levels



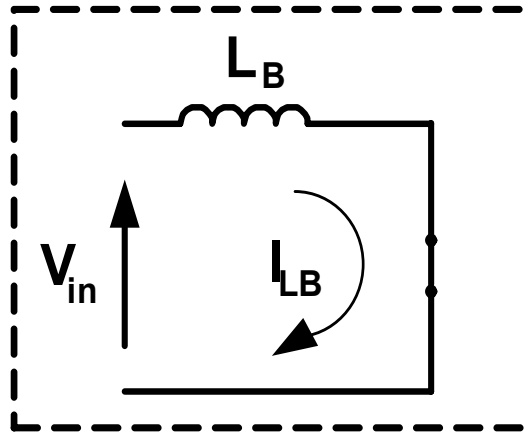
$V_{in}=230V$, $P_{out}=100W$, $50W$

Combined Stage (SEPIC with Transformer)

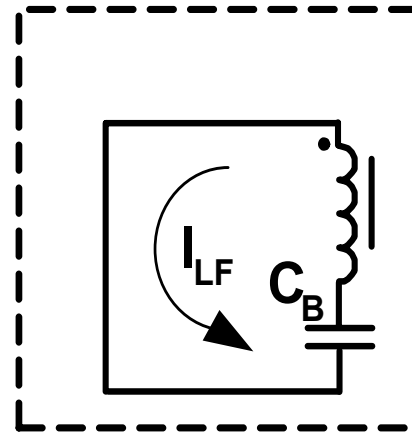


Principle of Operation

ON:

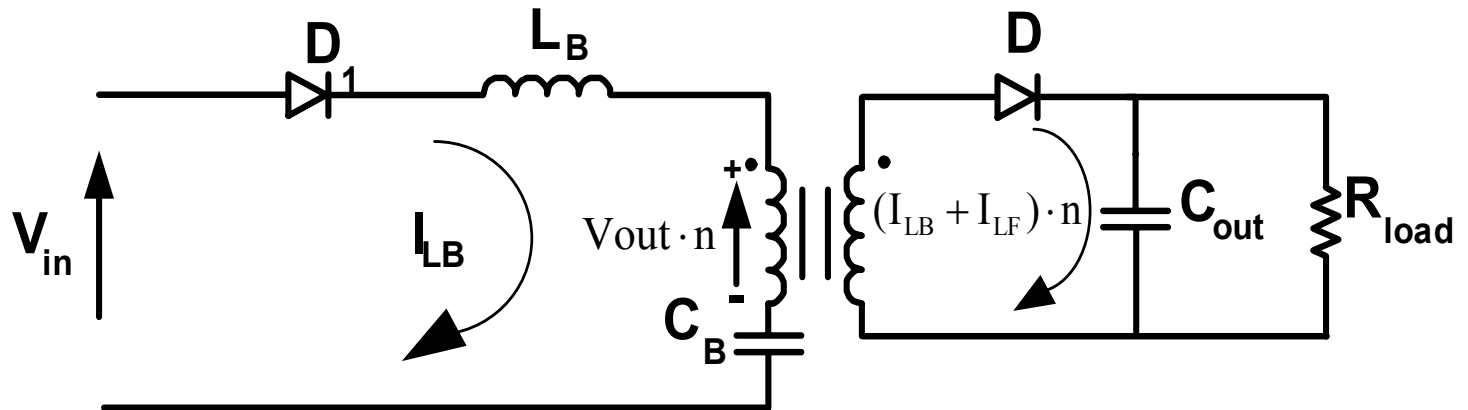


BOOST

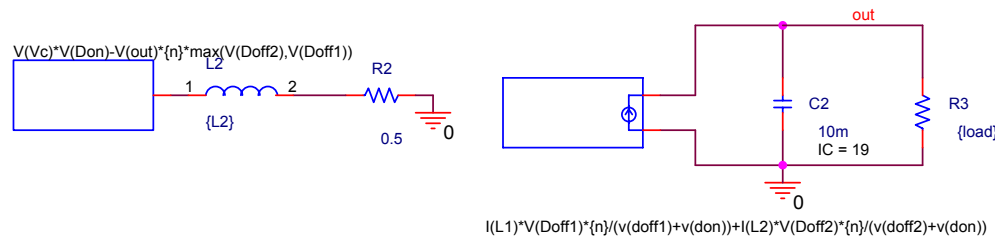
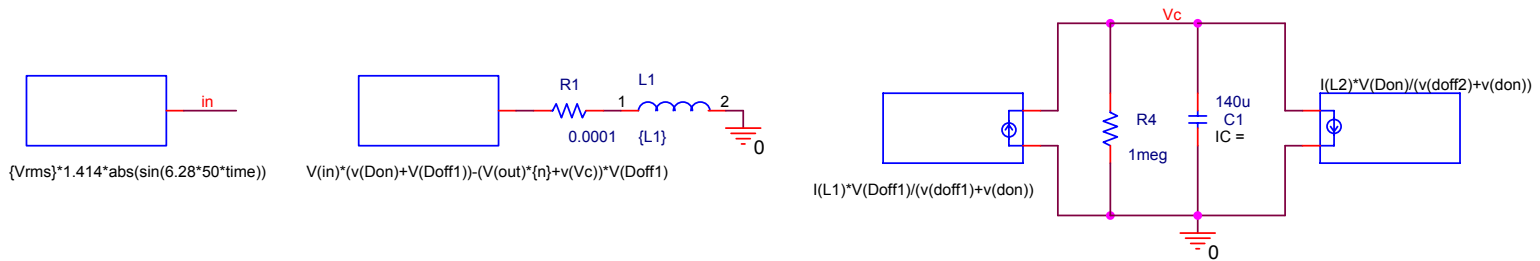


FLYBACK

OFF:

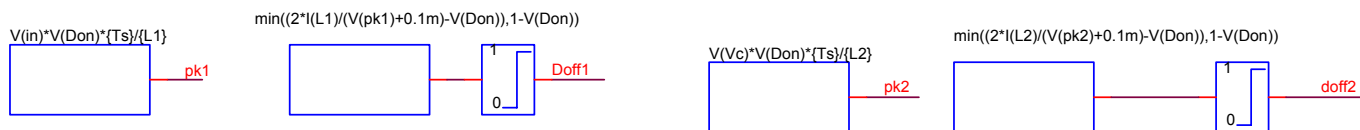
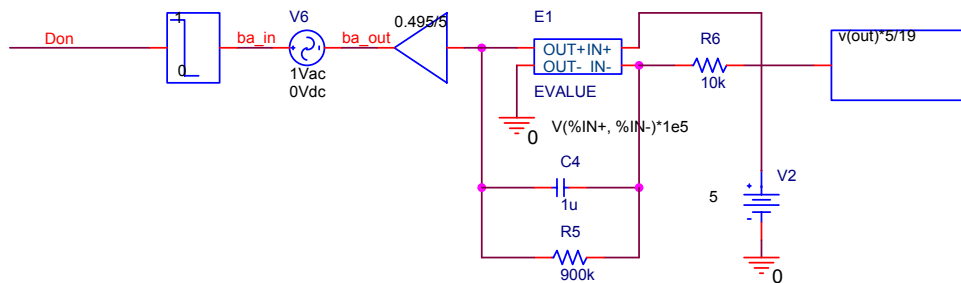


Average Model

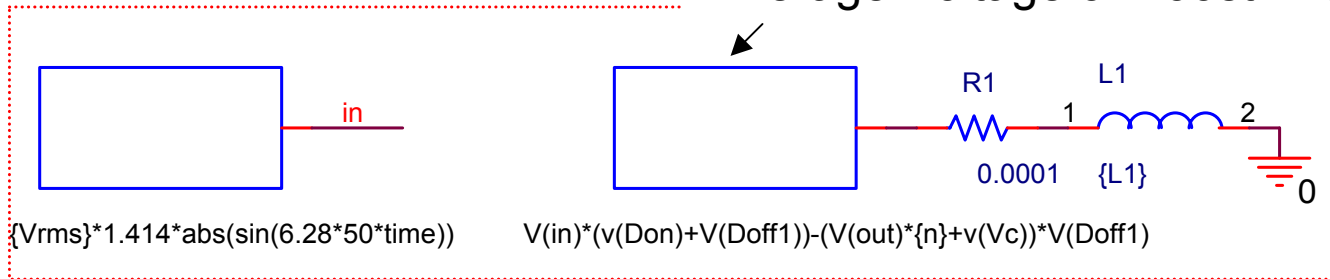


PARAMETERS:

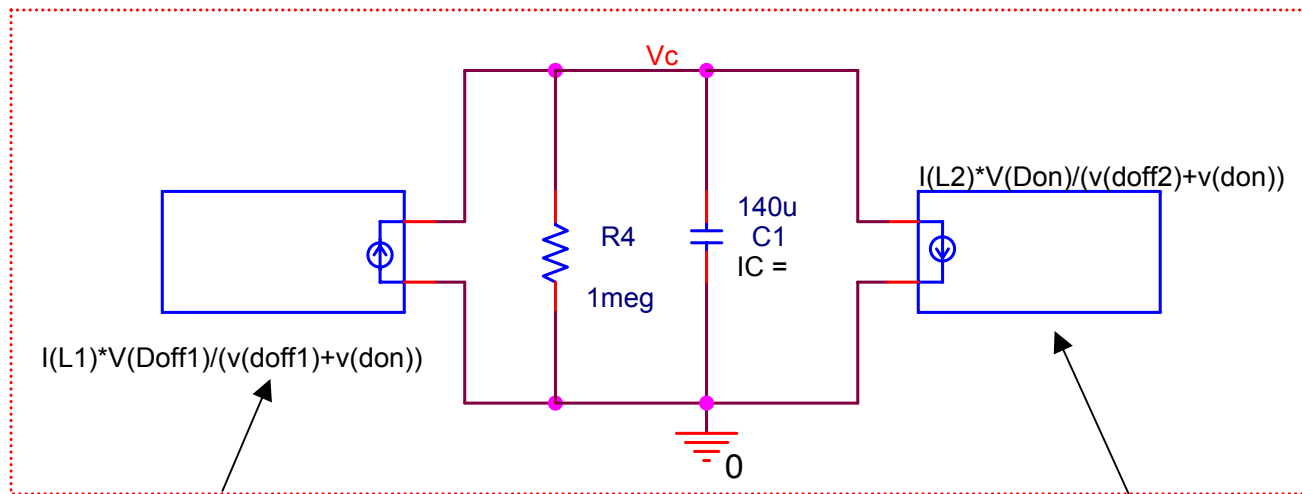
- L1 = 90u
- n = 6
- L2 = 225u
- Vrms = 265
- Load = 5
- Ts = {1/90kHz}



Average Voltage of Boost Inductor

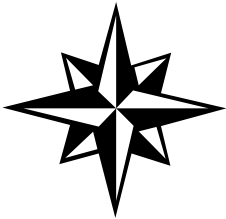


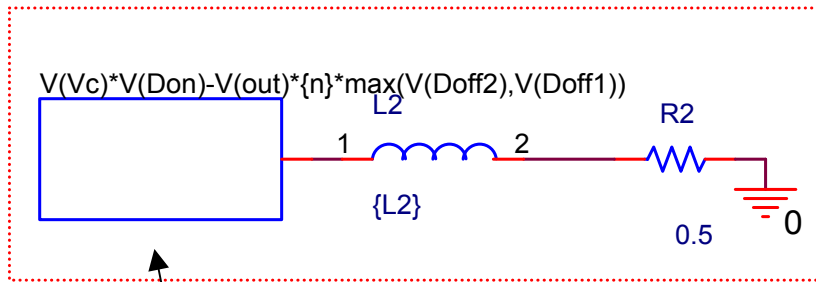
Boost Inductor Section



Capacitor charges by Boost inductor during $T_{off}(\text{Boost})$

... and discharges by Flyback inductor during T_{on}

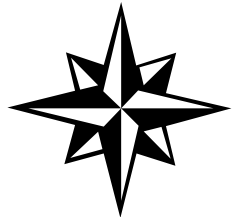




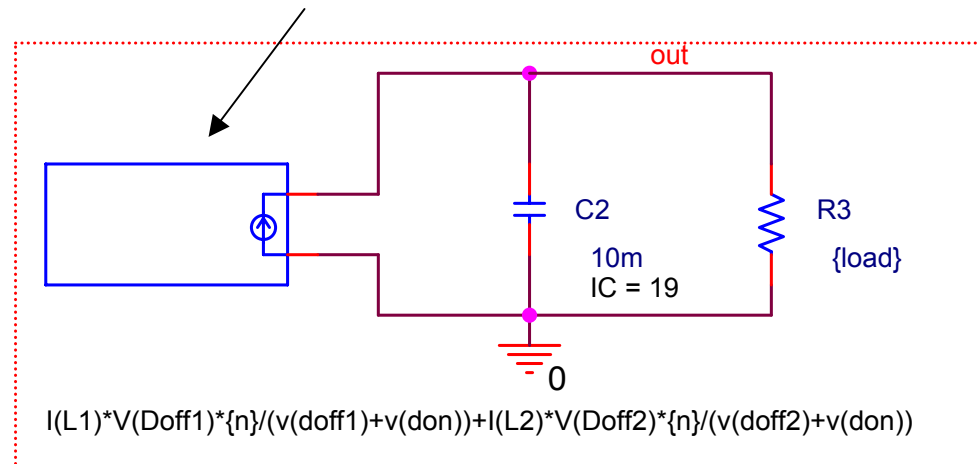
Flyback Inductor Section

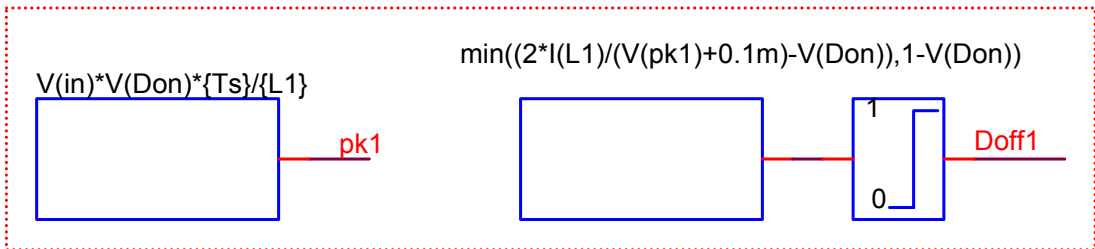
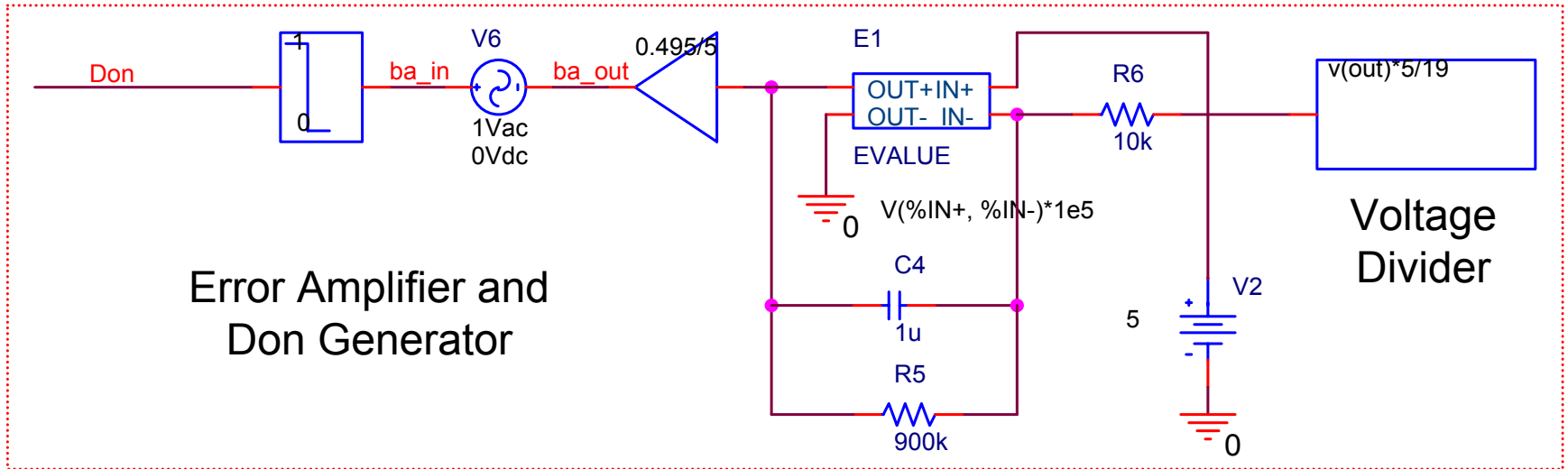
Average Voltage of Flyback Inductor

Average Load Current

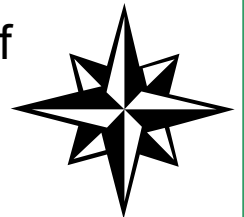


Load Section

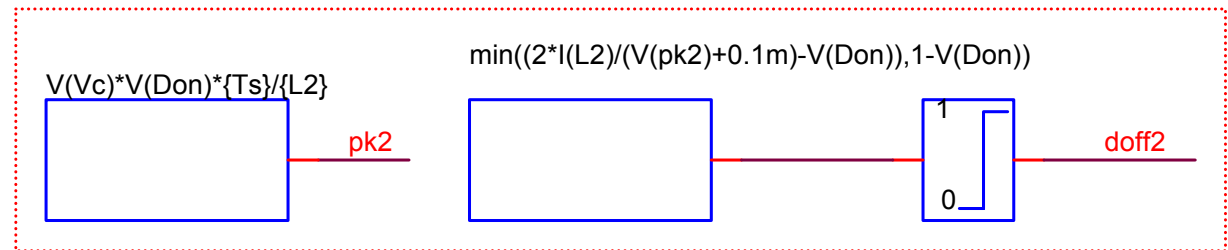




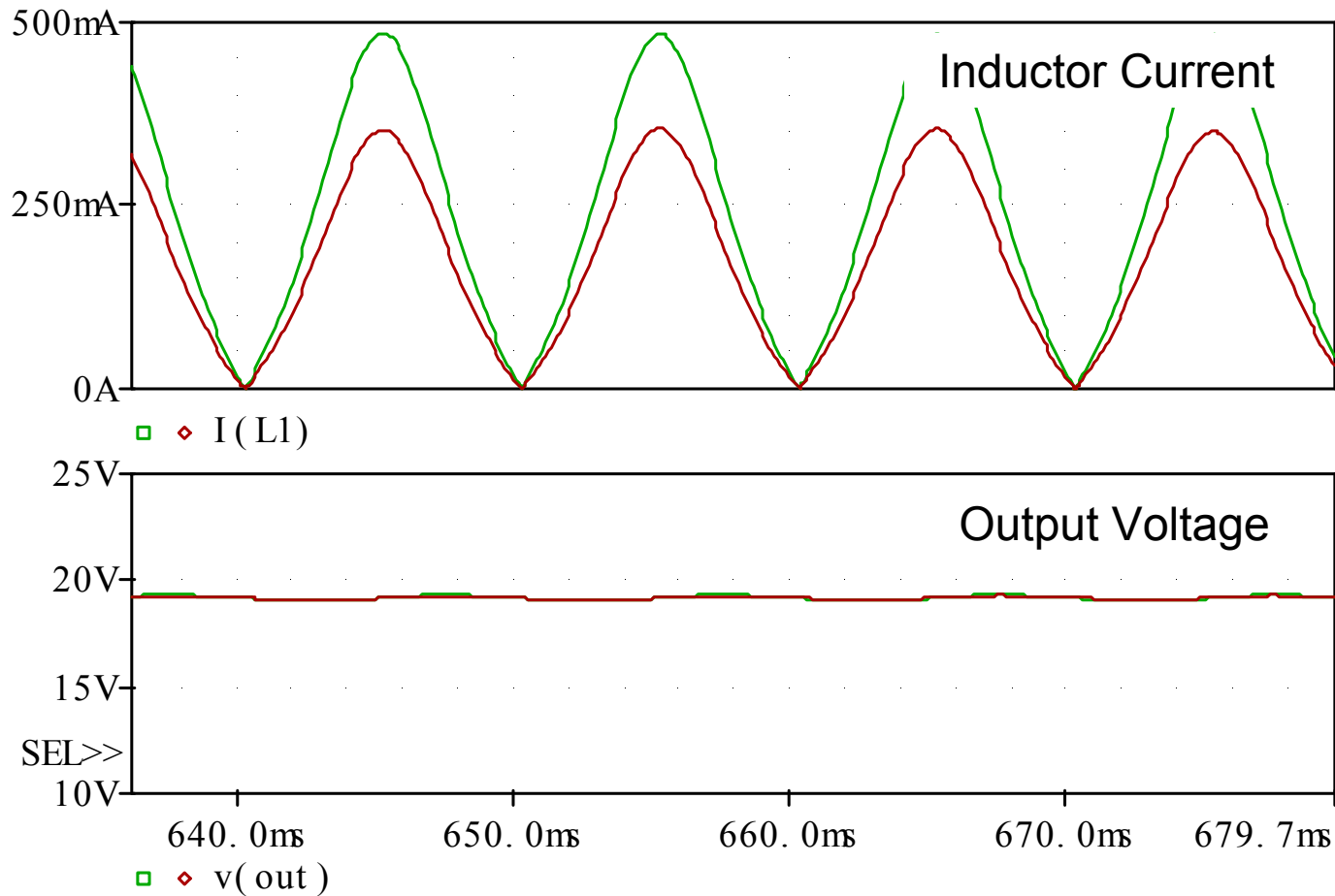
Doff Generator of Boost Section



Doff Generator of Flyback Section



Behavior at Different Power Levels



Time
 $V_{in}=230V$, $P_{out}=70W$, $50W$

Conclusions

- Average simulation provides an insight into the operation of Power Electronics Systems
- Simulation can replace tedious calculations and breadboarding
- Computer aided design can help shorten the design cycle – shorter time to market
- Behavioral models are useful engineering tools

Thank you
for your attention