Appendix

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Frequency Response Analysis Tools for Push-pull Converter
Origianl Rev. 12/22/05
Revision 12/26/05

This Mathcad design tool was developed to design the compensator with the Push-pull converter.

Define the BodePlot function:

BodePlot(F, MinFreq, MaxFreq) :=

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"ndk is number of points in each decade"
ndk ← 100
"n is total number of points"
n ← ndk·ceil(log(MaxFreq/MinFreq))
r ← ln(MaxFreq/MinFreq)
for i ∈ 0 .. n
    ω ← MinFreq·e^(i·r/n)
    Z[i,0] ← ω/(2π)
    V ← F(j·ω)
    Z[i,1] ← 20·log(|V|)
    Z[i,2] ← arg(V)·180/π
"Make -180 rollover"
for i ∈ 1 .. n
  Z[i,2] ← Z[i,2] − 360  if (|Z[i,2] − Z[i−1,2]|) > 300
Z
```

Input Voltage : **22V~32V**
Output Voltage : **24V**
Max Output Currunt : **5A**
Converter Topology : **Push-pull converter**
Control Mode : **Peak current mode**

Ro := 5 $\quad$ Ro = 5 $\quad$ $Io := \frac{24}{Ro}$ $\quad$ Io = 4.8 $\quad$ **Change the load**

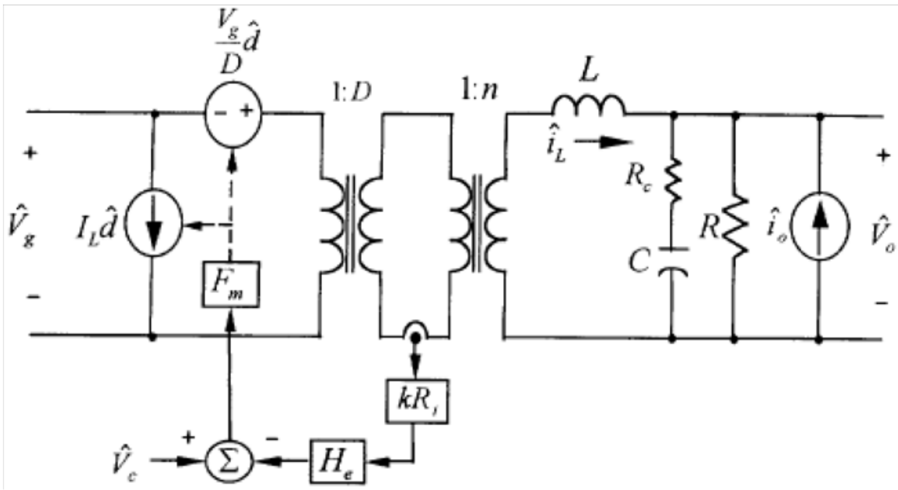
Vg := 28 $\quad$ Vg = 28 $\quad$ **Change the input**

$n := 3 \quad k := 0.01 \quad Ri := 10 \quad Rc := 0.1$

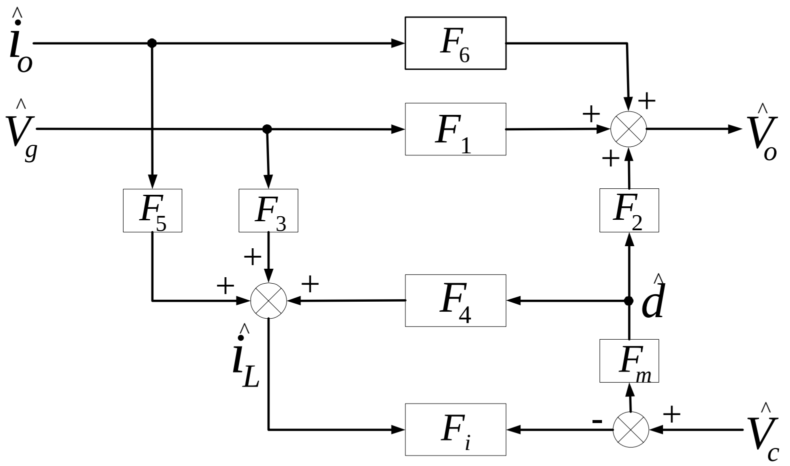
$\mu := 10^{-6} \quad Ts := 5\mu \quad Co := 100\mu \quad Lo := 60\mu$

$D := \frac{24 + 1}{Vg \cdot n} \quad D = 0.298$

Establish small signal model:



Small signal model of the converter



Transfer function model of the converter

Sn : the on-time slope of sensed-current

Se : the slope of external current

Fm(s) : the gain fuction of currrent-mode control modulator

He(s) : tranfer function used to model the sampling action of current mode control

$$Sn := \frac{n^2 \cdot k \cdot (1 - D) \cdot Vg \cdot Ri}{Lo}$$

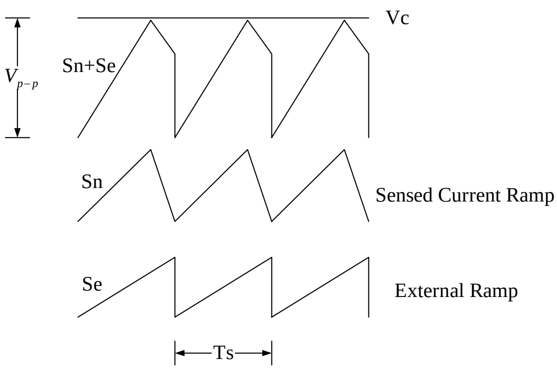
$$Se := 0.75Sn \qquad Mc := 1 + \frac{Se}{Sn}$$

$$He(s) := 1 - \frac{s \cdot Ts}{2} + \left(\frac{Ts}{\pi}\right)^2 \cdot s^2$$

$$Fi(s) := n \cdot k \cdot Ri \cdot He(s)$$

$$Fm := \frac{1}{Mc \cdot Sn \cdot Ts}$$

$$\Delta(s) := s^2 \cdot Lo \cdot Co + s \cdot \left(\frac{Lo}{Ro} + Co \cdot Rc\right) + 1$$



$$\frac{\hat{d}}{\hat{V}_c} = \frac{1}{V_{p-p}} \qquad F_m = \frac{1}{(s_n + S_e)T_s} = \frac{1}{M_c s_n T_s}$$

$$F1(s) := n \cdot D \cdot \frac{1 + s \cdot Co \cdot Rc}{\Delta(s)} \qquad F2(s) := n \cdot Vg \cdot \frac{1 + s \cdot Co \cdot Rc}{\Delta(s)}$$

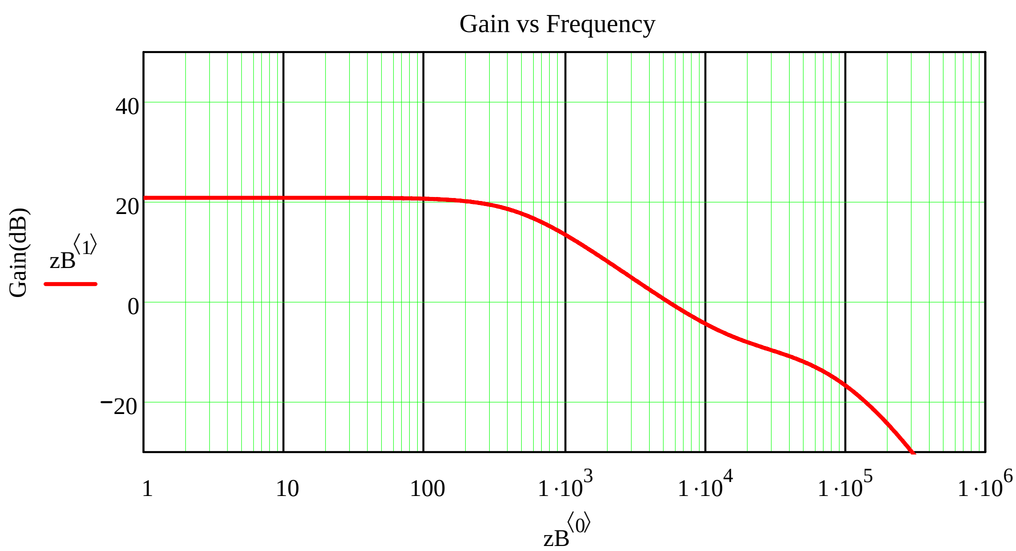
$$F3(s) := n \cdot \frac{D}{Ro} \cdot \frac{1 + s \cdot Co \cdot Ro}{\Delta(s)} \qquad F4(s) := n \cdot \frac{Vg}{Ro} \cdot \frac{1 + s \cdot Co \cdot Ro}{\Delta(s)} \qquad F5(s) := \frac{-(1 + s \cdot Co \cdot Ro)}{\Delta(s)}$$

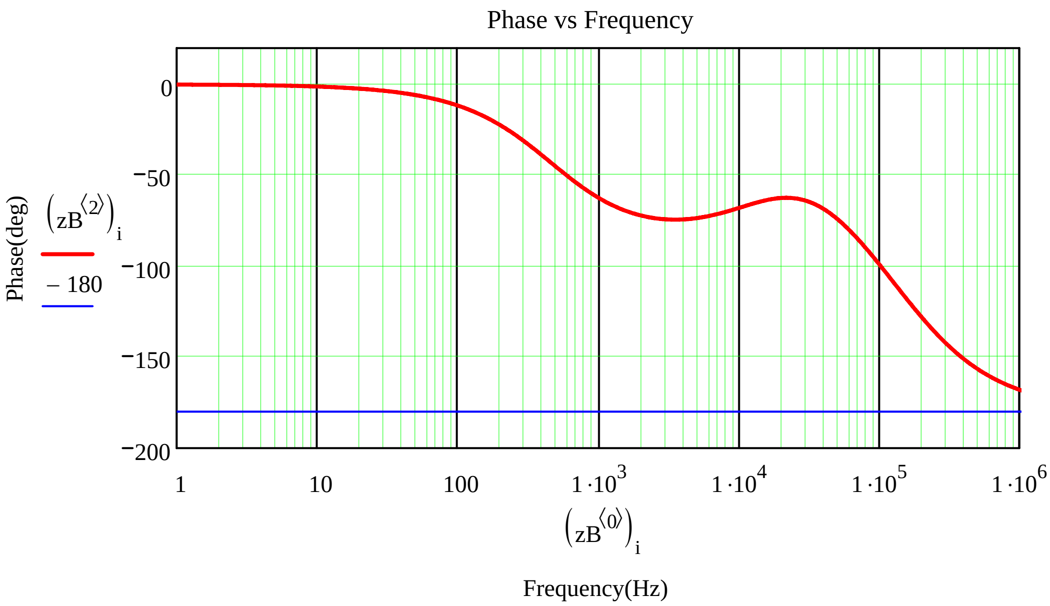
Current loop gain: $Ti(s) := F4(s) \cdot Fm \cdot Fi(s)$

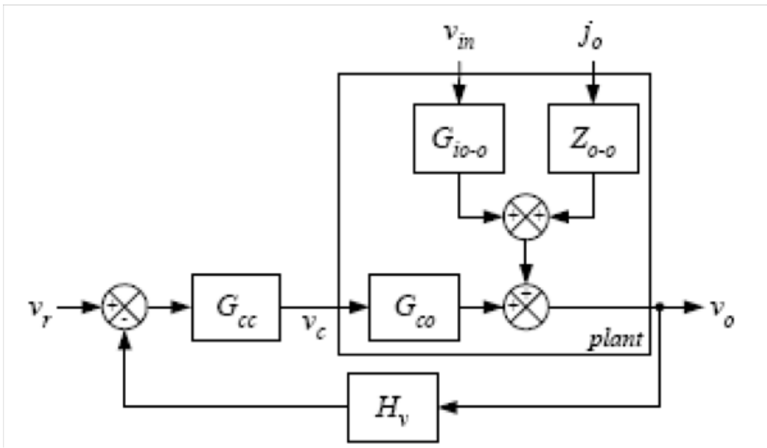
Control to output gain: $Gco(s) := \frac{F2(s) \cdot Fm}{1 + Ti(s)}$

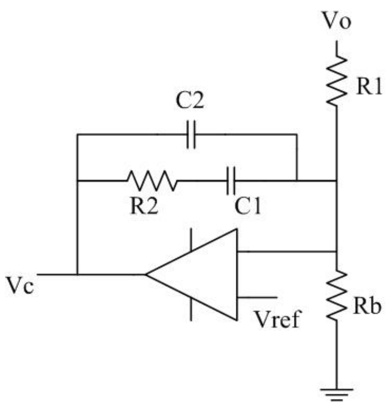
Control-to-output Bode Plot:

$zB := BodePlot\left(Gco, 1, 1 \cdot 10^7\right) \qquad i := 0 .. last\left(zB^{\langle 0 \rangle}\right)$









Control system block diagram of the SMPC **EA compensator**

$p := 10^{-12}$ $R2 := 51 \cdot 10^3$ $C1 := 10000 \cdot p$ $C2 := 220p$

$R1 :=$ 5000 $R1 = 5 \times 10^3$

Caculate bias resistor : $Rb := \frac{5.1}{24 - 5.1} \cdot R1$ $Rb = 1.349 \times 10^3$

Eliminate output filter pole : $\frac{1}{2\pi \cdot Ro \cdot Co} = 318.31$ $\frac{1}{2\pi R2 \cdot C1} = 312.069$

Eliminate ESR zero : $\frac{1}{2\pi Rc \cdot Co} = 1.592 \times 10^4$ $\frac{C1 + C2}{2\pi R2\, C1 \cdot C2} = 1.45 \times 10^4$

EA compensator transfer function :

$$Gcc(s) := \frac{\frac{\left(R2 + \frac{1}{s \cdot C1}\right) \cdot \frac{1}{s \cdot C2}}{\left(R2 + \frac{1}{s \cdot C1}\right) + \frac{1}{s \cdot C2}}}{R1}$$

Feedback transfer function : $Hv := \frac{5.1}{24}$

Open-loop transfer function : $Lv(s) := Gcc(s) \cdot Gco(s) \cdot Hv$

Close-loop transfer function : $Gl(s) := \frac{Gcc(s) \cdot Gco(s)}{1 + Lv(s)}$

Open-Loop Bode Plot:

$zB2 := \text{BodePlot}\left(Gcc, 1, 1\cdot10^{7}\right) \qquad i := 0..\text{last}\left(zB^{\langle 0\rangle}\right)$

$zB3 := \text{BodePlot}\left(Lv, 1, 1\cdot10^{7}\right) \qquad i := 0..\text{last}\left(zB^{\langle 0\rangle}\right)$

zB: Control to Output

zB2: EA Compensation

zB3: Overrall Gain - Full Load