CM6800 compensation rule Championmicro-Elvis Lin –July-2004

圖 1 為 CM6800 架構圖，以下將針對 CM6800 將其電壓迴路(voltage loop)與電流迴路(current loop)的應用討論如下：

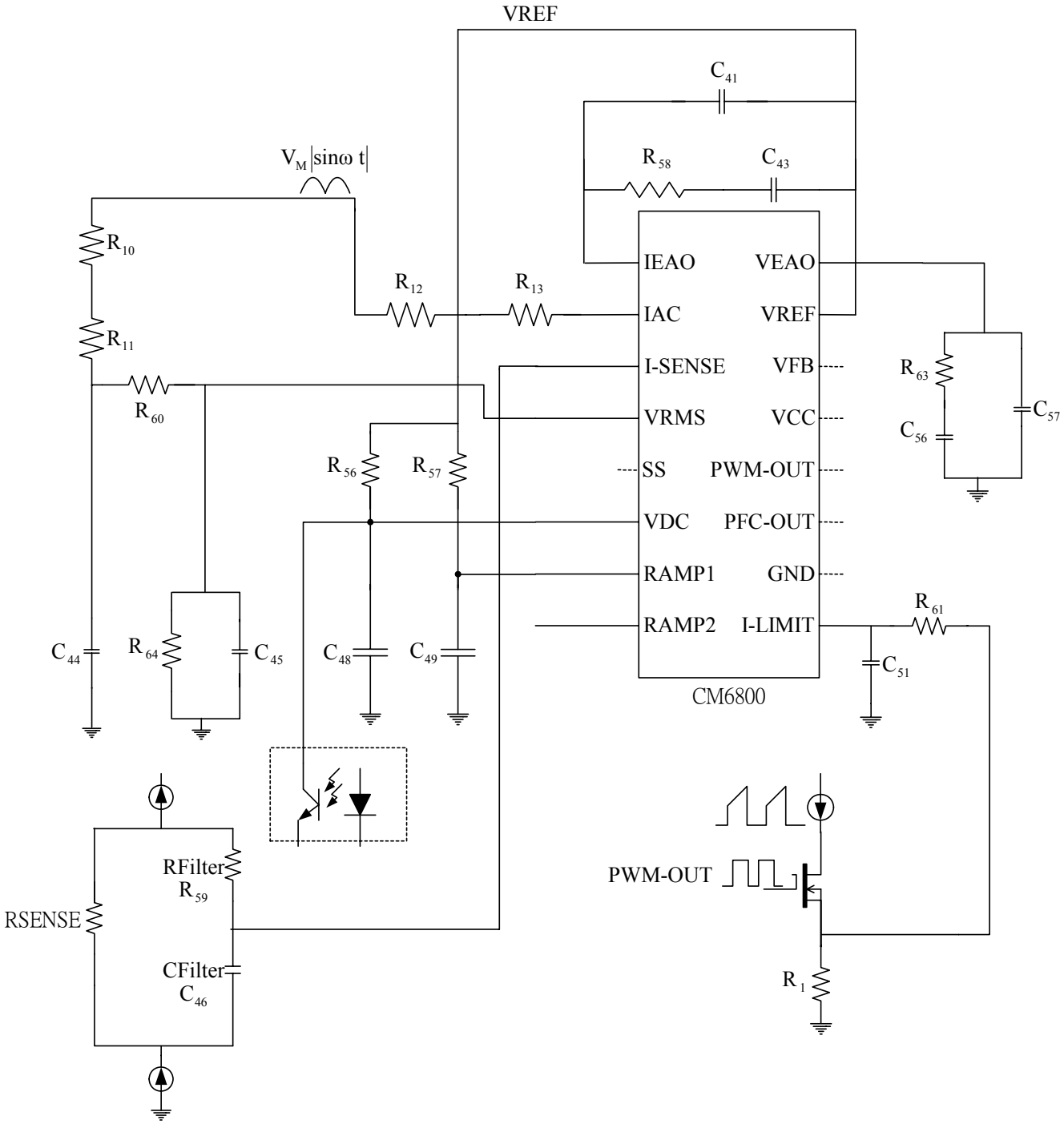


圖 1 CM6800 架構圖

(A)RAC：

RAC 為 gain modulator 的輸入，做為參考訊號，此電阻值的設定為 RAC= $vin_{PEAK} \times 10$ 以輸入電壓為 80 rms，RAC 的值約為 $80 \times \sqrt{2} \times 10 \approx 1M\Omega$ 。

(B)Isense：

Isense 訊號為當 boost converter 在開關切換動作時所流過的電流再乘上 RSENSE，經過一 low-pass filter 後送入 IC， R_{Filter} 的選擇 ，一般選擇 R_{Filter} 為 $47\Omega \sim 200\Omega$，因 Isense 之訊號需 filter (note1)為 $\frac{1}{6} \sim \frac{1}{10}$ switching frequency(f_s)，故可決定 C_{Filter} 。

note1：

$$Isense_{frequency} = \frac{1}{2\pi \times R_{Filter} \times C_{Filter}}$$

(C)VRMS：

VRMS，為橋式整流端經開關切換後的信號，再經過 2 階低通濾波器電路送入 IC 作為 A.G.C 之 input，在此設定 VRMS 電壓為 1.1V($80 v_{ac}$)。

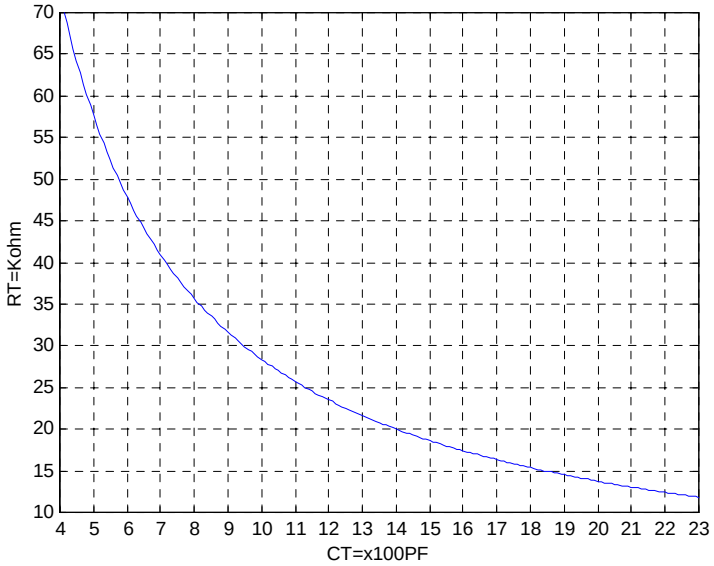
(D)RAMP1(R_T&C_T)的選擇：

在 CM6800 中 CT 建議值為 200PF~1000PF，其振盪頻率為：

$$f_{osc} = \frac{1}{(t_{RAMP} + t_{DEADTIME})} = 67K_{HZ}, t_{RAMP} = C_T \times R_T \times \ln \frac{V_{REF} - 1.25}{V_{REF} - 7.25}, V_{REF} = 7.5V = C_T \times R_T \times 0.51$$

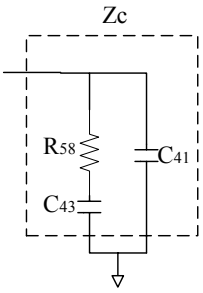
$$t_{DEADTIME} = \frac{2.5V}{5.5mA} \times C_T = 454.5 \times C_T$$

利用式(1)-(3)可求出 R_T 與 C_T 曲線，如圖 2，在此選用 C_T (C_{49})=470 PF 與 R_T (R_{57})=53.6KΩ 。



fig(2) R_T 與 C_T 曲線

NOTE：zero-pole net-work

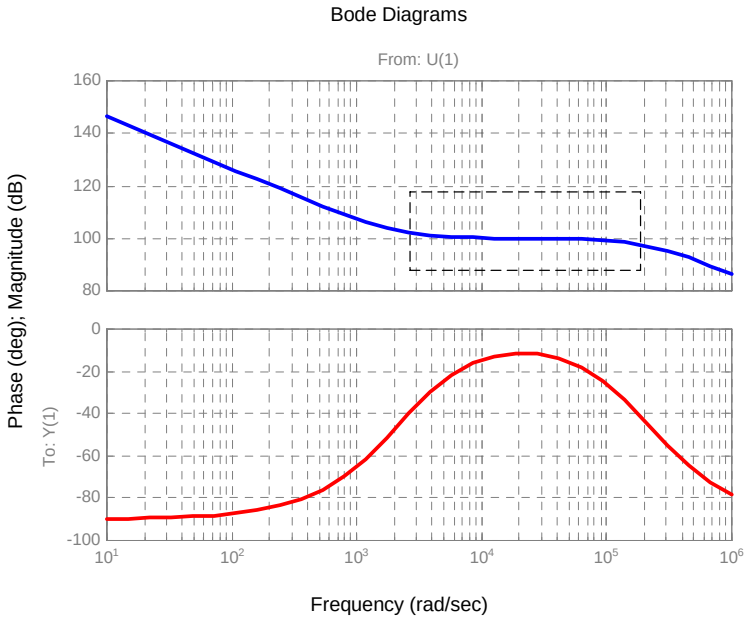


$$Z_{CI} = (R_{58} + \frac{1}{SC_{43}}) // \frac{1}{SC_{41}} = \frac{\frac{SR_{58}C_{43}+1}{SC_{43}SC_{41}}}{\frac{SR_{58}C_{43}+1}{SC_{43}} + \frac{1}{SC_{41}}} = \frac{SR_{58}C_{43}+1}{S^2R_{58}C_{43}C_{41} + S(C_{43}+C_{41})}$$

$$= \frac{SR_{58}C_{43}+1}{S(C_{43}+C_{41})(S\frac{R_{58}C_{43}C_{41}}{(C_{43}+C_{41})}+1)}$$

assume $C_{43} >> C_{41}$ 由式(9)可知 $Z_{CI} \approx \frac{SR_{58}C_{43}+1}{SC_{43}(S\frac{R_{58}C_{43}C_{41}}{C_{43}}+1)} = \frac{SR_{58}C_{43}+1}{SC_{43}(SR_{58}C_{41}+1)}$

有 2 個 pole 和一個 zero 其中 pole 的位置在 $S=0$ 和 $S=-\frac{1}{R_{58}C_{41}}$，zero 的位置在 $S=-\frac{1}{R_{58}C_{43}}$，由假設條件($C_{43} >> C_{41}$)可知系統一開始有一個 pole 在 $S=0$ 以此時以 -20db/dec 的 slope 下降，頻率增加遇到 zero，$S=-\frac{1}{R_{58}C_{41}}$，此時 slope=0，同時可得到一段平坦的增益，頻率再增加遇到 pole，$S=-\frac{1}{R_{58}C_{43}}$，以 -20db/dec 的 slope 下降，其波德圖可表示如下:



Z_{CI} 頻率響應圖

由圖可知，在圖中的平坦增益近似 R_{58}，由以上的分析，即可設計系統所需的 pole 與 zero 的位置

與增益的大小。

(E)IEAO：

IEAO 的補償為 GM_i 乘上 zero-pole network， 一般選擇其 unity-gain 為 $\frac{1}{6}$ switching-frequency $=23.33KH_Z$ ，zero 的位置為 0.1pole。

Example： current loop design

$$\text{Loop gain of the current loop} = \frac{V_o \times R_{SENSE}}{SLV_{R_TC_T p-p}} \times GM_i \times Z_{Ci} \qquad (0)$$

note:

Gmi：current loop error amplifier's transconductance，CM6800=100 μ ($\frac{1}{\Omega}$)

Z_{CI}：compensation net-work

Vout：PFC boost converter output voltage

fc：unity gain frequency, usually set $\frac{f_s}{6}$=11.166KHz(switching frequency),

set unity gain frequency at 11.166KHz, from equation (0) we can obtain equation (1).

$$1 = \frac{V_o \times R_{SENSE}}{SLV_{R_TC_T p-p}} \times GM_i \times Z_{Ci}, \text{at } 11.166KHz \qquad (1)$$

從式(1), 可求得 Z_{Ci}

$$GM_i \times Z_{Ci} = \frac{SLV_{R_TC_T p-p}}{V_o \times R_{SENSE}}$$

$$= \frac{2 \times \pi \times 11.166K_{HZ} \times 737.2987\mu 3 \times 2.5}{380 \times 0.09} \approx GM_i \times R_{58} \qquad (2)$$

note:

Vout=380V

$L = 735.2987\mu H$

GMi = 100μ mho

$V_{R_TC_T p-p} = 2.5V$

Set R_{SENSE}= 0.09Ω

Using equation (2), R_{58} is

$$R_{58} \approx 20K\Omega \quad \text{at} \quad GMi = 100\mu \text{ mho}$$

using unity gain frequency at 11.166KHz(f_c), $f_c = 11.166KHz \approx \frac{1}{2 \times \pi \times R_{58} \times C_{41}}$, therefore

$R_{58} = 20K\Omega$ $C_{41} = 347.878PF$ ， Let the zero=0.1 pole, therefore $C_{43} = 10C_{41}$

current loop compensation

current loop for leading edge modulation PFC，leading edge 可表示成圖 1

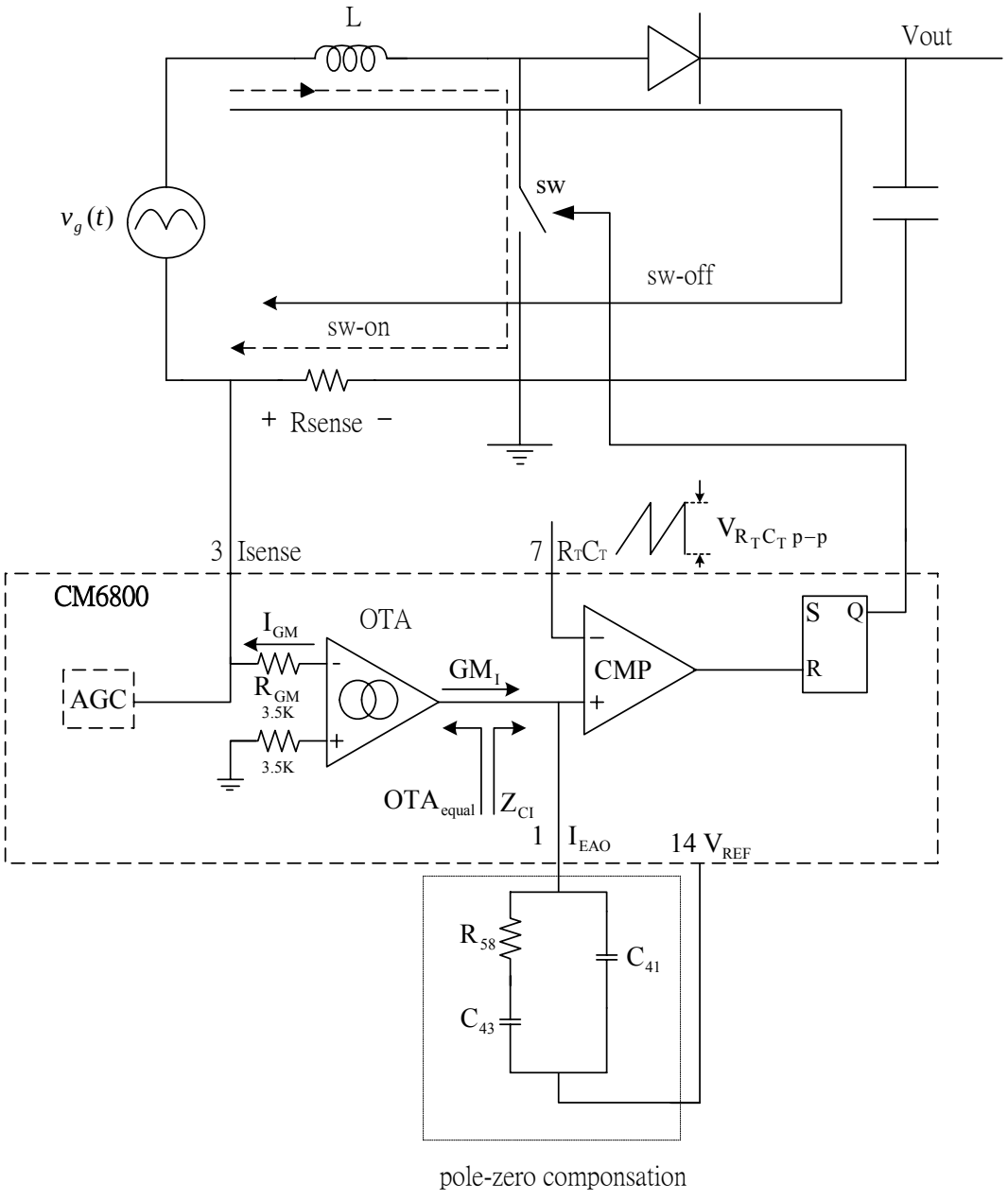


圖 1 PFC leading edge

current loop gain define：

$$\frac{\Delta V_{ISENSE}}{\Delta D_{OFF}} \times \frac{\Delta D_{OFF}}{\Delta I_{EAO}} \times \frac{\Delta I_{EAO}}{\Delta I_{Isense}} \tag{1}$$

$$\Delta V_{IEAO} = G_{MI} \times Z_{CI} \tag{2}$$

$$\frac{\Delta V_{R_{SENSE}}}{\Delta V_{I_{EAO}}} \equiv \frac{(b)}{(a)} \tag{3}$$

$$(b)\frac{(V_o - V_{IN})}{SL} \times R_{SENSE}$$

由 fig2 可知

$$\frac{V_{R_T C_T p-p}}{T_s} = \frac{\Delta V_{IEAO}}{DT_s}, \Delta V_{IEAO} = DV_{R_T C_T p-p} \tag{4}$$

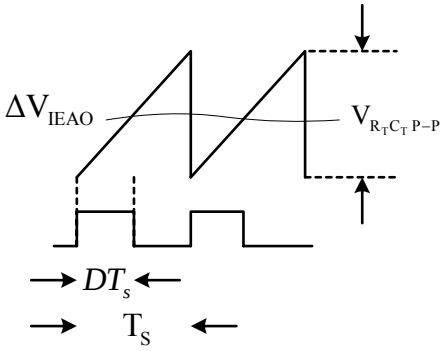


圖 2 ramp & ΔV_{IEAO} 波形

將式(4)代入(3)可得

$$\frac{\Delta V_{R_{SENSE}}}{\Delta V_{I_{EAO}}} \equiv \frac{(b)}{(a)} = \frac{\frac{(V_o - V_{IN})}{SL} \times R_{SENSE}}{DV_{R_T C_T p-p}} \tag{5}$$

boost 電壓轉換比：

$$\frac{V_o}{V_{IN}} = \frac{1}{(1-D)} \tag{6}$$

式(6)代入式(5)可得

$$\frac{\Delta V_{R_{SENSE}}}{\Delta V_{I_{EAO}}} \equiv \frac{(b)}{(a)} = \frac{\frac{(V_o - V_{IN})}{SL} \times R_{SENSE}}{DV_{R_T C_T p-p}} = \frac{V_o \times R_{SENSE}}{SLV_{R_T C_T p-p}} = \frac{V_o \times R_{SENSE}}{\omega L V_{R_T C_T p-p}} \tag{7}$$

set $\left|\frac{\Delta V_{R_{SENSE}}}{\Delta V_{I_{EAO}}}\right| = 1$ 可求出 crossover frequency $\omega_C = \frac{V_o \times R_{SENSE}}{LV_{R_T C_T p-p}}$ (8)

由式(8)可繪出其波德圖，其中 $\omega_P = \frac{2}{RC}$

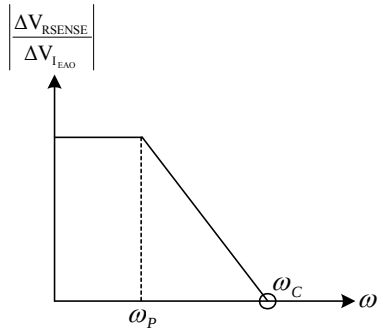


圖 3 $\left|\frac{\Delta V_{RSENSE}}{\Delta V_{I_{EAO}}}\right|$大小與頻率響應圖

(F)VEAO：

VEAO 的補償為GM_V乘上 zero-pole network， 一般選擇其 unity-in(crossover-frequency)為$\frac{1}{2}$line-frequency$=30H_Z$(或$25H_Z$)，zero 的位置為 0.1pole。

voltage loop show in fig1.As illustrated in fig.1 the loop gain can be written equation(1).

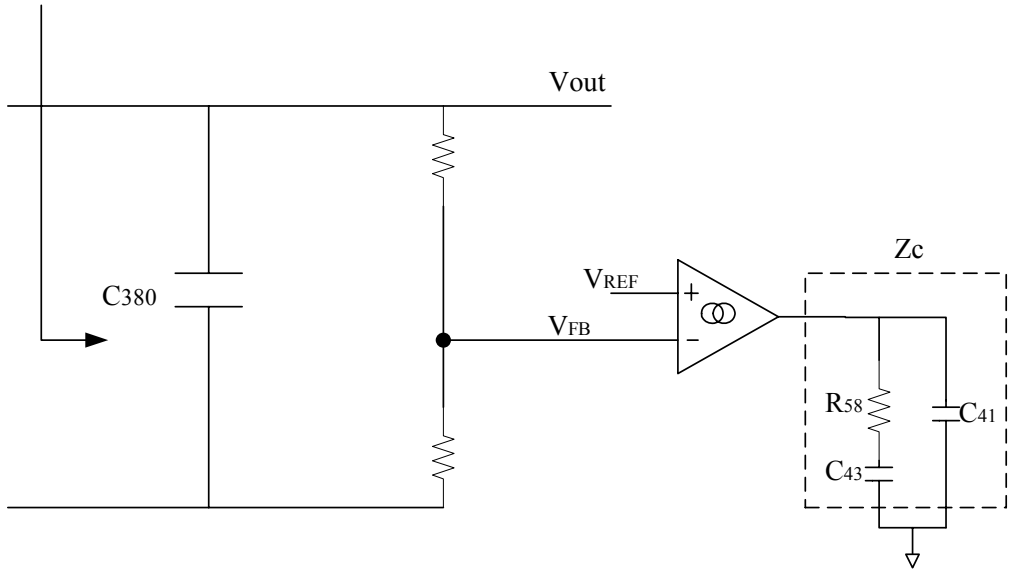


fig.1 voltage loop

$$\text{Loop gain of the voltage loop} = \left(\frac{dV_{out}}{dVeao}\right)\times\left(\frac{dV_{fb}}{dV_{out}}\right)\times\left(\frac{dV_{eao}}{dV_{fb}}\right)$$

$$= \frac{Pin\times 2.5V\times GM_V\times Z_{CV}}{V_{out}\times\Delta V_{eao}\times S\times C_{380}\times V_{out}} \qquad (1)$$

note:

Pin: Max. input power

GMv:VEAO's transconductance(90umho)

Zcv:compensation Net Work at VEAO(voltage error amplifier)

Vout:PFC boost converter output voltage

Dveao:Max. effective swing which is 6V-.625V=5.375V(IC internal)

set unity gain frequency at 25Hz, from equation (1) we can obtain equation (2).

$$1 = \frac{Pin\times 2.5V\times GM_V\times Z_{CV}}{V_{out}\times\Delta V_{eao}\times S\times C_{380}\times V_{out}}, \text{at } 25Hz \qquad (2)$$

using equation (2), we can find GMv×Zcv

$$GM_V \times Z_{CV} = \frac{V_{out} \times \Delta V_{eao} \times S \times C_{380} \times V_{out}}{Pin \times 2.5}$$
$$= \frac{390V \times 5.375V \times S \times 150uF \times 390}{Pin \times 2.5} \approx GM_V \times R_{58} \quad (3)$$

note:

Vout=390V

$C_{380} = 150uF$

GMv≈ 90u mho

Set Pout=240Watt,efficiency= 70% , ∴ Pin = 342Watt

Using equation (3), R_{58} is

$$R_{58} = 162K\Omega \quad at GMv = 90u \text{ mho}$$

using unity gain frequency at 7Hz(f_c), $f_c = 7\,HZ \approx \frac{1}{2 \times \pi \times R_{58} \times C_{41}}$, therefore

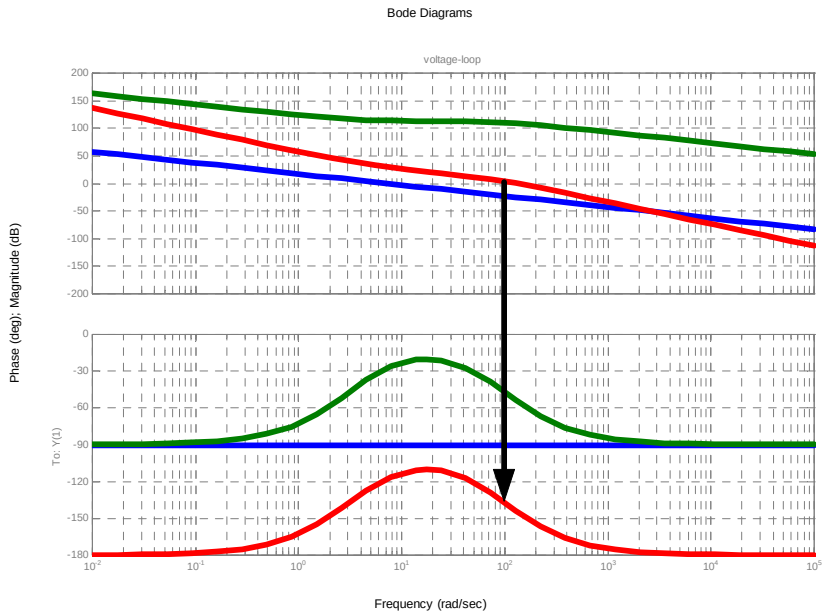
$R_{58} = 162K\Omega$ $C_{41} = 140nF$, $R_{58} = 124K\Omega$ $C_{41} = 183.358nF$ .Let the zero =0.1 pole ,therefore , $f_z = 0.7\,HZ$ and $C_{43} = 10C_{41}$, $R_{63} = 475K\Omega$ ， $C_{56} = 0.47\mu F$ ， $C_{57} = 0.022\mu F$

$$\text{pole} = \frac{1}{2 \times \pi \times R_{63} \times C_{56}} = 3.28\,H_z \text{ ， zero} = \frac{1}{2 \times \pi \times R_{63} \times C_{57}} = 0.328\,H_z \text{ 。}$$

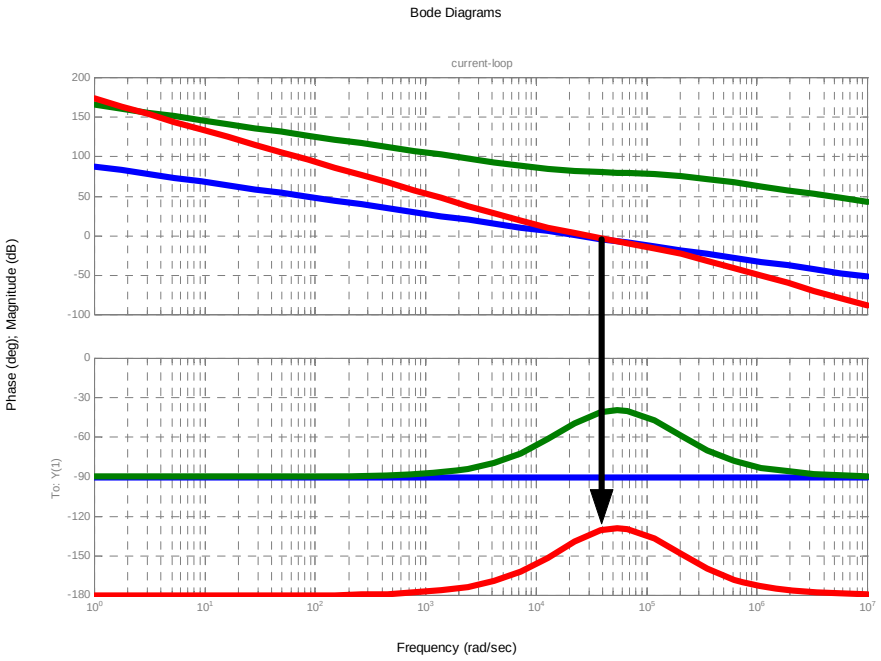
Example：Pout=240W, $\eta = 0.7$,PFC choke=800uH,bulk cap.=150uF,Rsense=0.1 Ω //0.15 Ω

bulk cap voltage=380(Veao:R=475K+C1=684P//C2=223P)

voltage-loop



current-loop(Ieao:R=11K+C1=472P//C2=681P)



Test conditions:

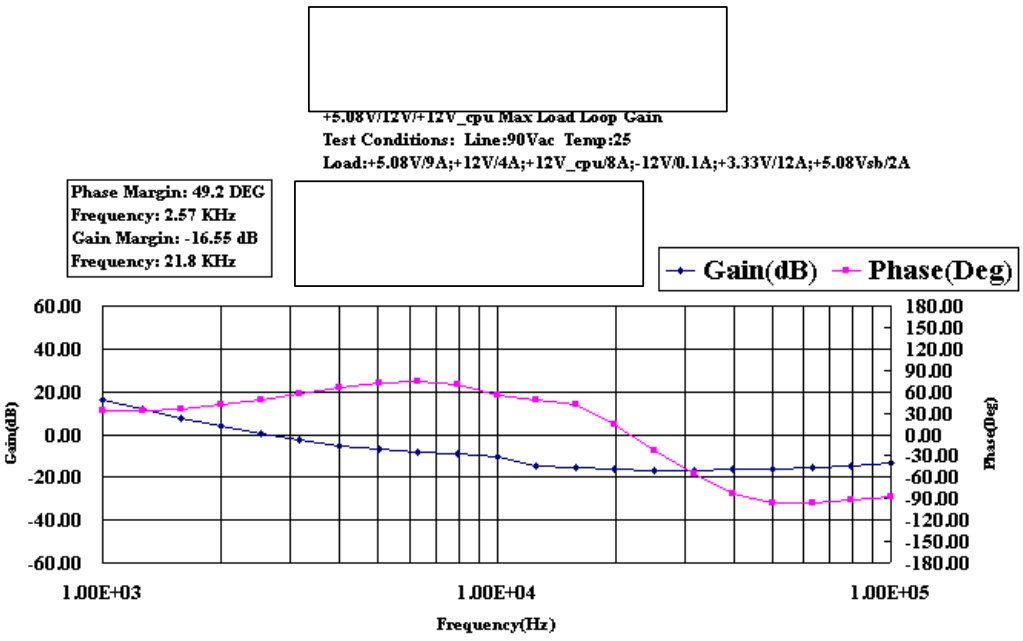
The loop stability is measured at the minimum and maximum AC line, and both at minimum and maximum load.

Pass/Fail criteria:

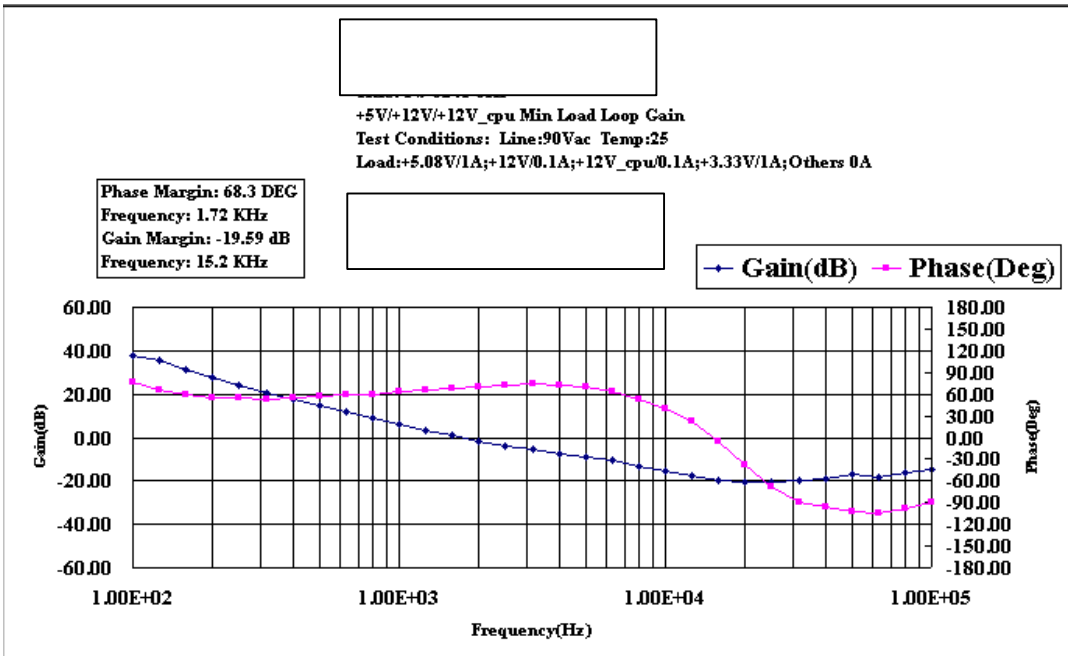
Phase margin has to be greater than 45deg. Data must be provided by the Power Supply vendor.

Test Result: **Pass**
The worse case is
Phase margin : 48.3º at 264V/50Hz max. load
Gain margin : -15.46 dB at 264V/50Hz max. load

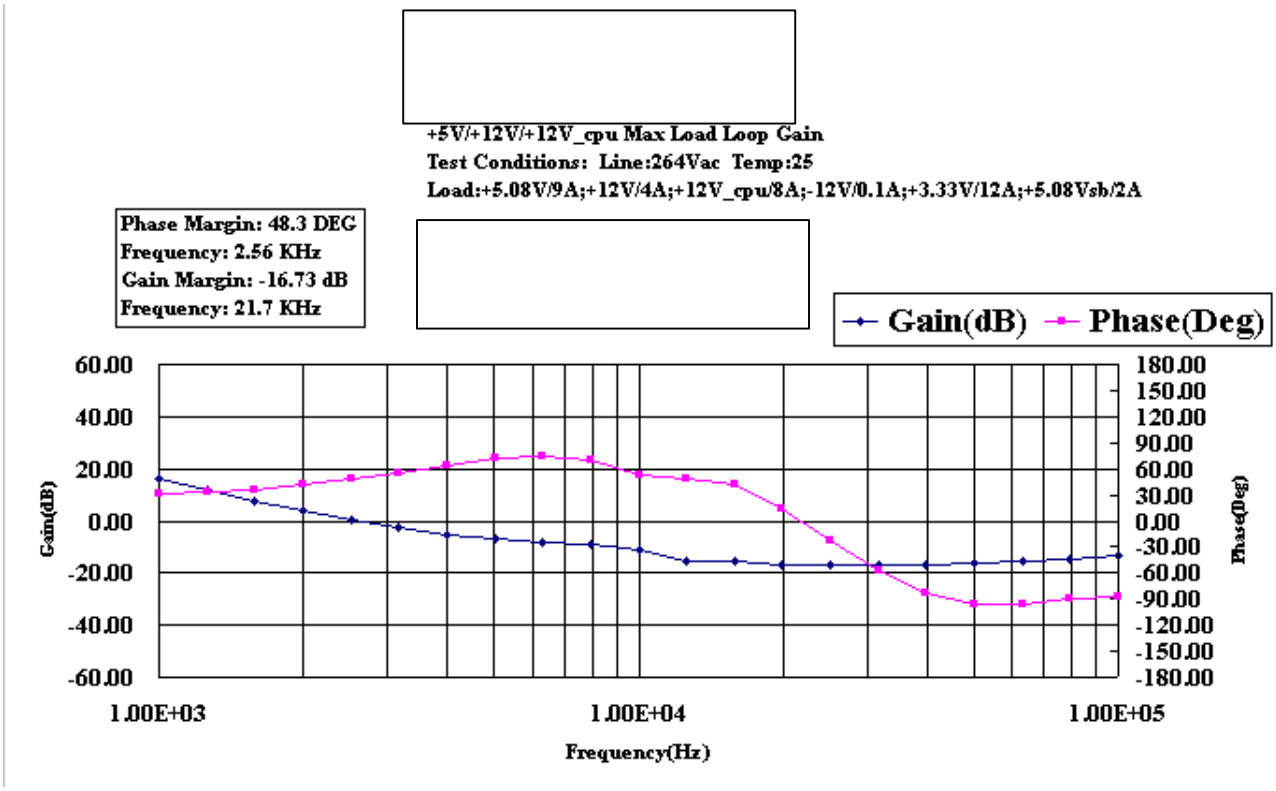
90Vac Max. Load (+5.08V/+12V/+12V_cpu Loop Gain)



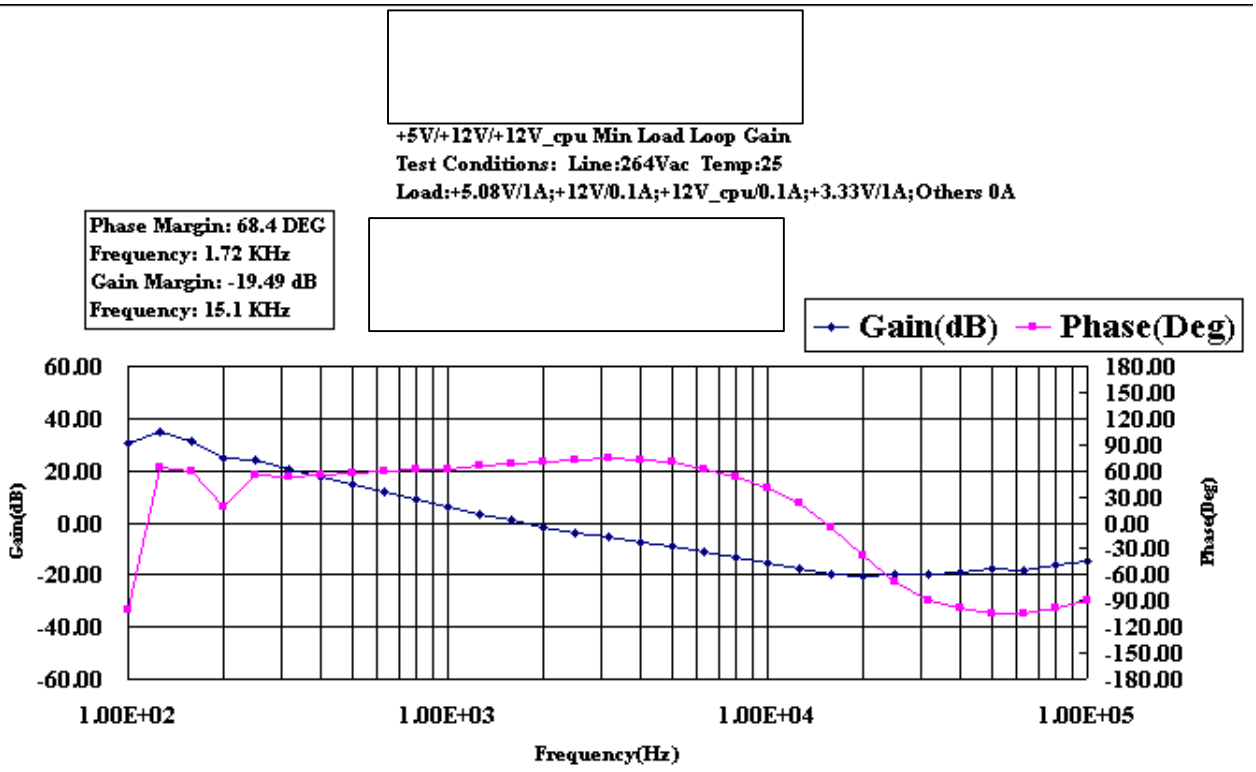
90Vac Min. Load (+5.08V/+12V/+12V_cpu Loop Gain)



264Vac Max. Load (+5.08V/+12V/+12V_cpu Loop Gain)



264Vac Min. Load (+5.08V/+12V/+12V_cpu Loop Gain)



AC 如何轉換成 DC

交流電壓如何轉換至直流電壓，如圖 1，在橋式整流輸入端與輸出端之間加入電力轉換器(converter)，同時可達到功因校正與輸出直流電壓的功能。

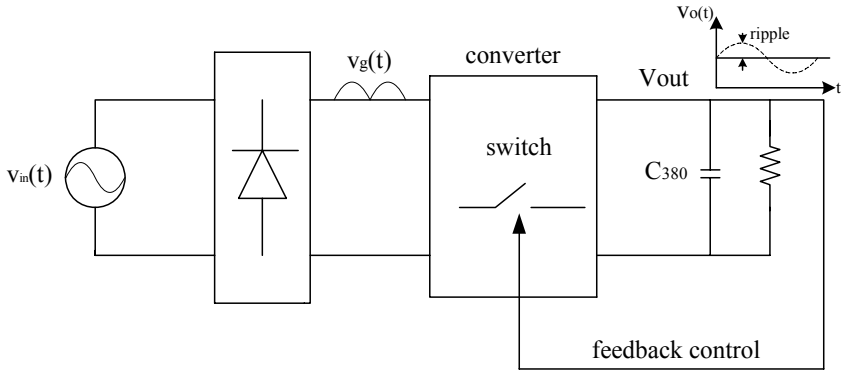


圖 1 AC to DC 方塊圖

在分析前先所需了解兩點，(a) $p_{in}(t) \neq p_{out}(t)$ 輸入瞬時功率不等於輸出瞬時功率，(b) $\langle p_{in}(t) \rangle = \langle p_{out}(t) \rangle$ 輸入平均功率等於輸出平均功率(note:符號〈 〉，表平均之意)。

法(1)：

$$W_{C_{380}} = \frac{1}{2} C v_C(t)^2 \qquad (1)$$

$$P_{C_{380}} = \frac{d}{d_t}[\frac{1}{2}Cv_C(t)^2] = P_{in}(t) - P_R(t) \tag{2}$$

$$P_{in}(t) = \frac{d}{d_t}[\frac{1}{2}C_{380}v_C(t)^2] + P_R(t) = \frac{d}{d_t}[\frac{1}{2}C_{380}v_c(t)^2] + \frac{v_C(t)^2}{R}$$

$$= \frac{d}{d_t}[\frac{1}{2}C_{380}v_C(t)^2] + \frac{2}{RC}\frac{1}{2}C_{380}v_C(t)^2 \tag{3}$$

將式(3)取 Laplace 可得

$$P_{in}(S) = [S + \frac{2}{RC_{380}}][\frac{1}{2}Cv_C(t)^2] \tag{4}$$

式(4)可表示成圖 2

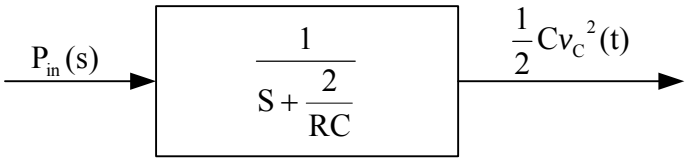


圖 2 AC to DC 轉移函數方塊圖

set $v_{in}(t) = V_M \sin\omega t$ ， $i_{in}(t) = I_M \sin\omega t$ ， V_M/I_M ：輸入電壓峰值/輸入電流峰值，輸入功瞬時功率可表示成

$$P_{in}(t) = V_M I_M \sin^2\omega t = \frac{V_M I_M}{2}(1 - \cos 2\omega t) \tag{5}$$

式(5)以波德圖可表示成圖 3，由圖 3 中可看出，若要輸出電壓漣波小，則 $\frac{2}{RC} << 2\omega t$，輸出電壓可得一個較好的直流電壓。

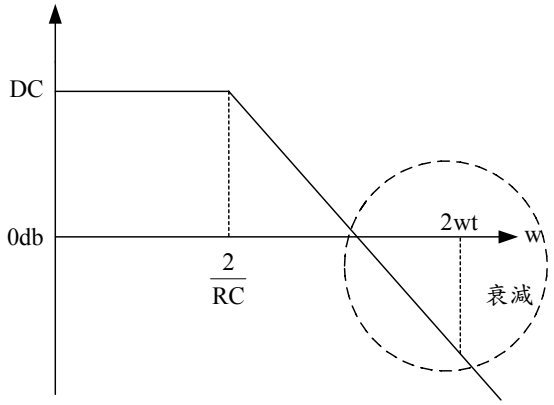


圖 3 輸入到輸出之 bode plot