



环路补偿很容易



课程的目的

- ✓ 确定功率级特性
- ✓ 说明 **Type II** 补偿 – 电流模式
- ✓ 阐述 **Type III** 补偿 – 电压模式
- ✓ 补偿电流模式降压
- ✓ 找出交越频率和相位裕量
- ✓ 使用 **Excel** 补偿器设计工具



电源转换器拓扑

降压 /
正激式

-

升压

-

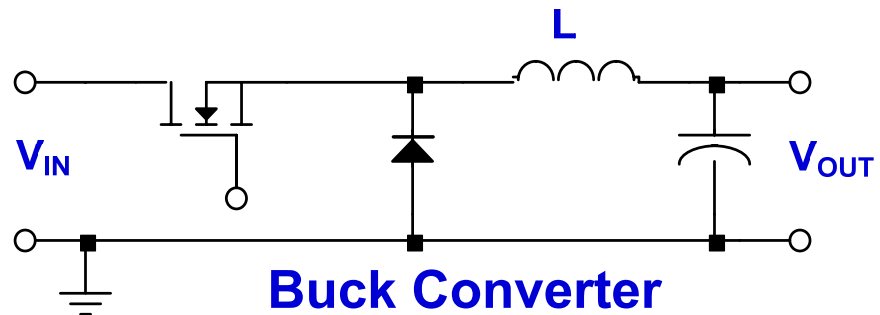
降压-升压 /
反激式

-



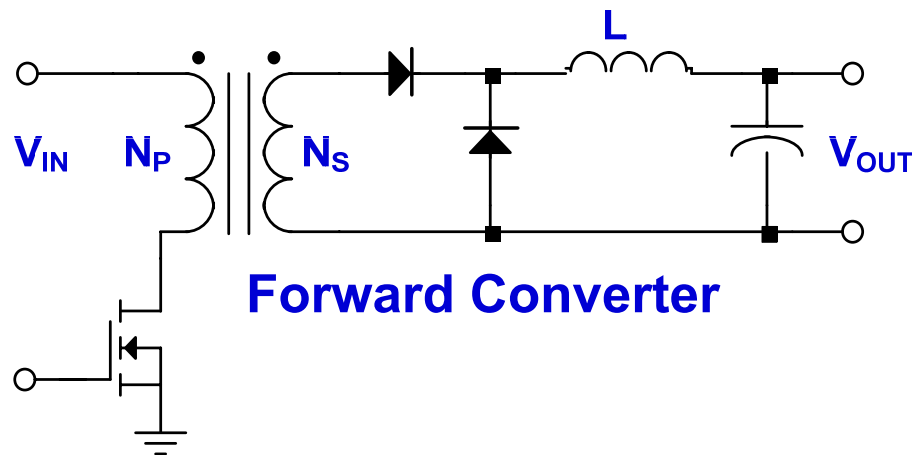
电源转换器拓扑

降压 /
正激式



$$V_{OUT} = V_{IN} \cdot D$$

升压



$$V_{OUT} = V_{IN} \cdot D \cdot \frac{N_S}{N_P}$$

降压-升压 /
反激式

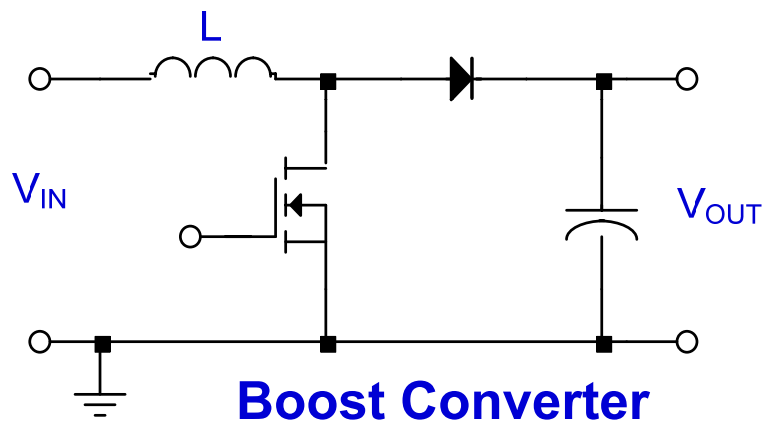


电源转换器拓扑

降压 /
正激式

升压

降压-升压 /
反激式



$$V_{OUT} = V_{IN} \cdot \frac{1}{1-D}$$

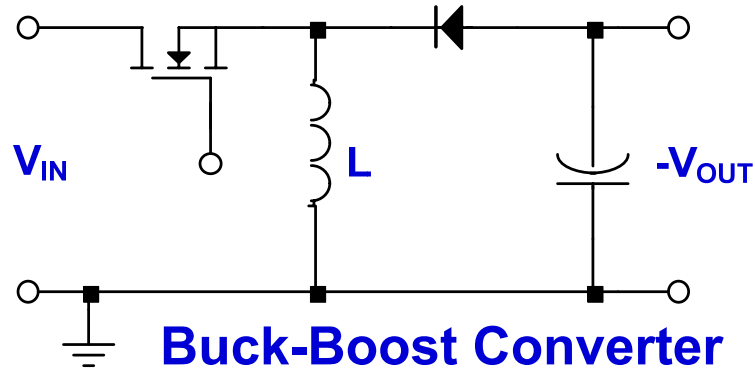


电源转换器拓扑

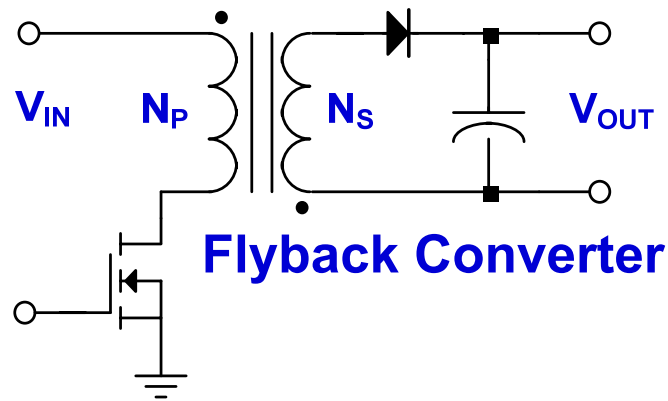
降压 /
正激式

升压

降压-升压 /
反激式



$$V_{OUT} = V_{IN} \cdot \frac{D}{1-D}$$



$$V_{OUT} = V_{IN} \cdot \frac{D}{1-D} \cdot \frac{N_S}{N_P}$$



极点/零点回顾

单个极点

单个零点

反相零点 (**Inverted Zero**)

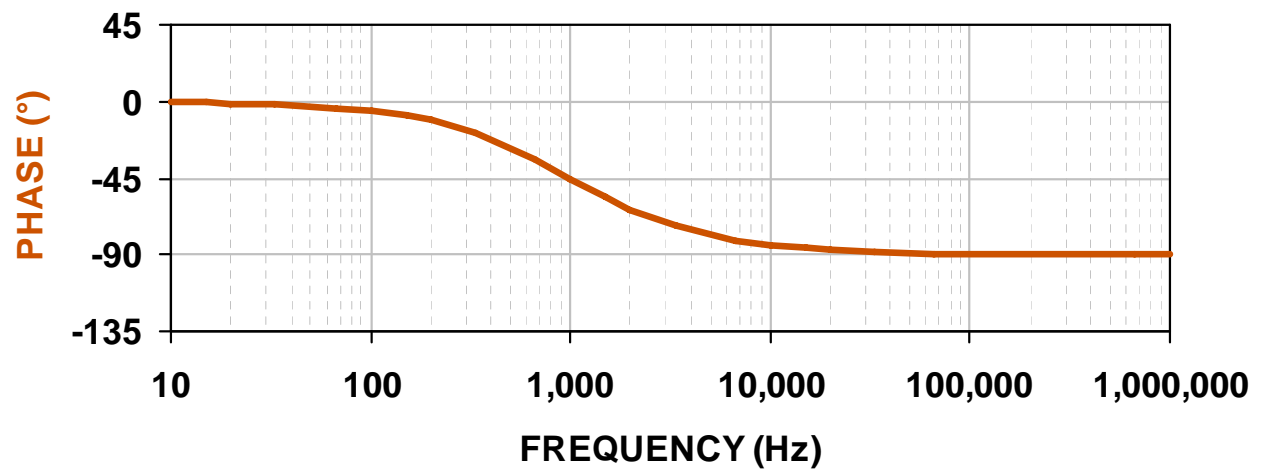
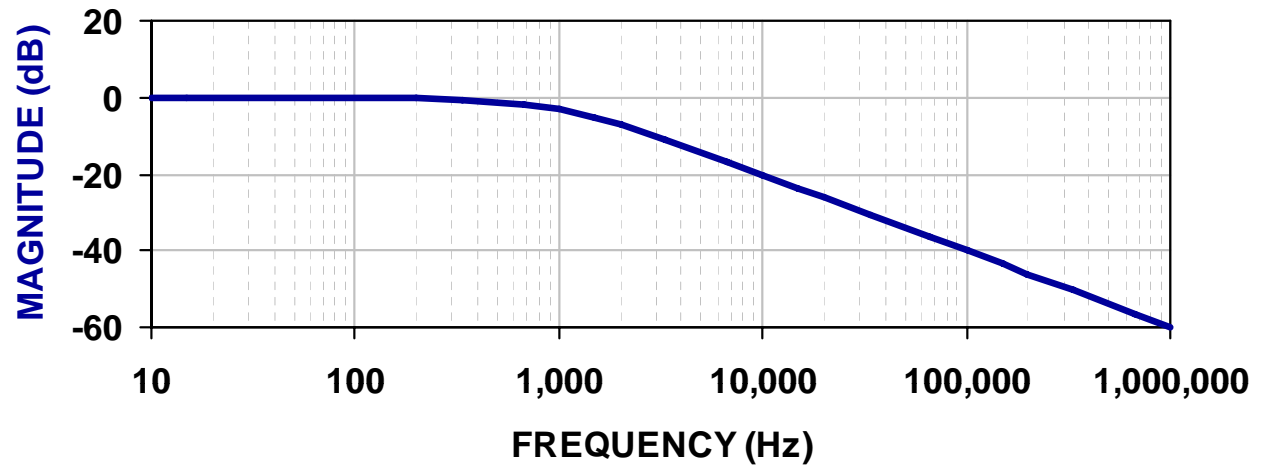
右半平面零点

共轭复极点



单个极点

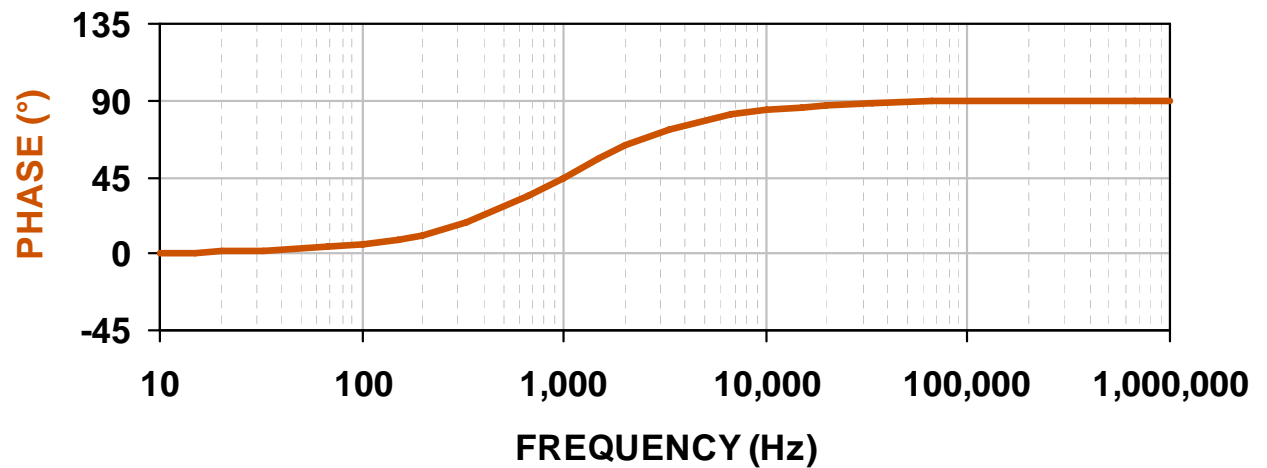
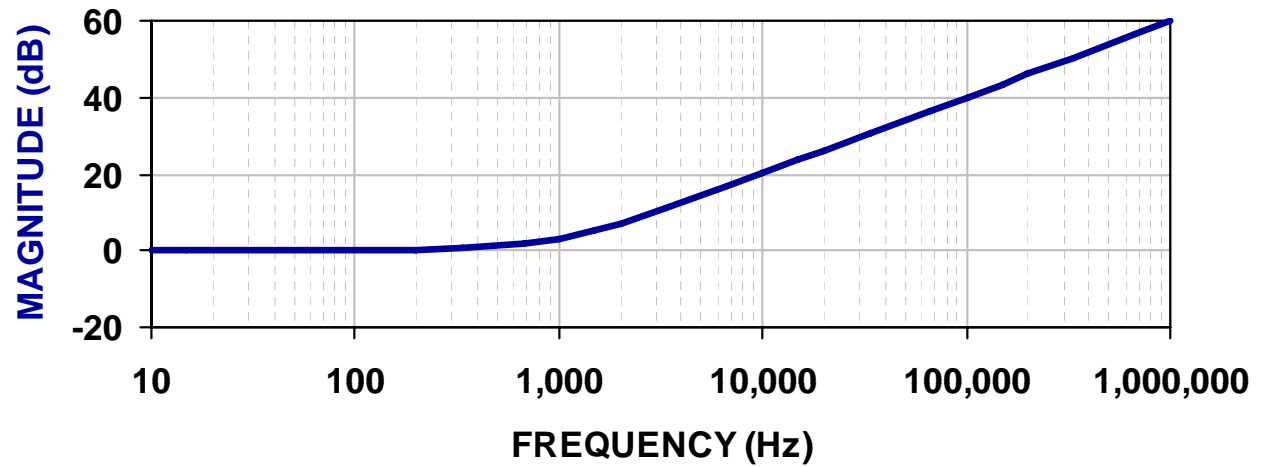
$$H(s) = \frac{1}{1 + \frac{s}{\omega_p}}$$





单个零点

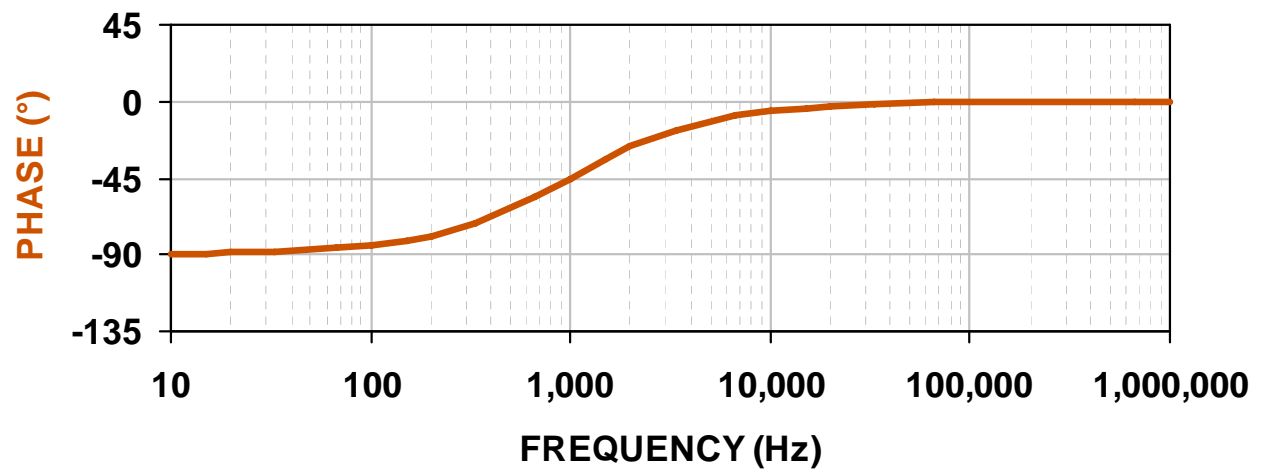
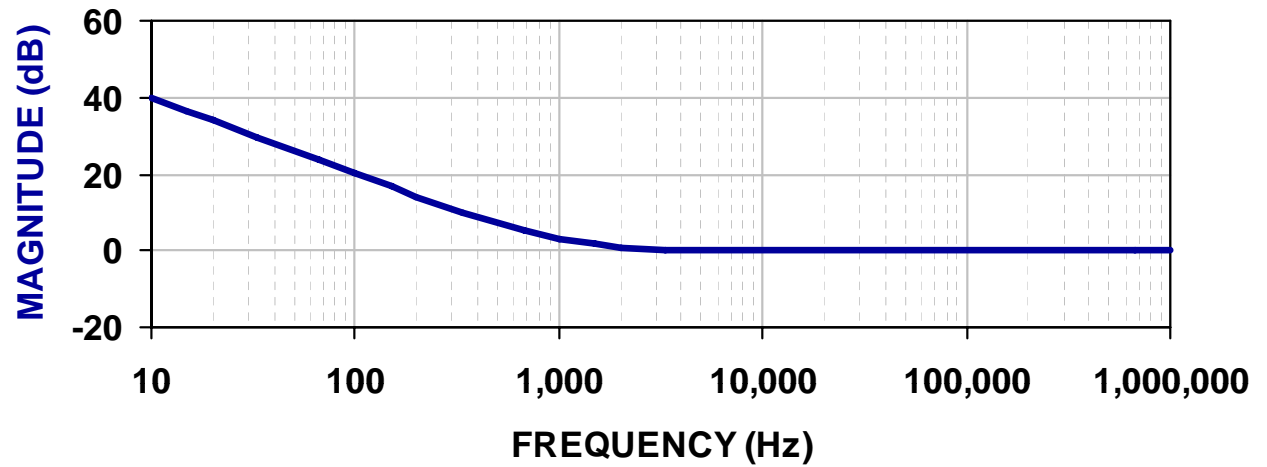
$$H(s) = \frac{1 + \frac{s}{\omega_z}}{1}$$





反相零点

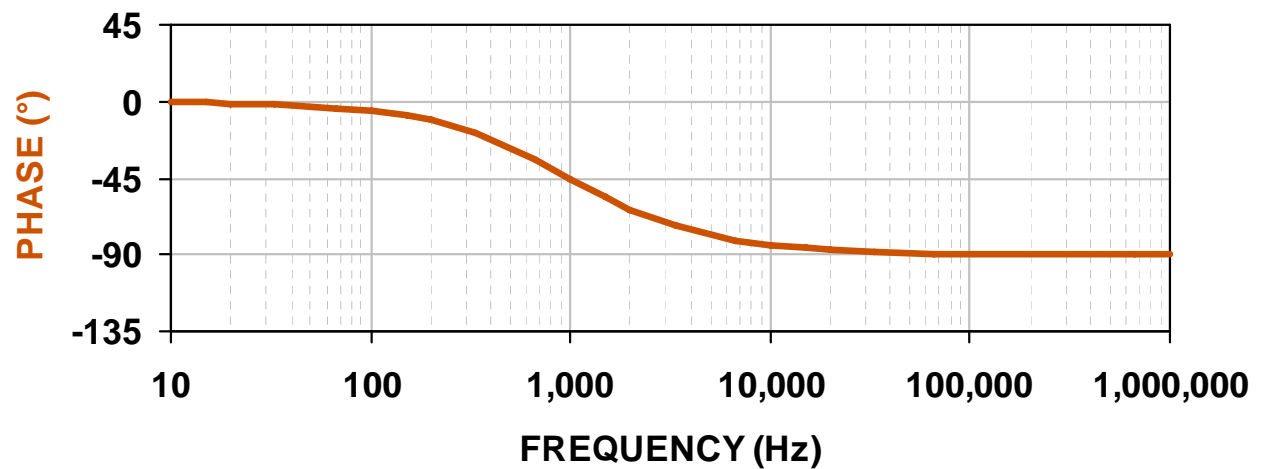
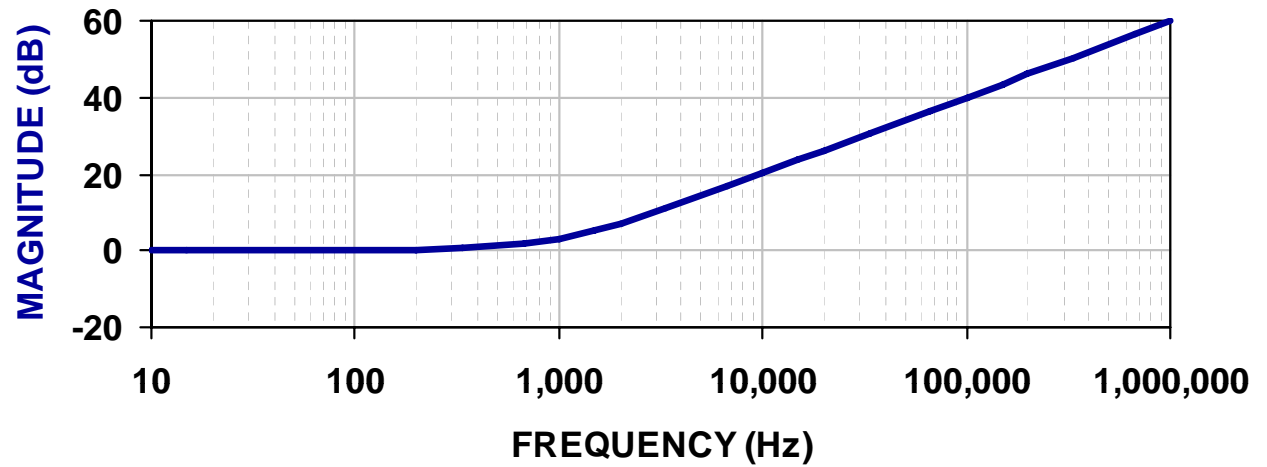
$$H(s) = \frac{1 + \frac{\omega_z}{s}}{1}$$





右半平面零点

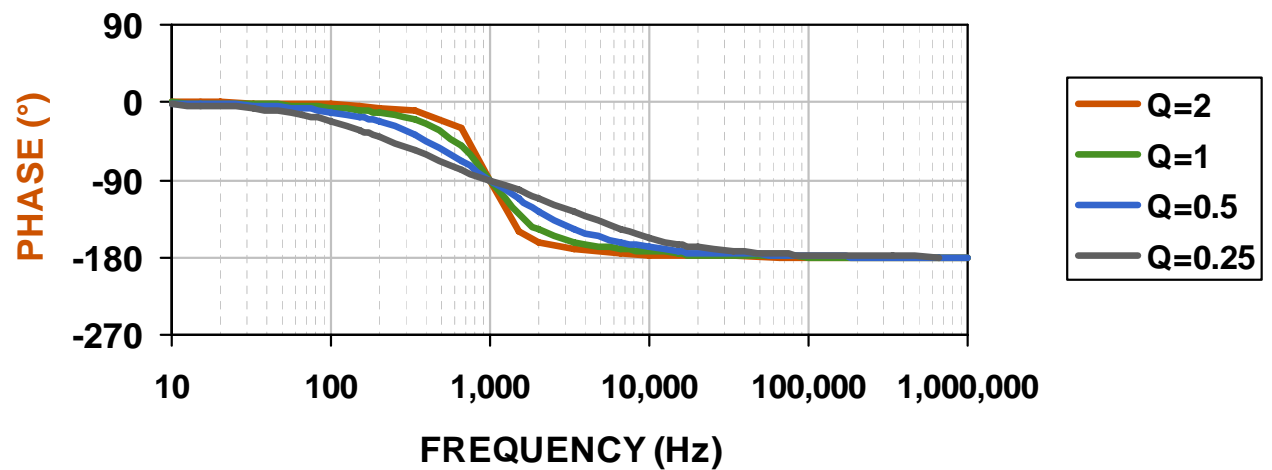
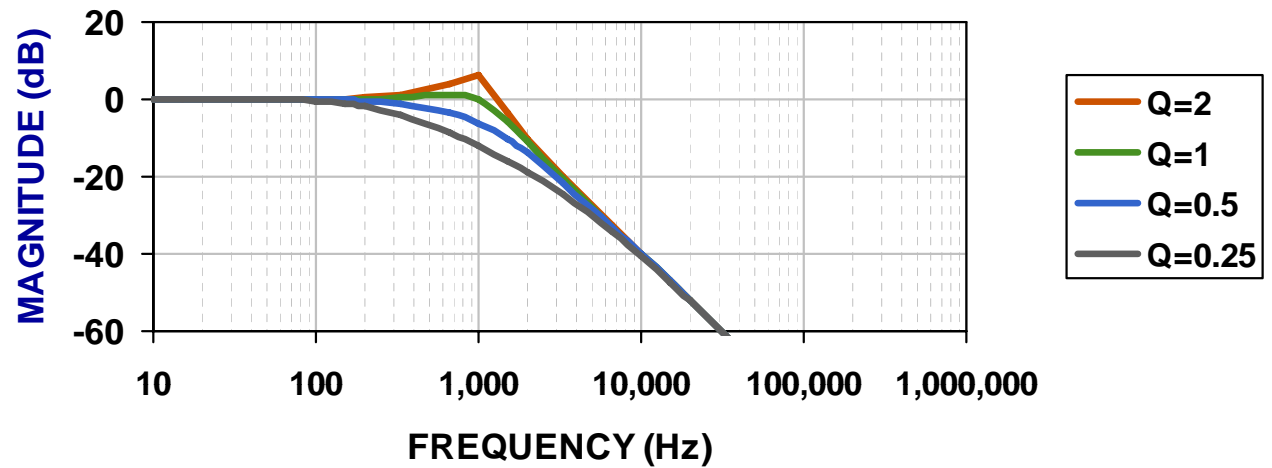
$$H(s) = \frac{1 - \frac{s}{\omega_z}}{1}$$





共轭复极点

$$H(s) = \frac{1}{1 + \frac{s}{Q_0 \cdot \omega_0} + \frac{s^2}{\omega_0^2}}$$





控制环路基础知识

环路补偿介绍

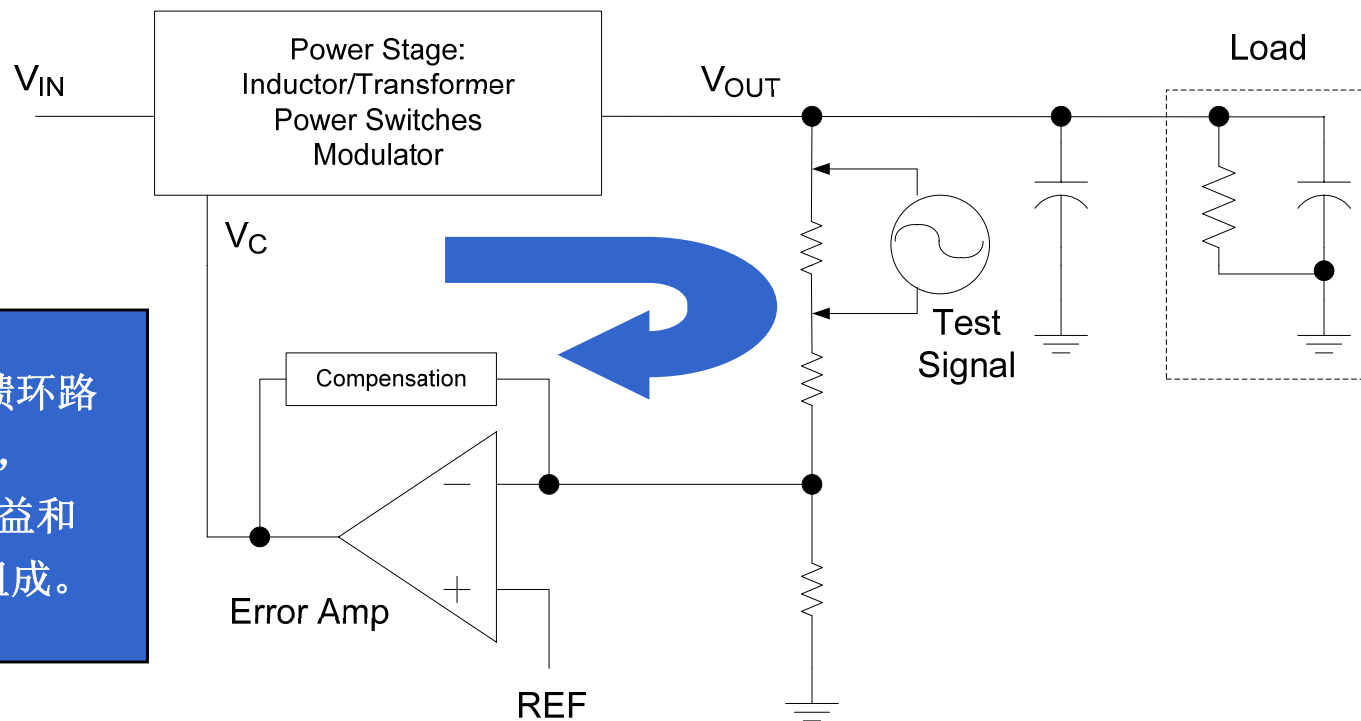
理想的控制环路

实用的反馈理论



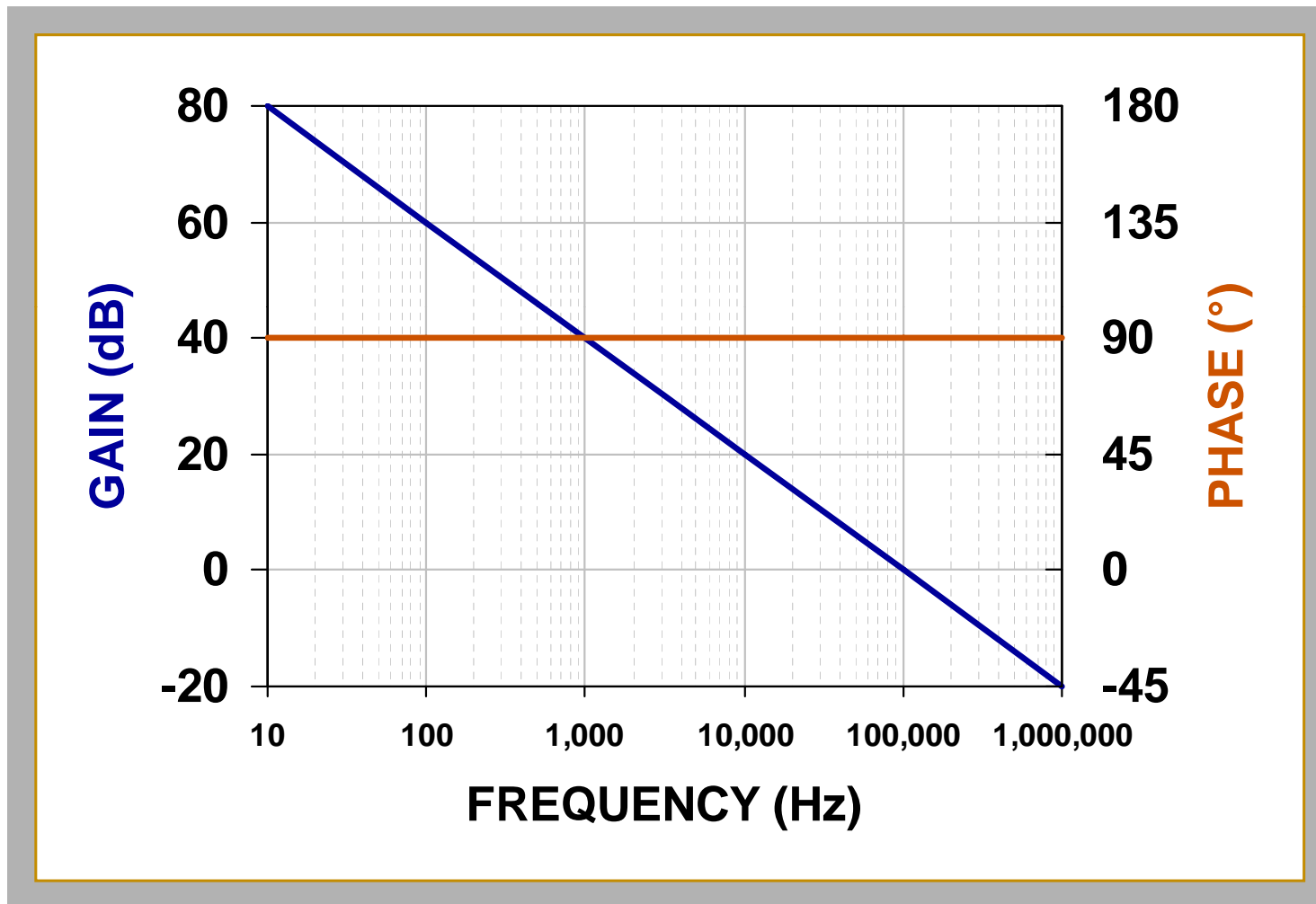
环路补偿介绍

环路增益是以反馈环路为中心的增益，由误差放大器增益和功率级增益部分组成。





理想的控制环路





实用的反馈理论

交越频率

- 控制环路的带宽决定了环路对于某种瞬态状况的响应速度
- 通常都会优先选择较高的交越频率，但存在着实际的限制。经验法则是将其设定为开关频率的 1/5 至 1/10
- 0° （增益裕量）时的衰减以及开关频率下的衰减也是很重要的

相位裕量

- 需要充足的相位裕量以避免发生振荡
- 最佳的相位裕量是 52°
- 低相位裕量将导致欠阻尼的系统响应
- 较高的相位裕量则导致过阻尼的系统响应



功率级回顾

电压模式降压

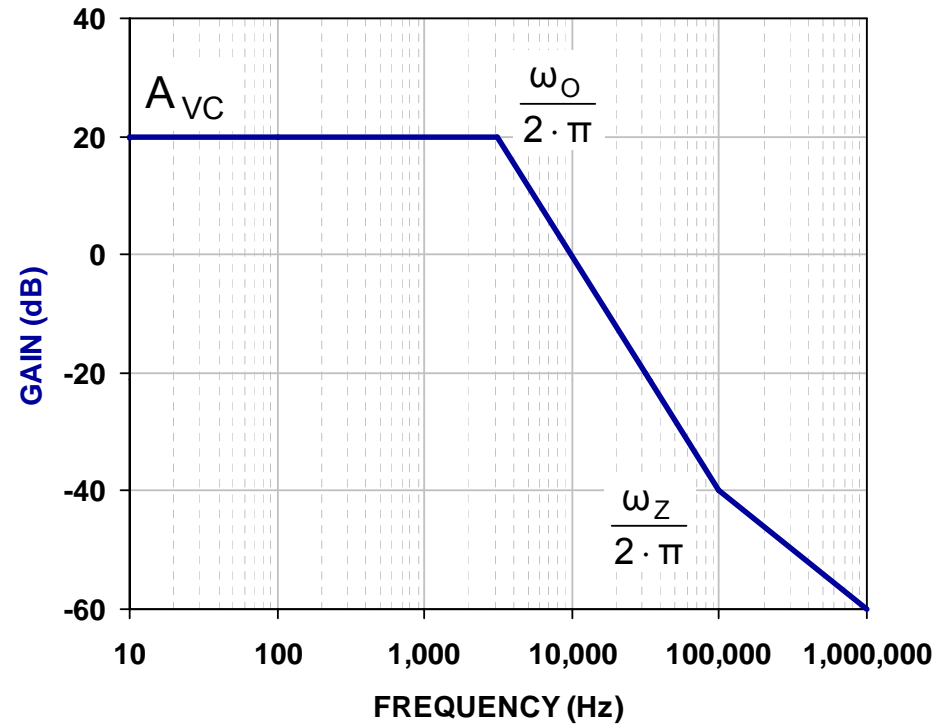
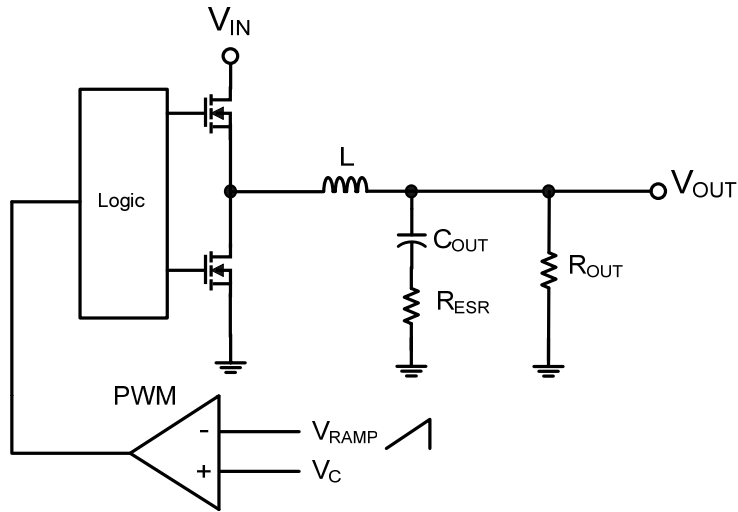
电流模式降压

电流模式升压

电流模式降压-升压



电压模式降压功率级



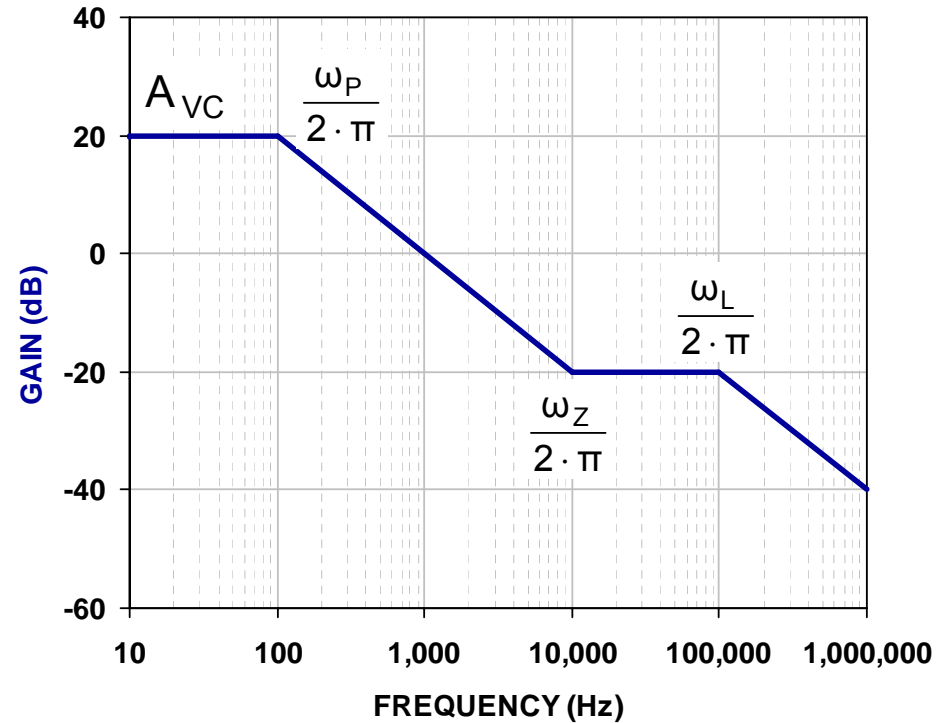
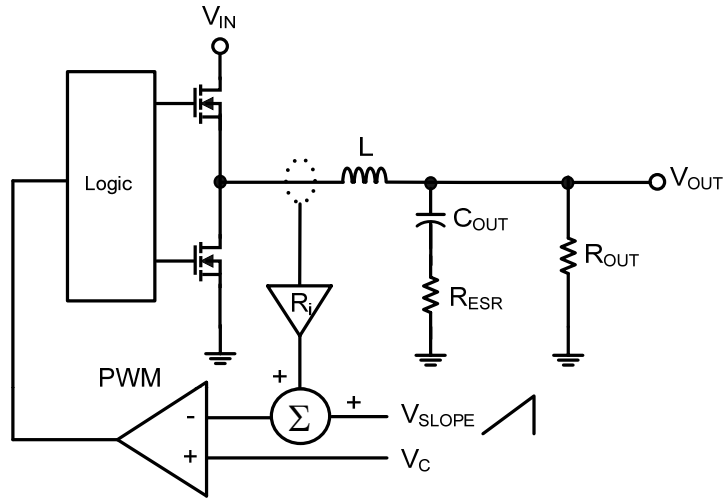
$$A_{VC} = \frac{V_{IN}}{V_{RAMP}} \quad \omega_0 = \frac{1}{\sqrt{L \cdot C_{OUT}}}$$

$$Q_0 = \frac{R_{OUT}}{\sqrt{L/C_{OUT}}} \quad \omega_z = \frac{1}{R_{ESR} \cdot C_{OUT}}$$

$$\frac{\hat{V}_{OUT}}{\hat{V}_C} = A_{VC} \cdot \frac{1 + \frac{s}{\omega_z}}{1 + \frac{s}{Q_0 \cdot \omega_0} + \frac{s^2}{\omega_0^2}}$$



电流模式降压功率级



$$A_{VC} \approx \frac{R_{OUT}}{R_i}$$

$$\omega_P \approx \frac{1}{C_{OUT} \cdot R_{OUT}}$$

$$\omega_Z = \frac{1}{R_{ESR} \cdot C_{OUT}}$$

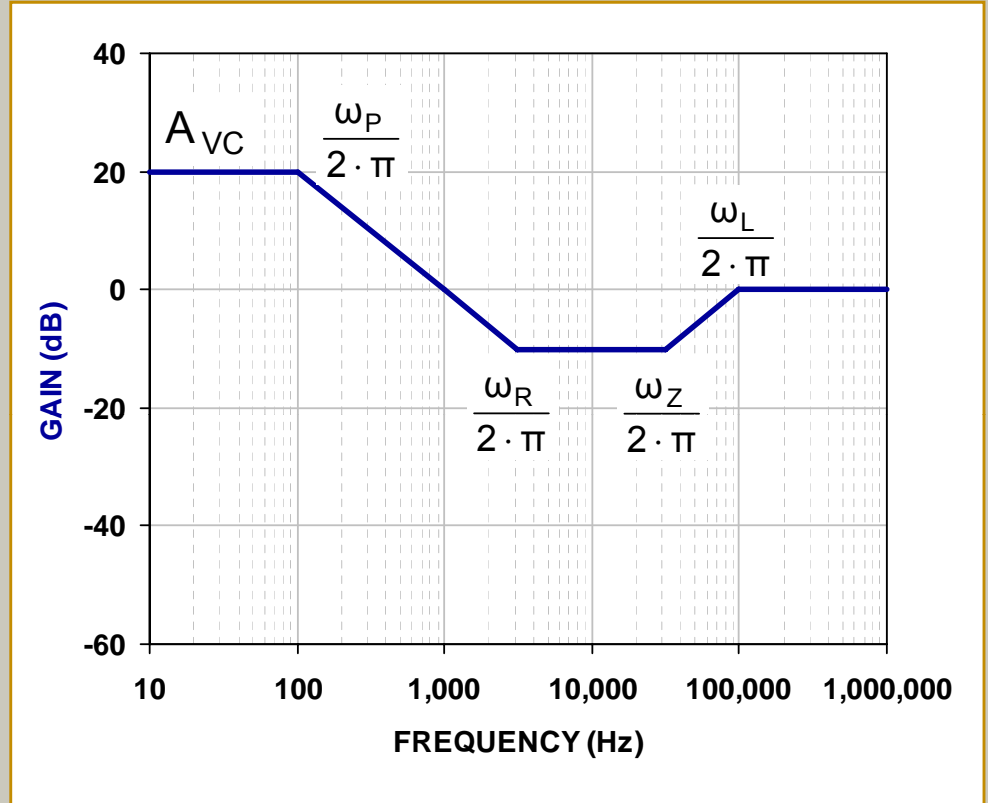
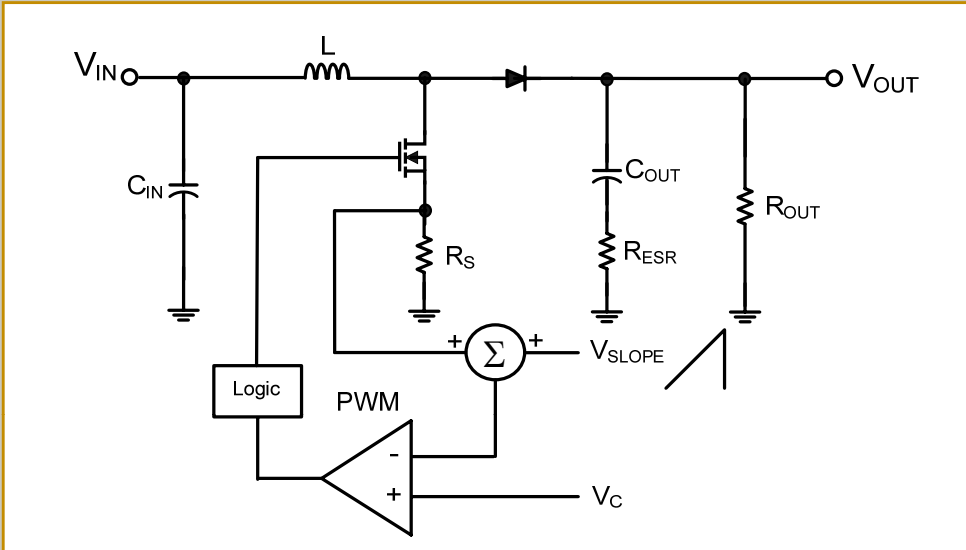
$$K_m \approx \frac{V_{IN}}{V_{SLOPE}}$$

$$\omega_L = \frac{K_m \cdot R_i}{L}$$

$$\frac{\hat{V}_{OUT}}{\hat{V}_C} \approx A_{VC} \cdot \frac{1 + \frac{s}{\omega_Z}}{\left(1 + \frac{s}{\omega_P}\right) \cdot \left(1 + \frac{s}{\omega_L}\right)}$$



电流模式升压功率级



$$A_{VC} \approx \frac{R_{OUT} \cdot D'}{2 \cdot R_i} \quad \omega_R = \frac{R_{OUT} \cdot D'^2}{L}$$

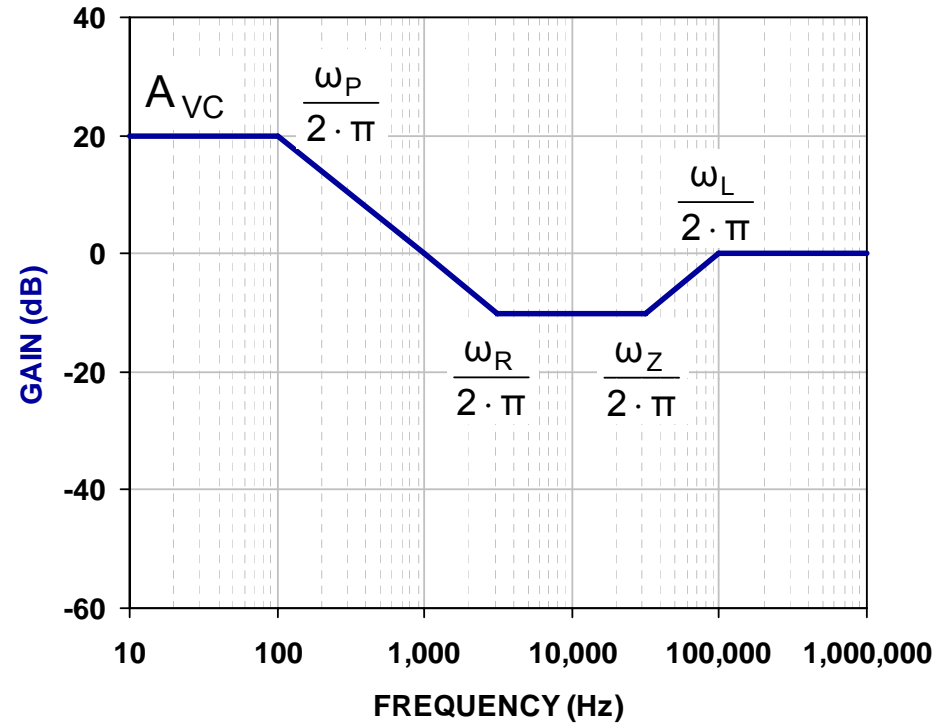
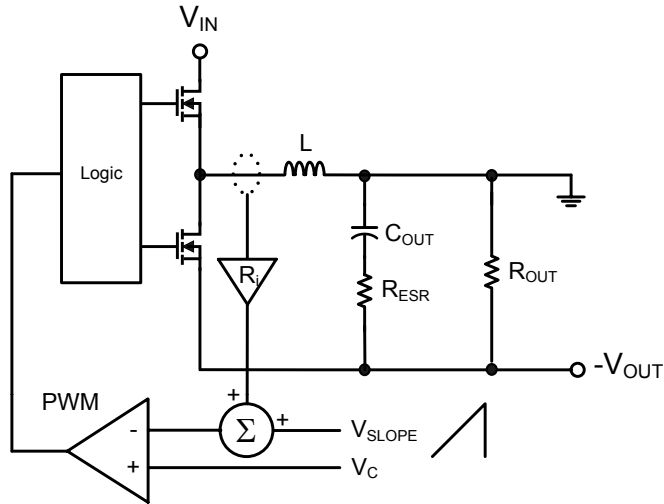
$$\omega_P \approx \frac{2}{C_{OUT} \cdot R_{OUT}} \quad K_m \approx \frac{V_{OUT}}{V_{SLOPE}}$$

$$\omega_Z = \frac{1}{R_{ESR} \cdot C_{OUT}} \quad \omega_L = \frac{K_m \cdot R_i}{L}$$

$$\frac{\hat{V}_{OUT}}{\hat{V}_C} \approx A_{VC} \cdot \frac{\left(1 - \frac{s}{\omega_R}\right) \cdot \left(1 + \frac{s}{\omega_Z}\right)}{\left(1 + \frac{s}{\omega_P}\right) \cdot \left(1 + \frac{s}{\omega_L}\right)}$$



电流模式降压-升压功率级



$$A_{VC} \approx \frac{R_{OUT} \cdot D'}{(1+D) \cdot R_i}$$

$$\omega_R \approx \frac{R_{OUT} \cdot D'^2}{L \cdot D}$$

$$\omega_P \approx \frac{1+D}{C_{OUT} \cdot R_{OUT}}$$

$$K_m \approx \frac{V_{IN} + V_{OUT}}{V_{SLOPE}}$$

$$\omega_Z = \frac{1}{R_{ESR} \cdot C_{OUT}}$$

$$\omega_L = \frac{K_m \cdot R_i}{L}$$

$$\frac{\hat{V}_{OUT}}{\hat{V}_C} \approx A_{VC} \cdot \frac{\left(1 - \frac{s}{\omega_R}\right) \cdot \left(1 + \frac{s}{\omega_Z}\right)}{\left(1 + \frac{s}{\omega_P}\right) \cdot \left(1 + \frac{s}{\omega_L}\right)}$$



误差放大器回顾

Type I 误差放大器

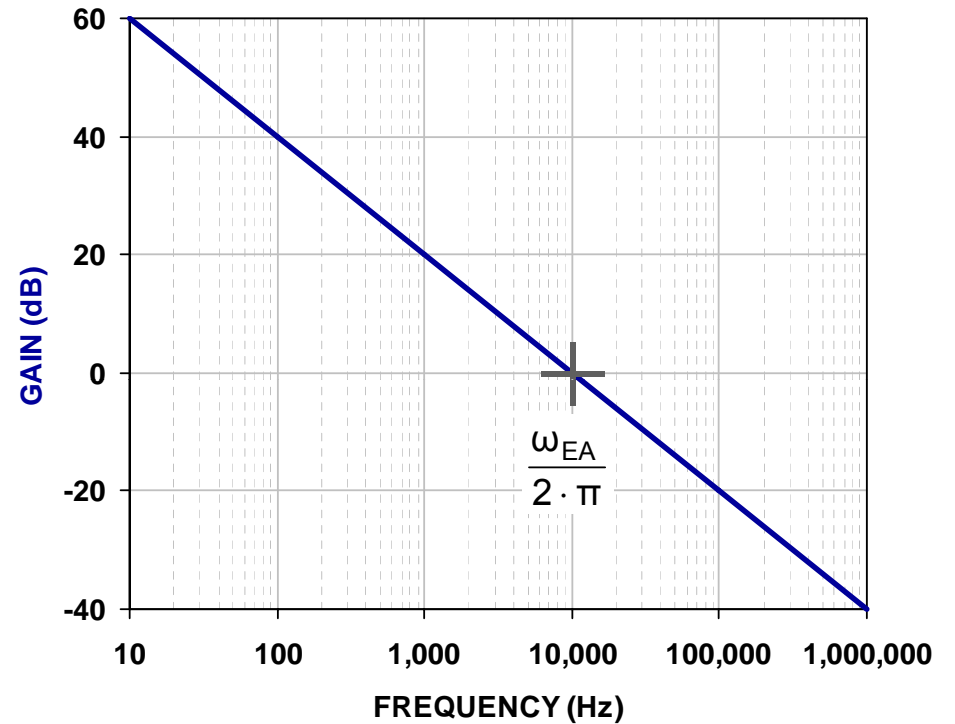
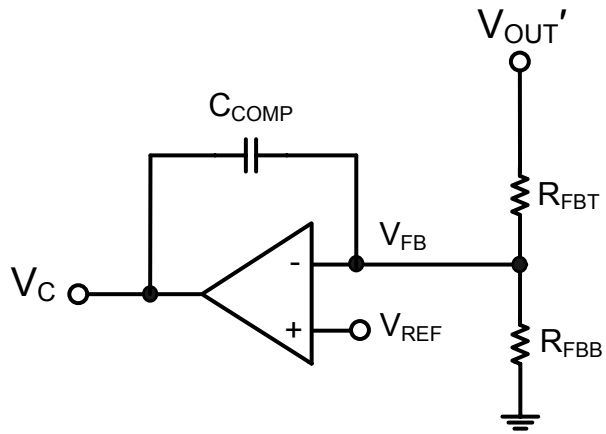
Type II 误差放大器

Type II 跨导放大器

Type III 误差放大器



Type I 误差放大器

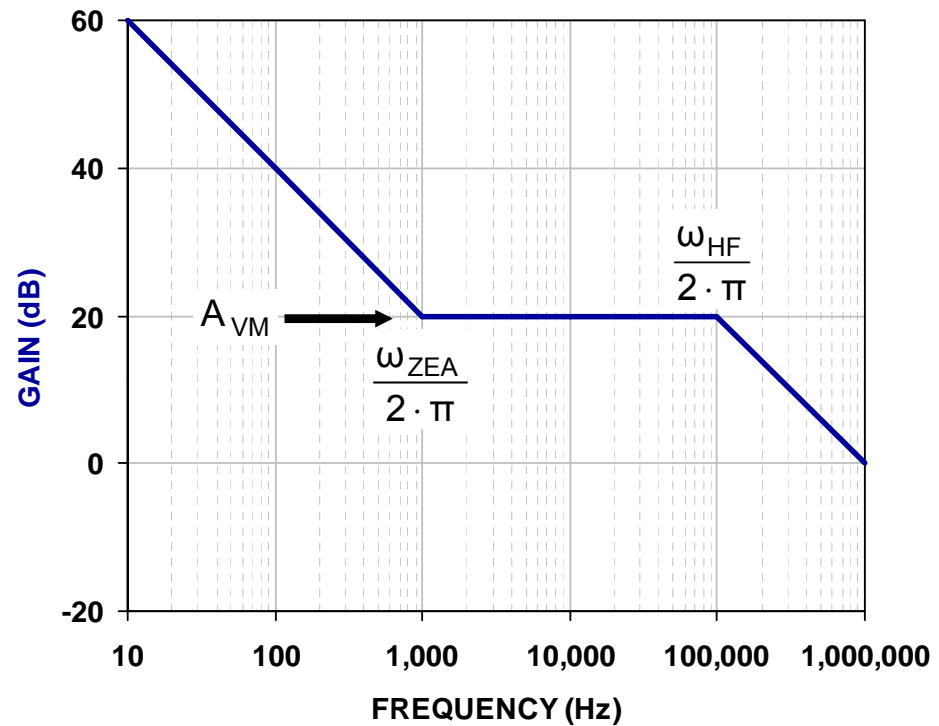
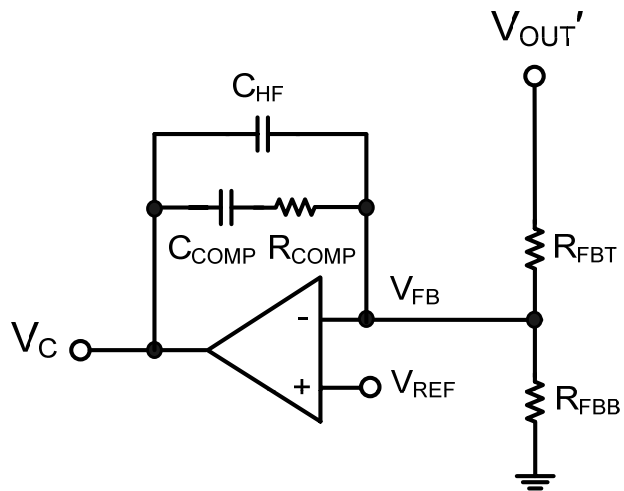


$$\omega_{EA} = \frac{1}{R_{FBT} \cdot C_{COMP}}$$

$$\frac{\hat{V}_C}{\hat{V}_{OUT}'} \approx -\frac{\omega_{EA}}{s}$$



Type II 误差放大器



$$A_{VM} \approx \frac{R_{COMP}}{R_{FBT}}$$

$$\omega_{ZEA} = \frac{1}{R_{COMP} \cdot C_{COMP}}$$

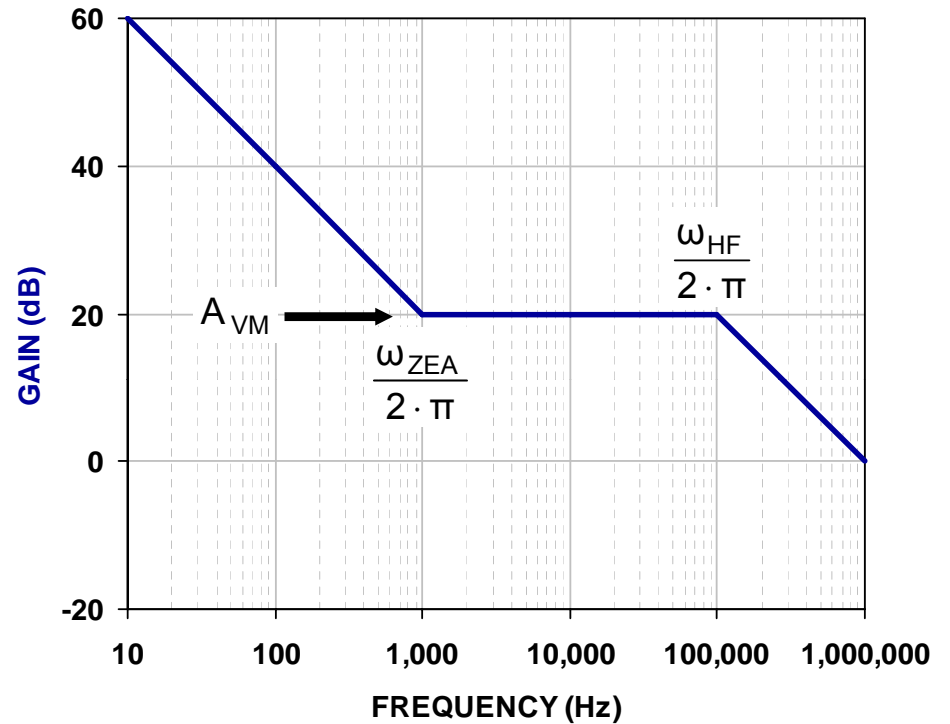
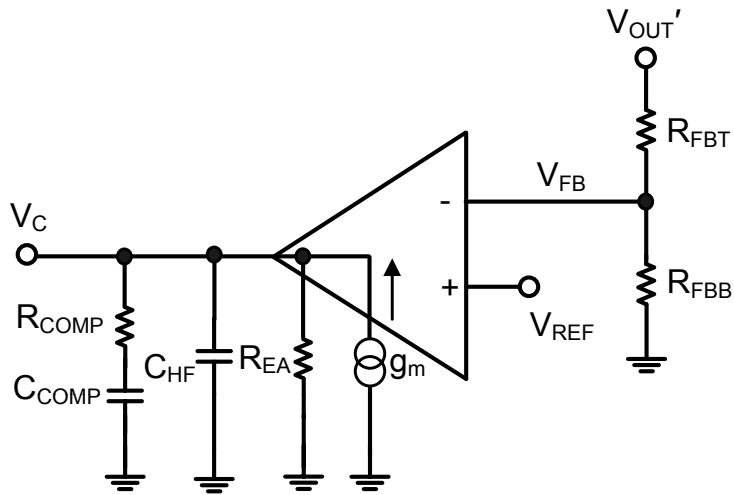
$$\omega_{HF} \approx \frac{1}{R_{COMP} \cdot C_{HF}}$$

假设: $C_{COMP} \gg C_{HF}$

$$\frac{\hat{V}_C}{\hat{V}_{OUT}} \approx -A_{VM} \cdot \frac{1 + \frac{\omega_{ZEA}}{s}}{1 + \frac{s}{\omega_{HF}}}$$



Type II 跨导放大器



$$A_{VM} = K_{FB} \cdot g_m \cdot R_{COMP}$$

$$\omega_{ZEA} = \frac{1}{R_{COMP} \cdot C_{COMP}} \quad K_{FB} = \frac{R_{FBB}}{R_{FBB} + R_{FBT}}$$

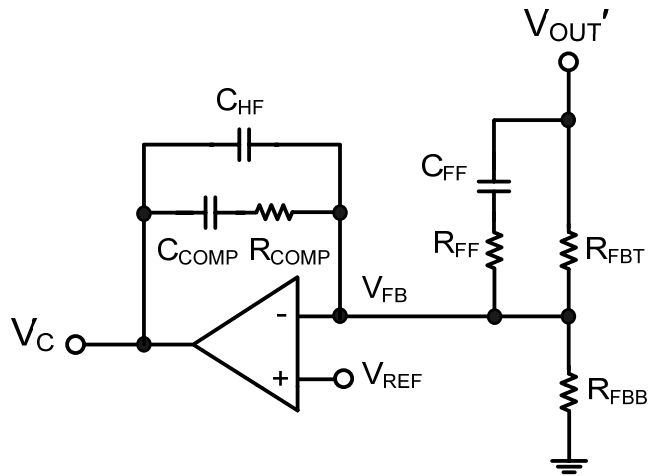
$$\omega_{HF} \approx \frac{1}{R_{COMP} \cdot C_{HF}} \quad A_{OL} = g_m \cdot R_{EA}$$

假设: $C_{COMP} \gg C_{HF}$ & $R_{EA} \gg R_{COMP}$

$$\frac{\hat{v}_C}{\hat{v}_{OUT}} \approx -A_{VM} \cdot \frac{1 + \frac{\omega_{ZEA}}{s}}{1 + \frac{s}{\omega_{HF}}}$$



Type III 误差放大器



$$A_{VM} \approx \frac{R_{COMP}}{R_{FBT}}$$

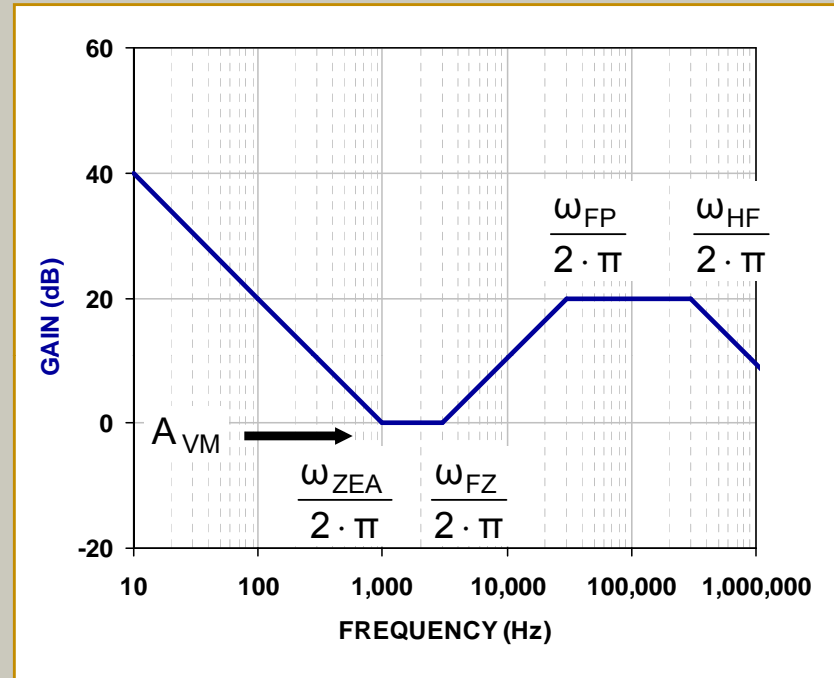
$$\omega_{ZEA} = \frac{1}{R_{COMP} \cdot C_{COMP}}$$

$$\omega_{FZ} \approx \frac{1}{R_{FBT} \cdot C_{FF}}$$

$$\omega_{FP} = \frac{1}{R_{FF} \cdot C_{FF}}$$

$$\omega_{HF} \approx \frac{1}{R_{COMP} \cdot C_{HF}}$$

假设: $C_{COMP} \gg C_{HF}$ & $R_{FBT} \gg R_{FF}$



$$\frac{\hat{v}_C}{\hat{v}_{OUT}} = -A_{VM} \cdot \frac{\left(1 + \frac{\omega_{ZEA}}{s}\right) \cdot \left(1 + \frac{s}{\omega_{FZ}}\right)}{\left(1 + \frac{s}{\omega_{FP}}\right) \cdot \left(1 + \frac{s}{\omega_{HF}}\right)}$$



开关稳压器补偿

电流模式降压 – **Type II** 补偿

电流模式升压 – **Type II** 补偿

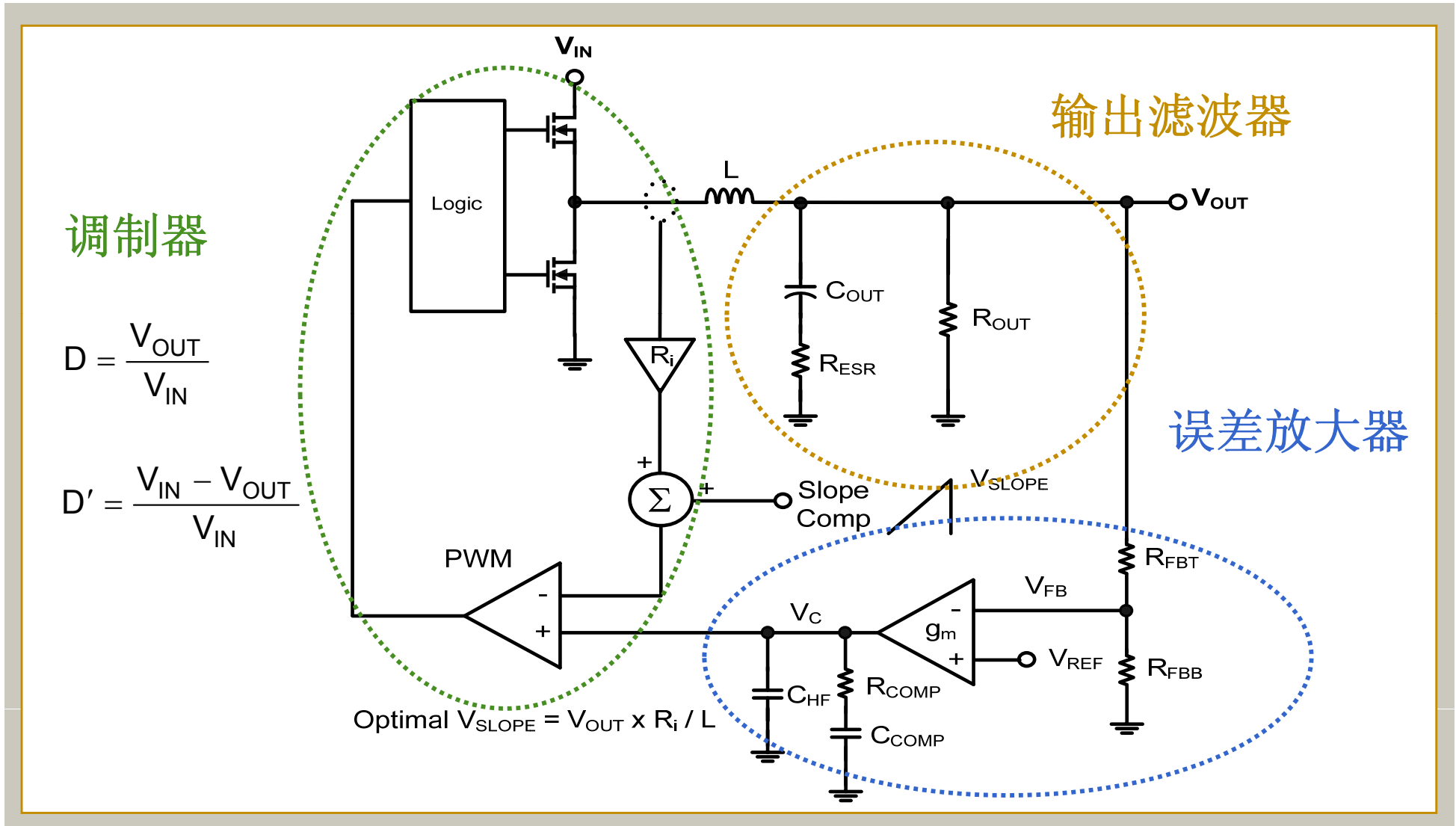
电流模式降压-升压 – **Type II** 补偿

电压模式降压 – **Type II** 补偿

电压模式降压 – **Type III** 补偿



电流模式降压模型





电流模式降压

Type II 补偿

- 选择一个大的 R_{FBT} 阻值，介于 2 k Ω 和 200 k Ω 之间
- 找出调制器跨导（单位：A/V）
- 选择一个目标带宽，通常为 $F_{\text{SW}}/10$
- 设定中频段增益 A_{VM} 以实现目标带宽： $\omega_{\text{C}} = 2 \cdot \pi \cdot F_{\text{C}}$
- 设定 $\omega_{\text{ZEA}} = 1/10$ 目标交越频率： $\omega_{\text{ZEA}} = \omega_{\text{C}}/10$
- 设定 $\omega_{\text{HF}} = \text{ESR}$ 零点频率： $\omega_{\text{HF}} = \omega_{\text{Z}}$

$$G_{\text{m}}(\text{mod}) = \frac{1}{R_{\text{i}}}$$

$$R_{\text{COMP}} = A_{\text{VM}} \cdot R_{\text{FBT}}$$

$$C_{\text{COMP}} = \frac{1}{\omega_{\text{ZEA}} \cdot R_{\text{COMP}}}$$

或：

$$A_{\text{VM}} = \frac{\omega_{\text{C}} \cdot C_{\text{O}}}{G_{\text{m}}(\text{mod})}$$

$$R_{\text{COMP}} = \frac{A_{\text{VM}}}{g_{\text{m}} \cdot K_{\text{FB}}}$$

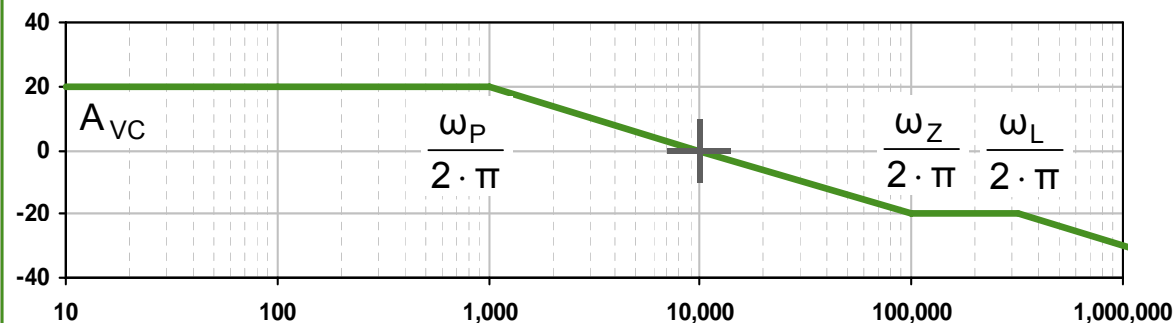
$$C_{\text{HF}} = \frac{1}{\omega_{\text{HF}} \cdot R_{\text{COMP}}}$$



电流模式降压控制环路

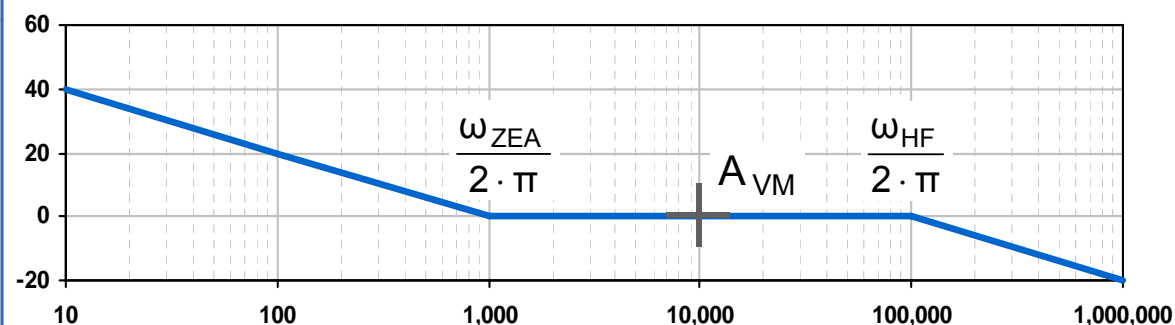
功率级

$$\frac{\hat{V}_{OUT}}{\hat{V}_C} \approx A_{VC} \cdot \frac{1 + \frac{s}{\omega_Z}}{\left(1 + \frac{s}{\omega_P}\right) \cdot \left(1 + \frac{s}{\omega_L}\right)}$$



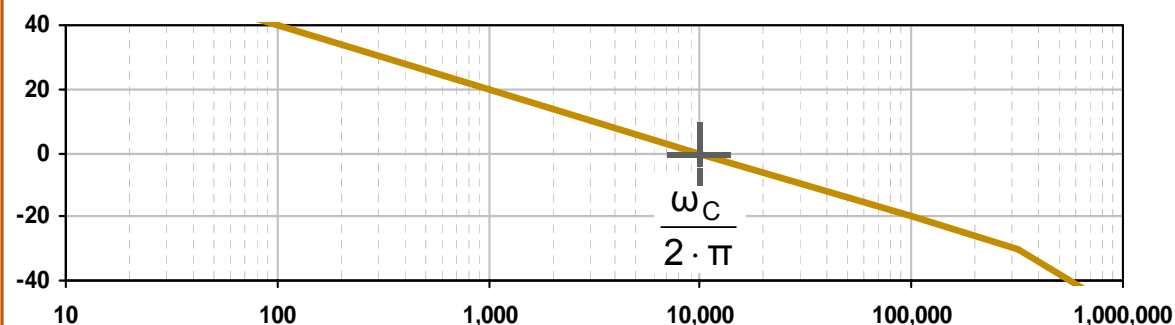
误差放大器

$$\frac{\hat{V}_C}{\hat{V}_{OUT}} \approx -A_{VM} \cdot \frac{1 + \frac{\omega_{ZEA}}{s}}{1 + \frac{s}{\omega_{HF}}}$$



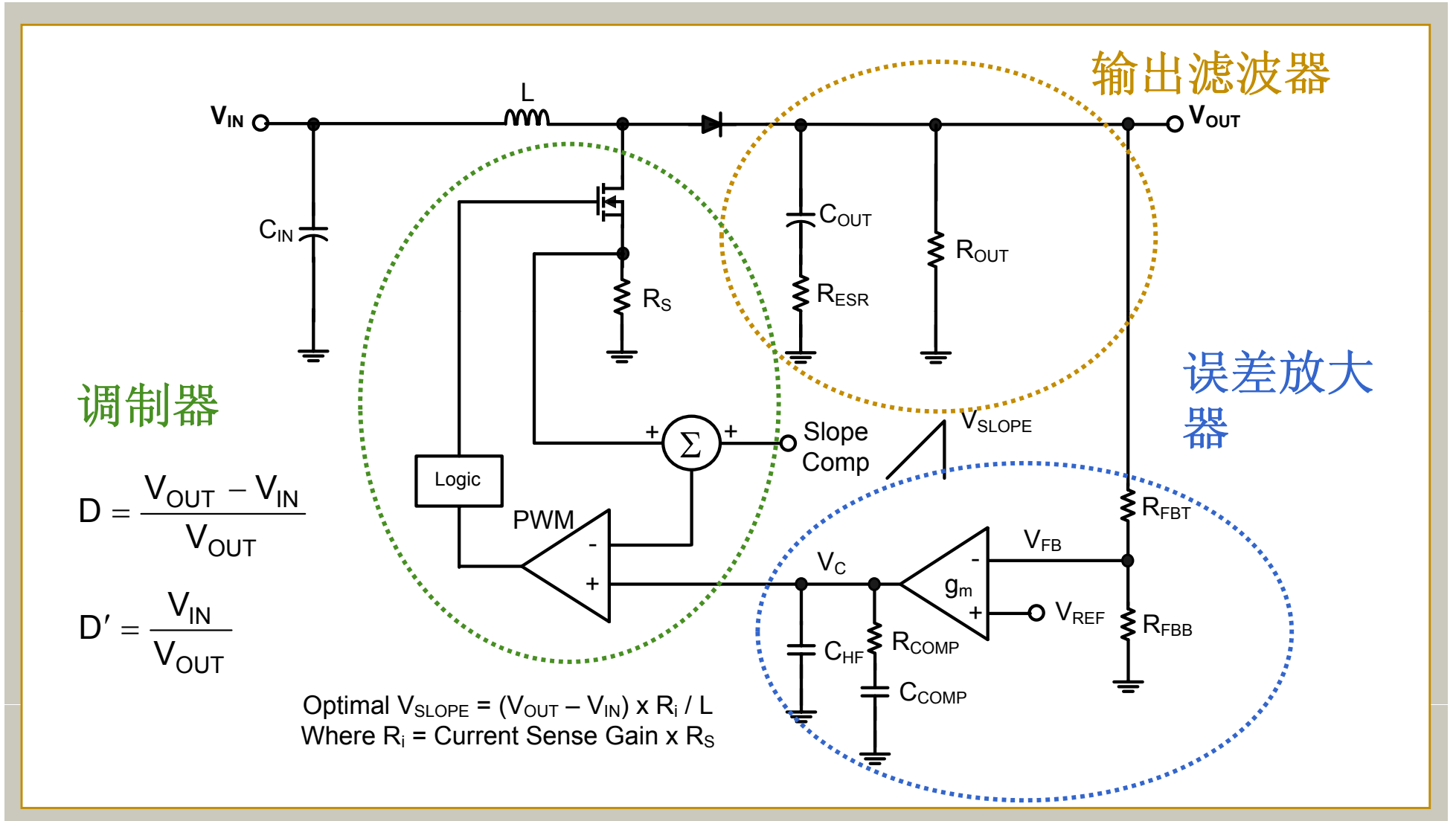
控制环路

$$\frac{\hat{V}_{OUT}}{\hat{V}_{OUT}} = \frac{\hat{V}_{OUT}}{\hat{V}_C} \cdot \frac{\hat{V}_C}{\hat{V}_{OUT}}$$





电流模式升压模型





电流模式升压

Type II 补偿

- 选择一个大的 R_{FBT} 阻值，介于 2 k Ω 和 200 k Ω 之间
- 找出调制器跨导（单位：A/V）
- 找出最小输入电压和最大负载电流条件下的 RHPZ 频率
- 将目标带宽设定为 RHPZ 频率的 1/4: $\omega_C = \omega_R/4$
- 设定中频段增益 A_{VM} 以实现目标带宽: $\omega_C = 2 \cdot \pi \cdot F_C$
- 设定 $\omega_{\text{ZEA}} = 1/10$ 的目标交越频率: $\omega_{\text{ZEA}} = \omega_C/10$
- 设定 $\omega_{\text{HF}} = \text{RHP}$ 或 ESR 零点频率当中较低的那个: $\omega_{\text{HF}} = \omega_R$ 或 ω_Z

$$G_m(\text{mod}) = \frac{D'}{R_i}$$

$$\omega_R = \frac{R_{\text{OUT}} \cdot D'^2}{L}$$

$$A_{\text{VM}} = \frac{\omega_C \cdot C_O}{G_m(\text{mod})}$$

$$R_{\text{COMP}} = A_{\text{VM}} \cdot R_{\text{FBT}}$$

或:

$$R_{\text{COMP}} = \frac{A_{\text{VM}}}{g_m \cdot K_{\text{FB}}}$$

$$C_{\text{COMP}} = \frac{1}{\omega_{\text{ZEA}} \cdot R_{\text{COMP}}}$$

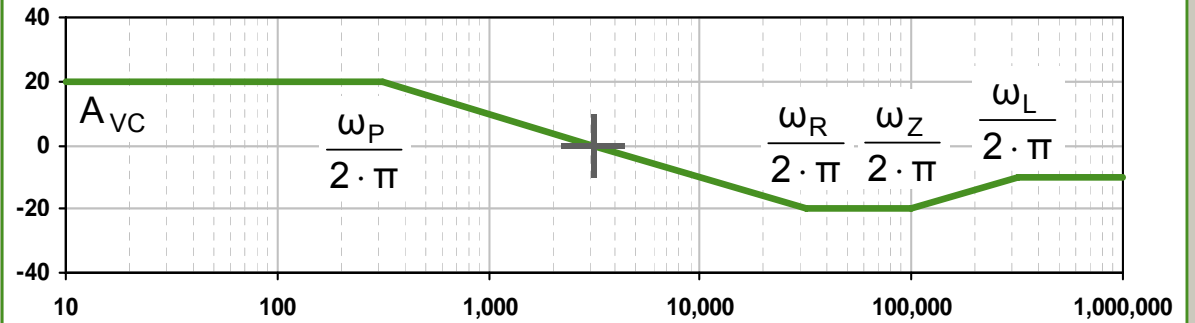
$$C_{\text{HF}} = \frac{1}{\omega_{\text{HF}} \cdot R_{\text{COMP}}}$$



电流模式升压控制环路

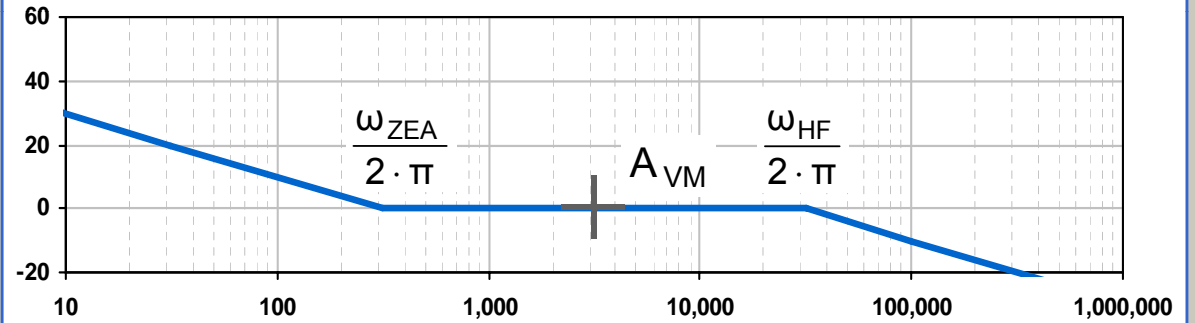
功率级

$$\frac{\hat{V}_{OUT}}{\hat{V}_C} \approx A_{VC} \cdot \frac{\left(1 - \frac{s}{\omega_R}\right) \cdot \left(1 + \frac{s}{\omega_Z}\right)}{\left(1 + \frac{s}{\omega_P}\right) \cdot \left(1 + \frac{s}{\omega_L}\right)}$$



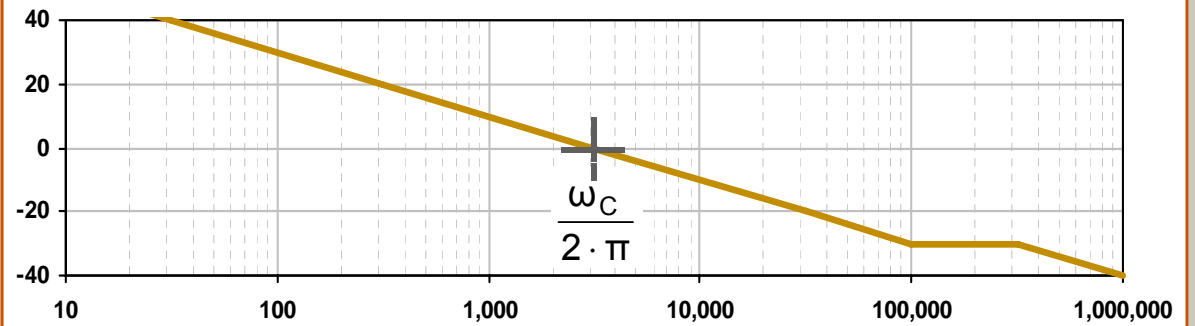
误差放大器

$$\frac{\hat{V}_C}{\hat{V}_{OUT}} \approx -A_{VM} \cdot \frac{1 + \frac{\omega_{ZEA}}{s}}{1 + \frac{s}{\omega_{HF}}}$$



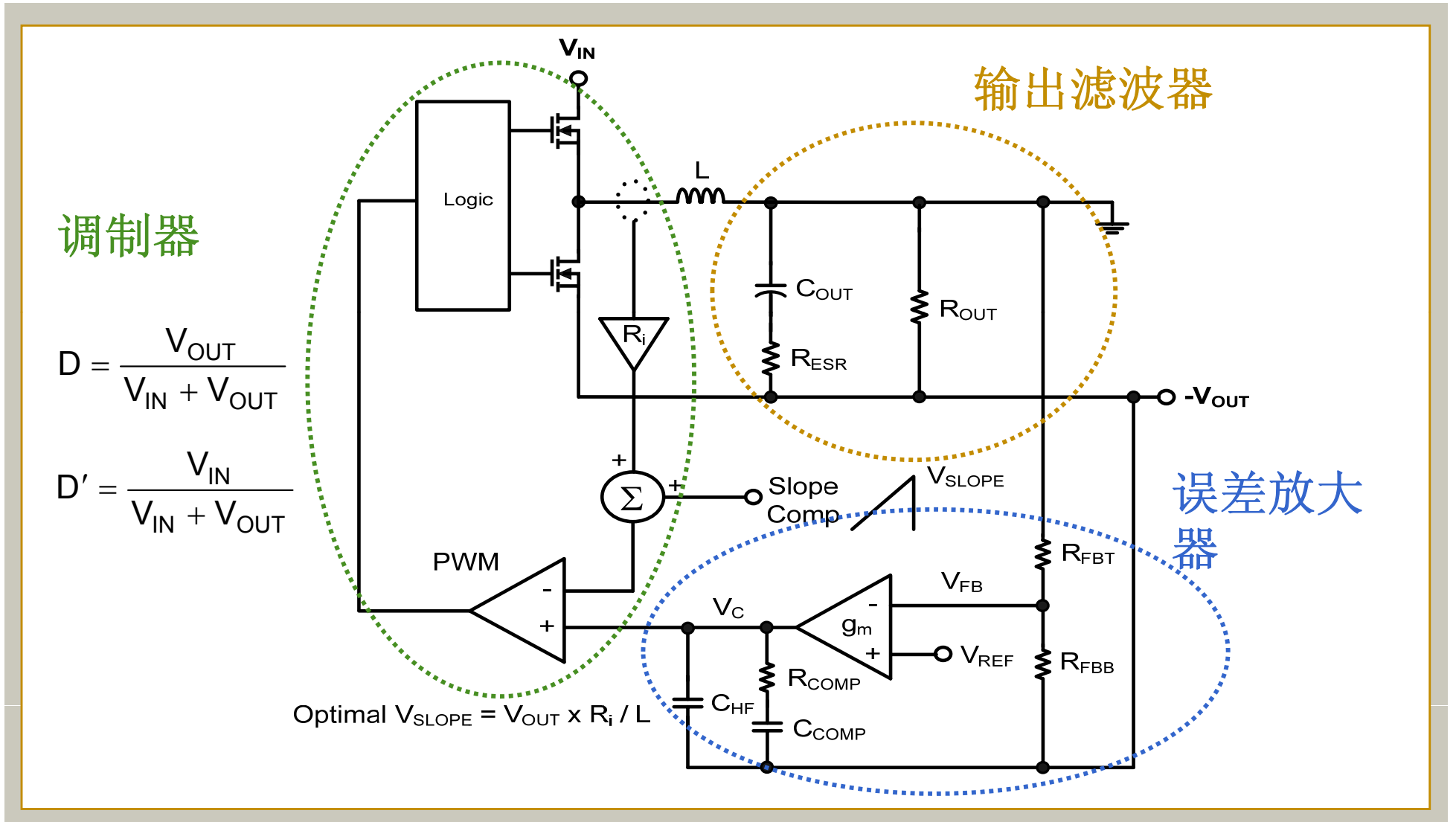
控制环路

$$\frac{\hat{V}_{OUT}}{\hat{V}_{OUT}} = \frac{\hat{V}_{OUT}}{\hat{V}_C} \cdot \frac{\hat{V}_C}{\hat{V}_{OUT}}$$





电流模式降压-升压模型





- 选择一个大的 R_{FBT} 阻值，介于 2 k Ω 和 200 k Ω 之间
- 找出调制器跨导（单位：A/V）
- 找出最小输入电压和最大负载电流条件下的 RHPZ 频率
- 将目标带宽设定为 RHPZ 频率的 1/4: $\omega_C = \omega_R/4$
- 设定中频段增益 A_{VM} 以实现目标带宽: $\omega_C = 2 \cdot \pi \cdot F_C$
- 设定 $\omega_{\text{ZEA}} = 1/10$ 的目标交越频率: $\omega_{\text{ZEA}} = \omega_C/10$
- 设定 $\omega_{\text{HF}} = \text{RHP}$ 或 ESR 零点频率当中较低的那个: $\omega_{\text{HF}} = \omega_R$ 或 ω_Z

$$G_m(\text{mod}) = \frac{D'}{R_i} \quad \omega_R = \frac{R_{\text{OUT}} \cdot D'^2}{L \cdot D} \quad A_{\text{VM}} = \frac{\omega_C \cdot C_O}{G_m(\text{mod})}$$

$$R_{\text{COMP}} = A_{\text{VM}} \cdot R_{\text{FBT}} \quad \text{或:} \quad R_{\text{COMP}} = \frac{A_{\text{VM}}}{g_m \cdot K_{\text{FB}}}$$

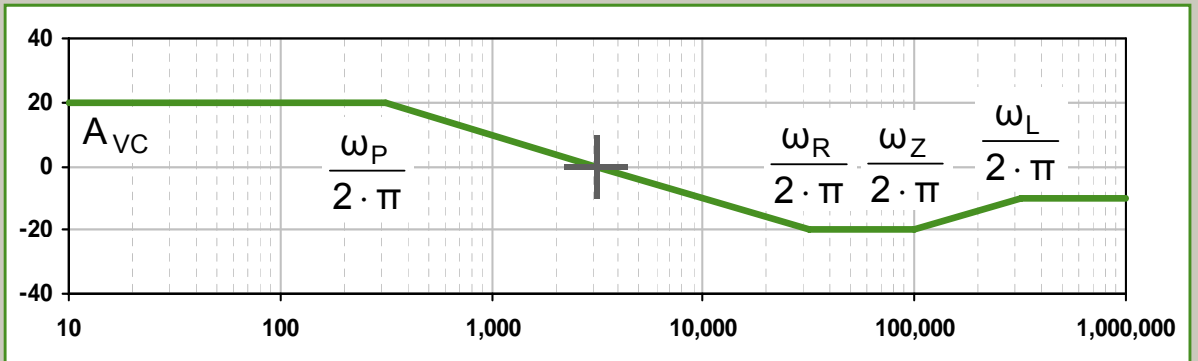
$$C_{\text{COMP}} = \frac{1}{\omega_{\text{ZEA}} \cdot R_{\text{COMP}}} \quad C_{\text{HF}} = \frac{1}{\omega_{\text{HF}} \cdot R_{\text{COMP}}}$$



电流模式降压-升压控制环路

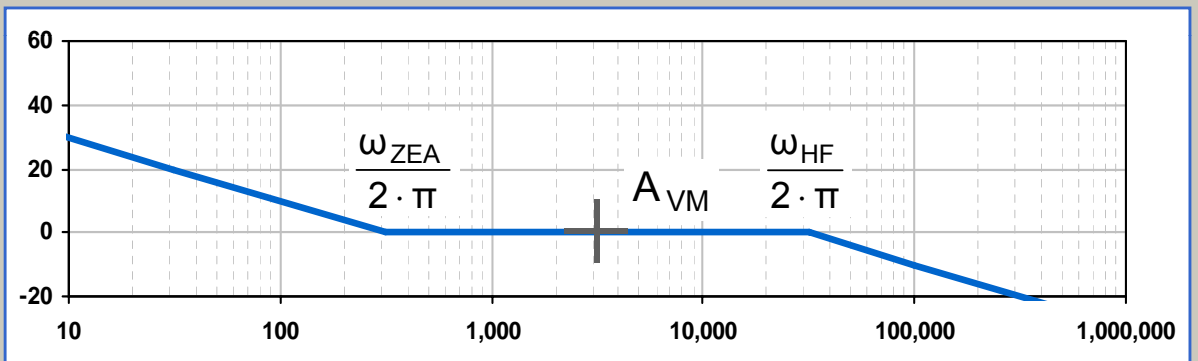
功率级

$$\frac{\hat{V}_{OUT}}{\hat{V}_C} \approx A_{VC} \cdot \frac{\left(1 - \frac{s}{\omega_R}\right) \cdot \left(1 + \frac{s}{\omega_Z}\right)}{\left(1 + \frac{s}{\omega_P}\right) \cdot \left(1 + \frac{s}{\omega_L}\right)}$$



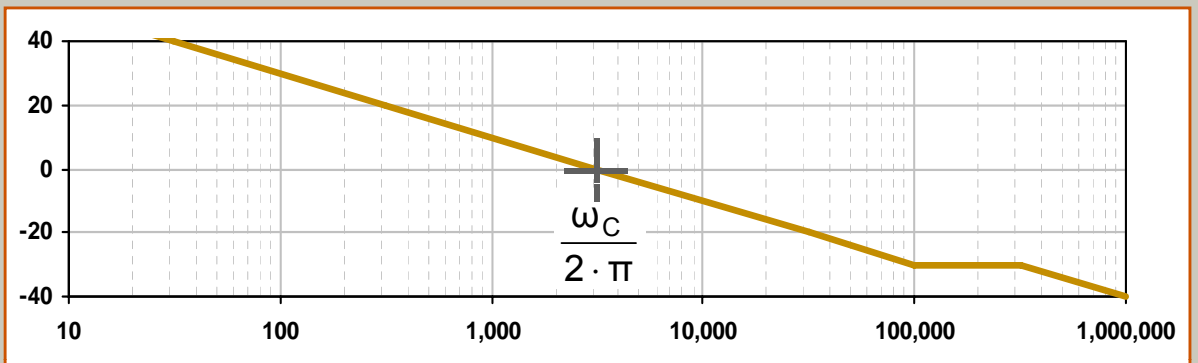
误差放大器

$$\frac{\hat{V}_C}{\hat{V}_{OUT}} \approx -A_{VM} \cdot \frac{1 + \frac{\omega_{ZEA}}{s}}{1 + \frac{s}{\omega_{HF}}}$$



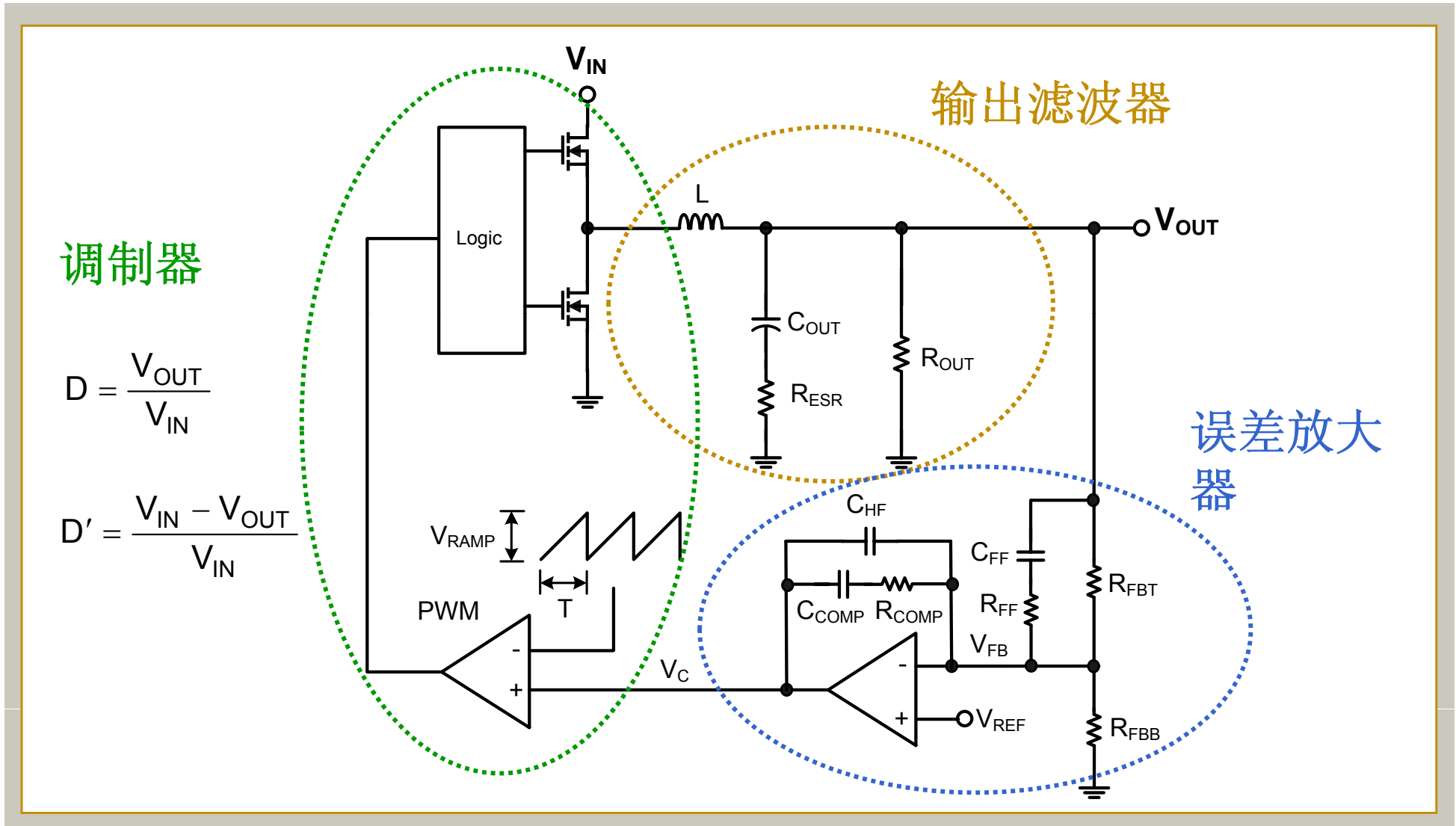
控制环路

$$\frac{\hat{V}_{OUT}}{\hat{V}_{OUT}} = \frac{\hat{V}_{OUT}}{\hat{V}_C} \cdot \frac{\hat{V}_C}{\hat{V}_{OUT}}$$





电压模式降压稳压器





电压模式降压

Type II 补偿

- 与高 ESR 输出电容器配合使用
- 选择一个大的 R_{FBT} 阻值，介于 2 k Ω 和 200 k Ω 之间
- 设定中频段增益 A_{VM} 以获得期望的带宽
- 设定 $\omega_{ZEA} =$ 输出滤波器共轭复极点 ω_O
- 设定 $\omega_{HF} = 1/2$ 开关频率: $\omega_{HF} = 2 \cdot \pi \cdot F_{SW}/2$

$$R_{COMP} = A_{VM} \cdot R_{FBT} \quad C_{COMP} = \frac{1}{\omega_{ZEA} \cdot R_{COMP}} \quad C_{HF} = \frac{1}{\omega_{HF} \cdot R_{COMP}}$$



电压模式降压

Type III 补偿

- 与低 ESR 输出电容器配合使用
- 选择一个大的 R_{FBT} 阻值，介于 2 k Ω 和 200 k Ω 之间
- 设定中频段增益 A_{VM} 以实现目标带宽： $\omega_C = 2 \cdot \pi \cdot F_C$
- 设定 ω_{ZEA} 和 $\omega_{FZ} =$ 输出滤波器共轭复极点 ω_O
- 设定 $\omega_{FP} =$ 输出滤波器零点 ω_Z
- 设定 $\omega_{HF} = \frac{1}{2}$ 开关频率： $\omega_{HF} = 2 \cdot \pi \cdot F_{SW}/2$

$$A_{VM} = \frac{\omega_C}{A_{VC} \cdot \omega_O}$$

$$R_{COMP} = A_{VM} \cdot R_{FBT}$$

$$C_{COMP} = \frac{1}{\omega_{ZEA} \cdot R_{COMP}}$$

$$C_{FF} = \frac{1}{\omega_{FZ} \cdot R_{FBT}}$$

$$R_{FF} = \frac{1}{\omega_{FP} \cdot C_{FF}}$$

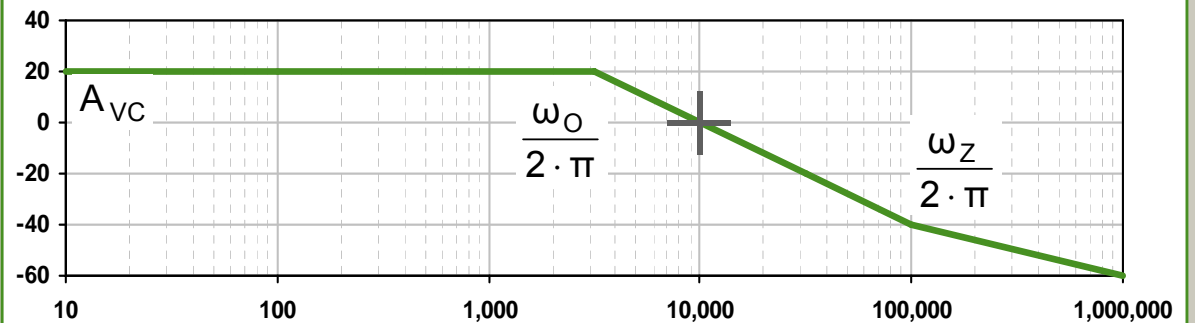
$$C_{HF} = \frac{1}{\omega_{HF} \cdot R_{COMP}}$$



电压模式降压控制环路

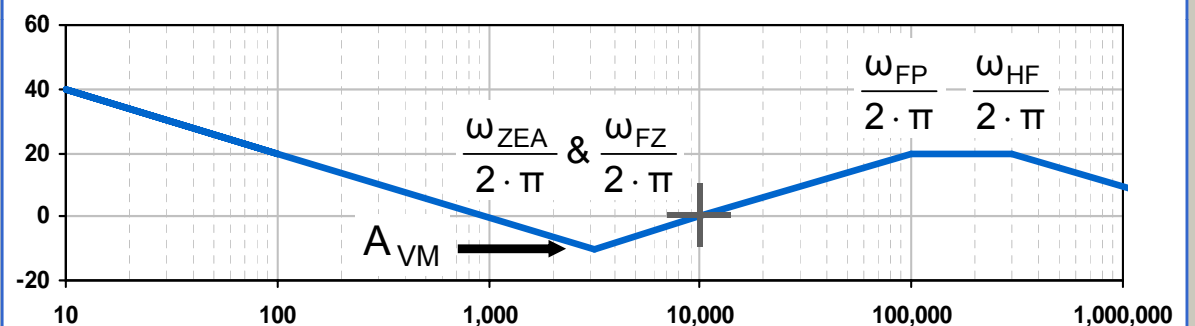
功率级

$$\frac{\hat{V}_{OUT}}{\hat{V}_C} \approx A_{VC} \cdot \frac{1 + \frac{s}{\omega_Z}}{1 + \frac{s}{Q_O \cdot \omega_O} + \frac{s^2}{\omega_O^2}}$$



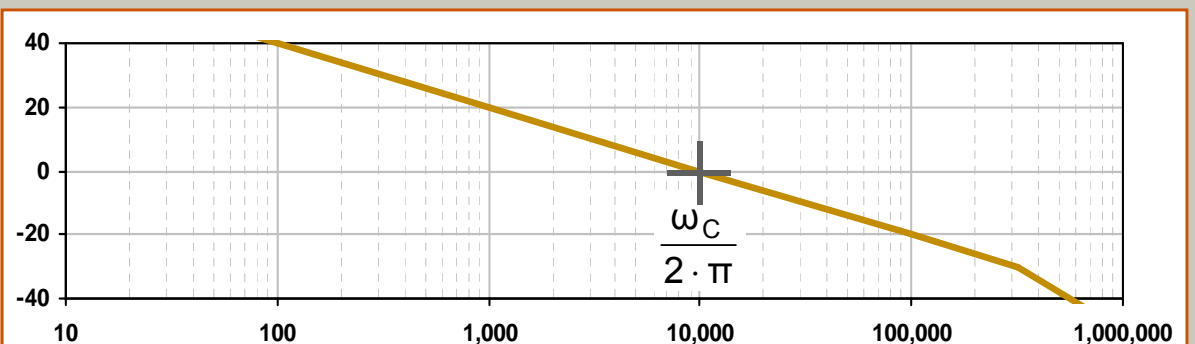
误差放大器

$$\frac{\hat{V}_C}{\hat{V}_{OUT}'} \approx -A_{VM} \cdot \frac{\left(1 + \frac{\omega_{ZEA}}{s}\right) \cdot \left(1 + \frac{s}{\omega_{FZ}}\right)}{\left(1 + \frac{s}{\omega_{FP}}\right) \cdot \left(1 + \frac{s}{\omega_{HF}}\right)}$$



控制环路

$$\frac{\hat{V}_{OUT}}{\hat{V}_{OUT}'} = \frac{\hat{V}_{OUT}}{\hat{V}_C} \cdot \frac{\hat{V}_C}{\hat{V}_{OUT}'}$$





误差放大器考虑因素

需要关注的是：

- 误差放大器必须驱动的阻抗
- 误差放大器的带宽
- 误差放大器的开环增益
- LC 滤波器的 Q 值



环路测量方法

测量选项

1: 瞬态响应测试

- 简单易行
- 无需专用设备

2: 伯德图

- 需要网络分析仪以获得完整的曲线图
- 可利用普通的测试设备获得关键性的数据点



负载阶跃分析

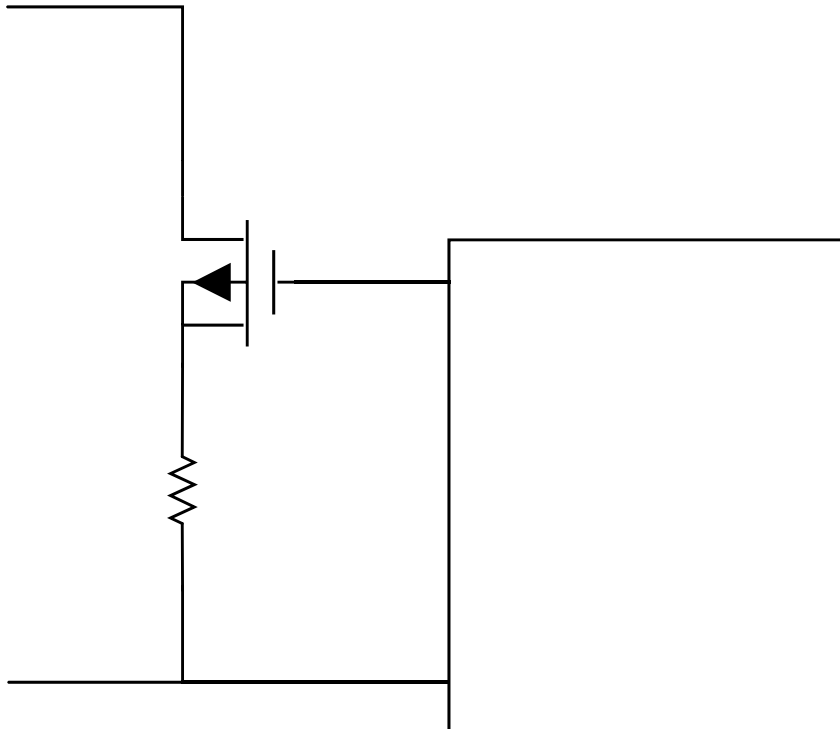
瞬态测试

负载阶跃实例

伯德图与瞬态



用于瞬态测试的简单电路



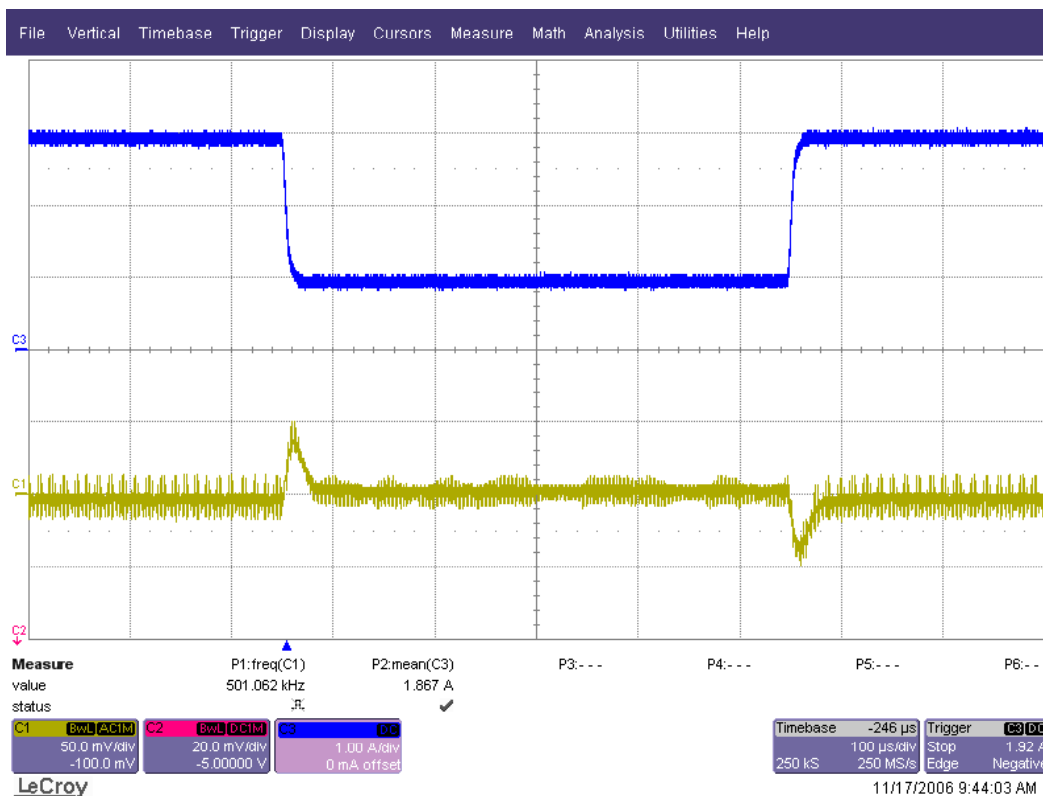
针对一个从 $0V$ 至大约比 V_{OUT} 高 $5V$ 的脉冲幅度及 $100Hz$ 左右的频率来设置发生器。负载将跟随发生器的上升/下降时间。

增设用于设定最小负载的 DC 负载箱。 V_{OUT}/R_{LOAD} 设定了 ΔI 。



负载阶跃实例

典型的瞬态响应测试



负载电流
每格 1A

输出电压
每格 50 mV

时标
每格 100 μ s

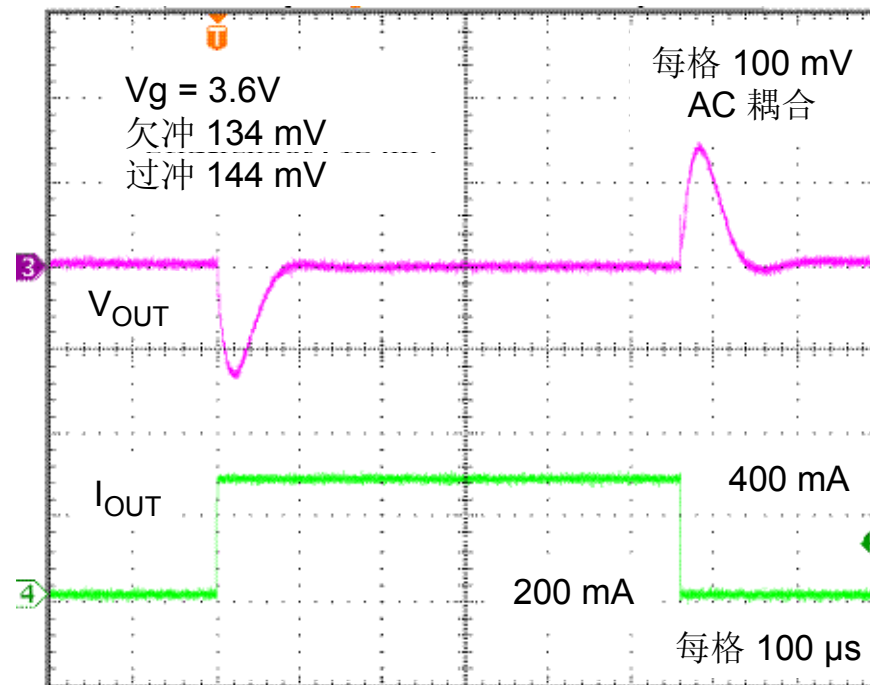
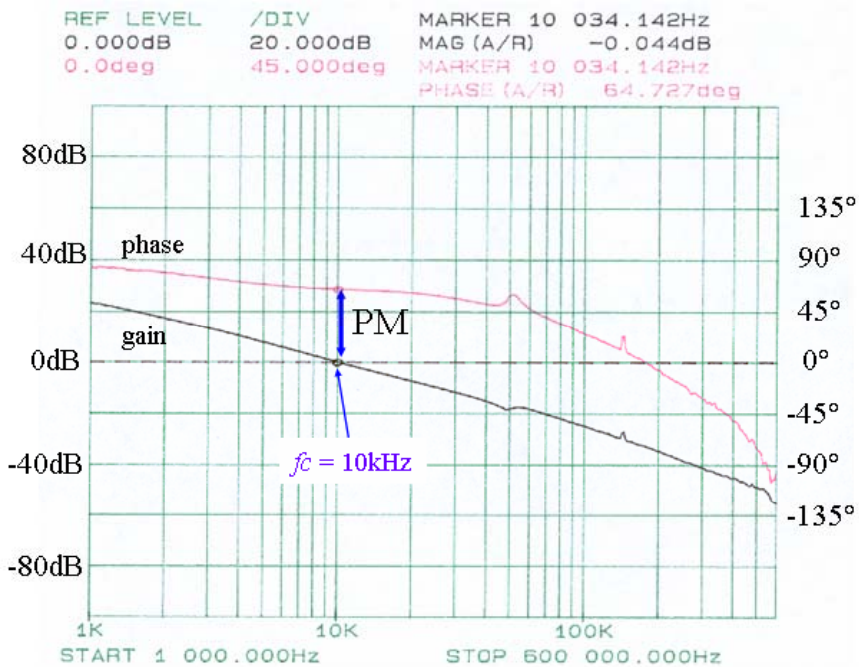


伯德图与瞬态响应对比案例一

稳定的稳压 器

$f_c = 10 \text{ kHz}$, $PM = 65^\circ$

过阻尼



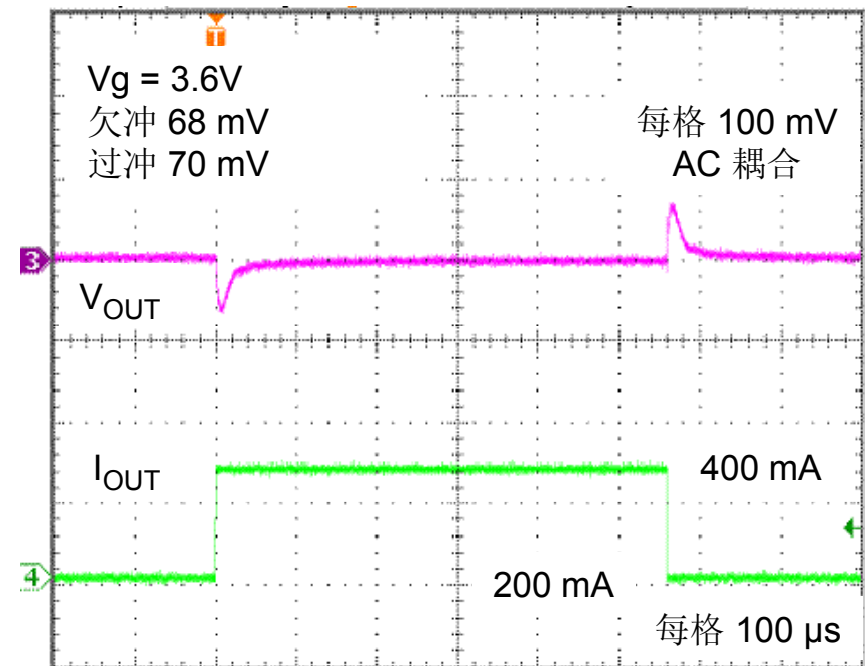
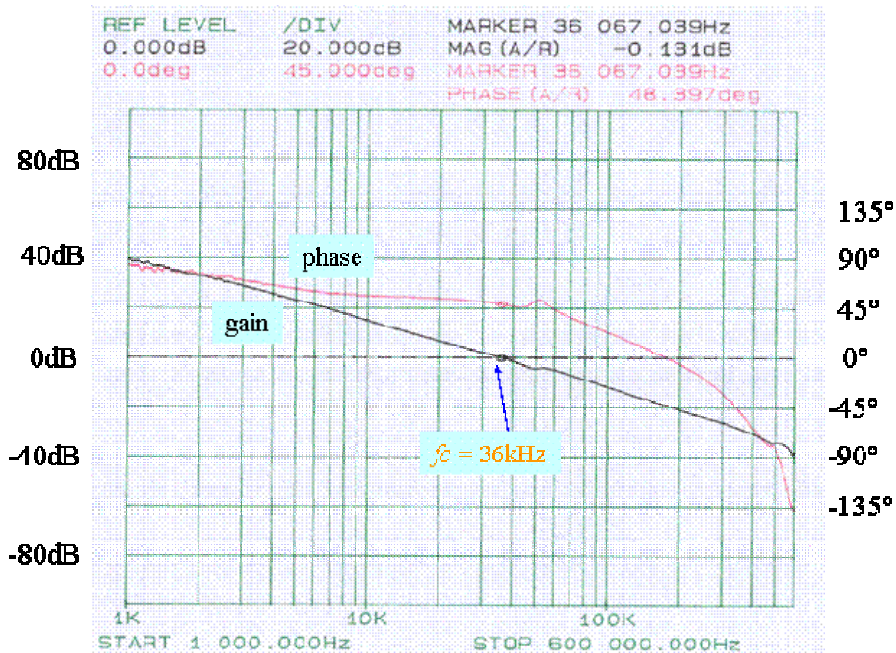


伯德图与瞬态响应对比案例二

稳定的稳压器

$f_c = 36 \text{ kHz}$, $PM = 48^\circ$

临界阻尼



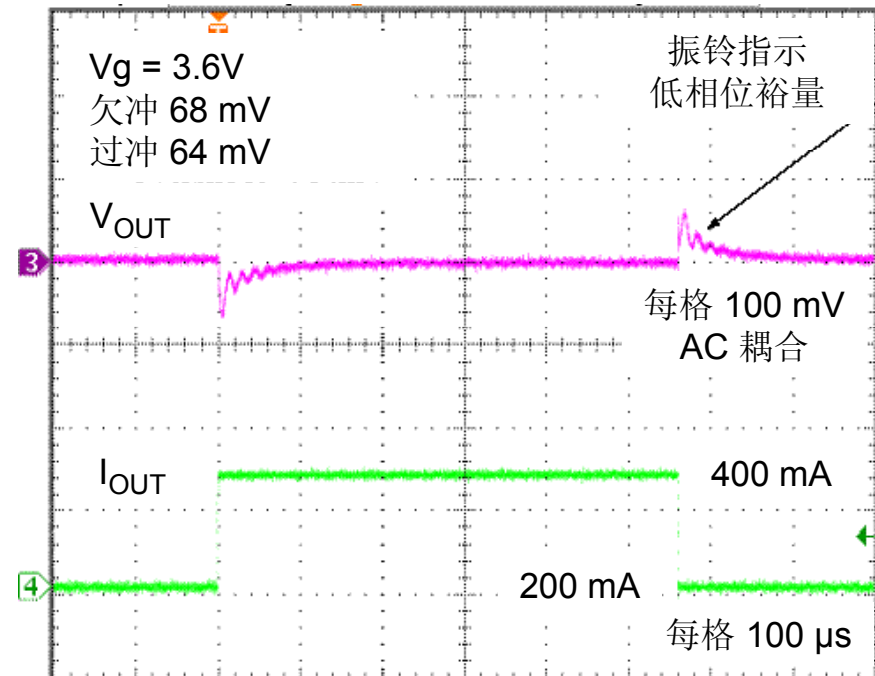
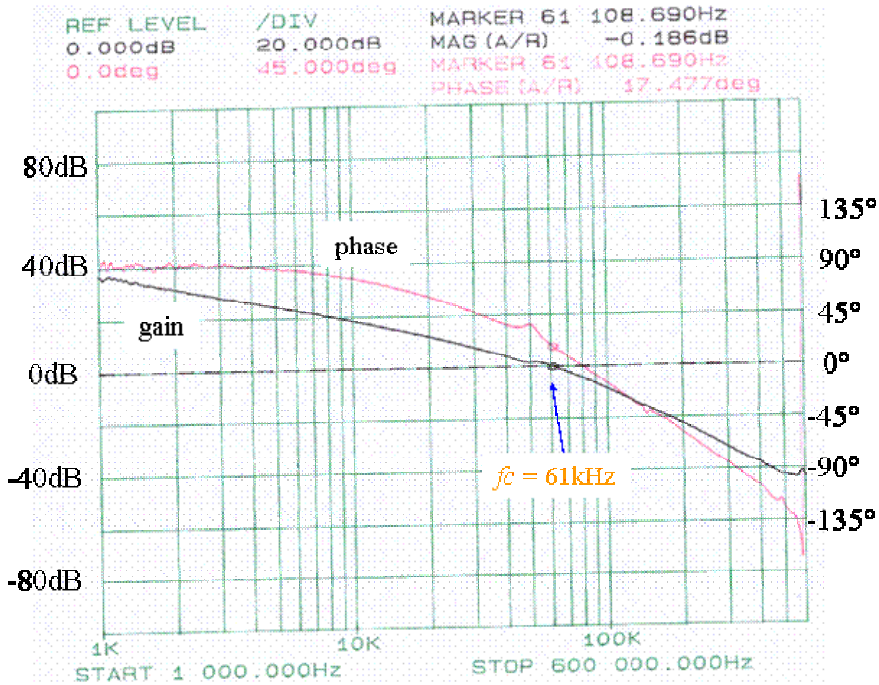


伯德图与瞬态响应对比案例三

边际稳定性

$f_c = 61 \text{ kHz}, PM = 17^\circ$

欠阻尼

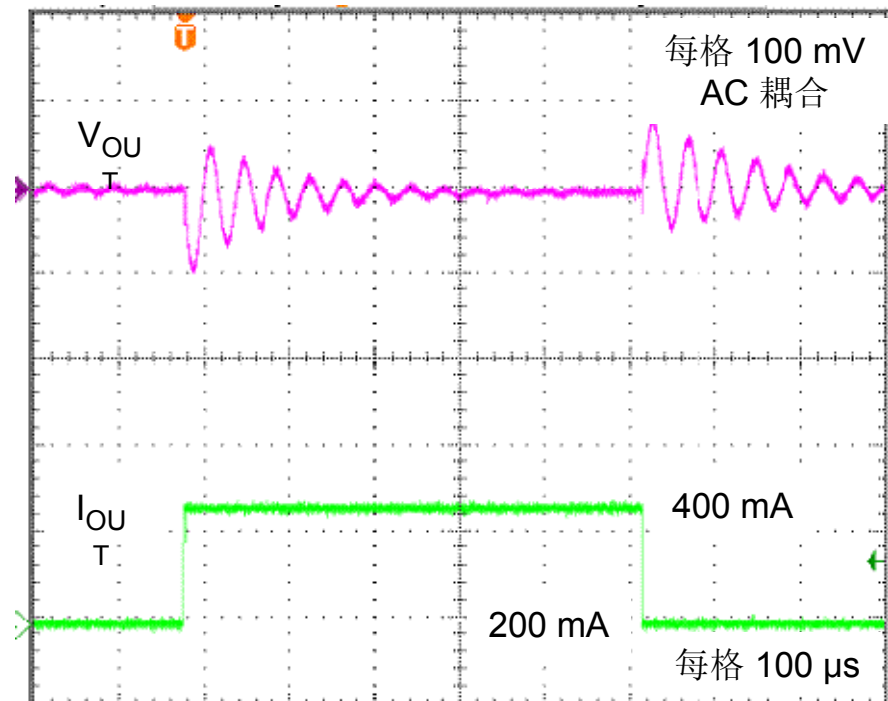
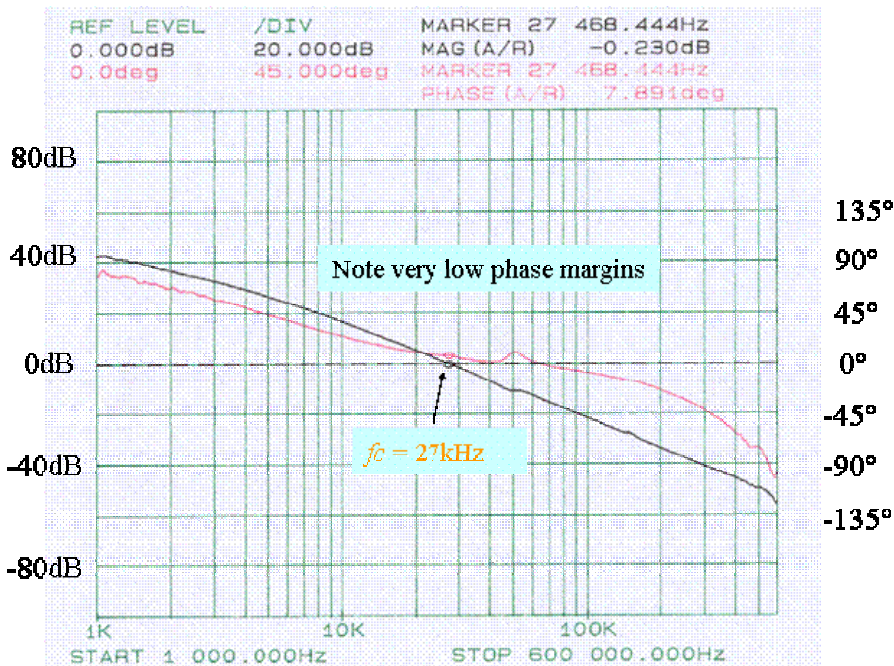




伯德图与瞬态响应对比案例四 不稳定的稳压器

$f_c = 27 \text{ kHz}$, $PM = 8^\circ$

不稳定的稳压器





环路测量

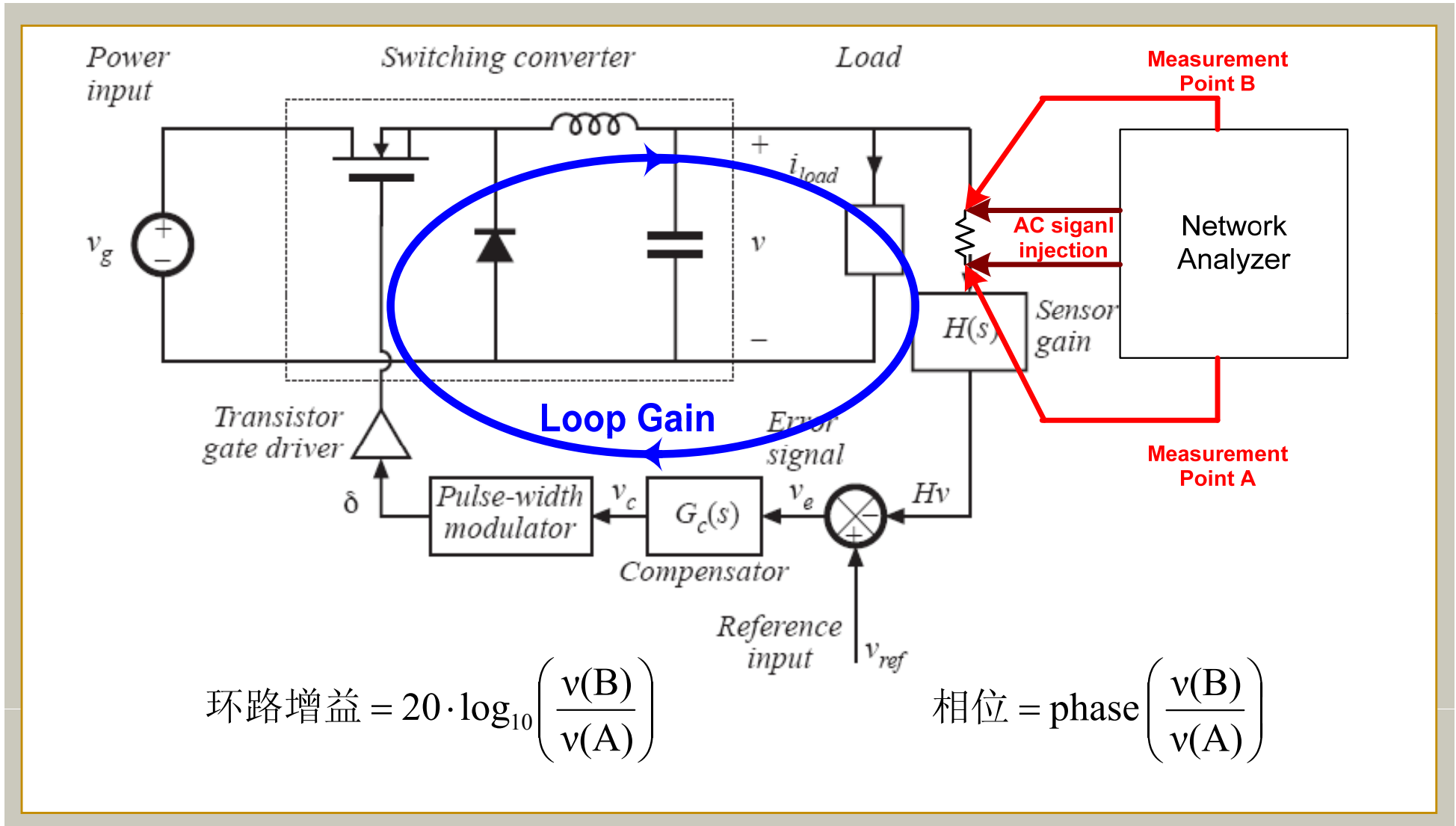
网络分析仪测量

正弦波注入

穿越频率和相位裕量

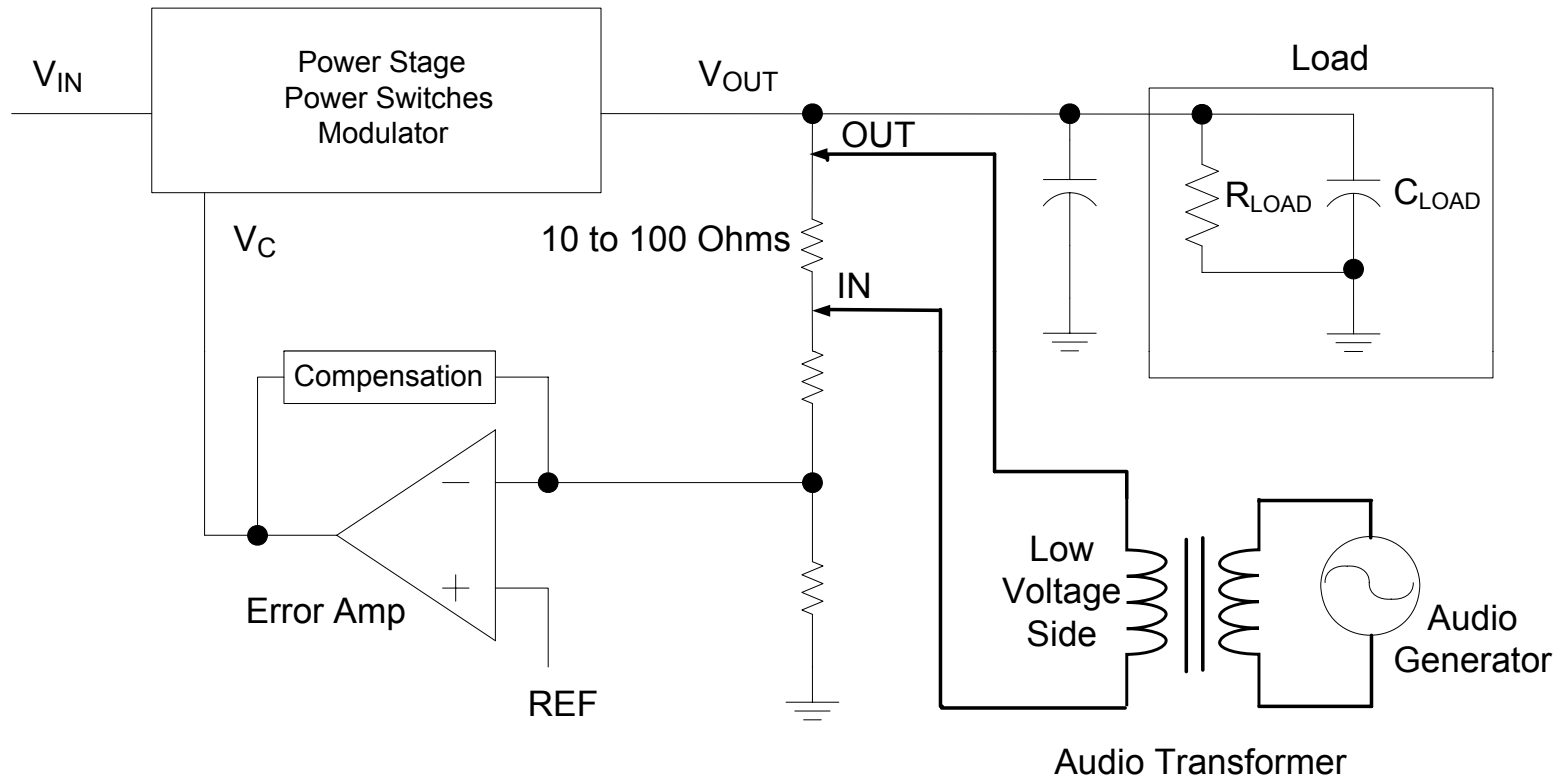


网络分析仪测量





正弦波注入



Connect oscilloscope channel 1 to OUT, channel 2 to IN. Both relative to the local controller ground.

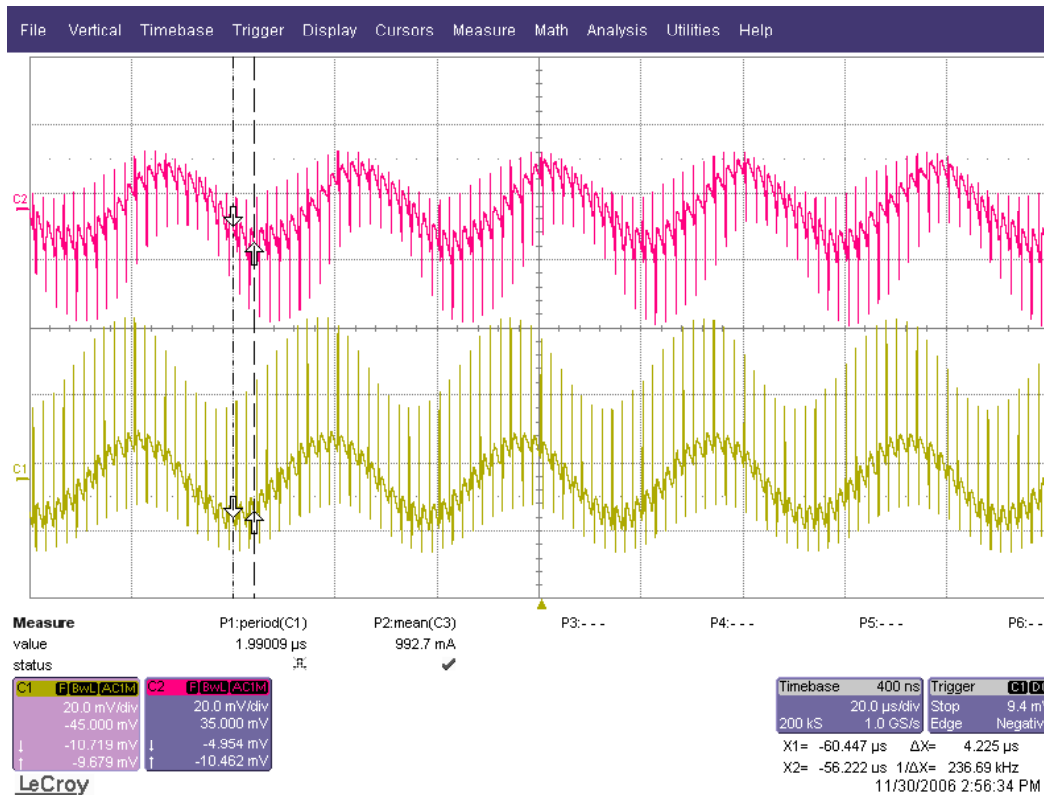


穿越频率和相位裕量

LM5576 – 500 kHz 开关频率

输出

输入



24V V_{IN} 5V V_{OUT}
1A 负载
幅度 120 mV pk-pk
26.5 kHz 交越频率
相位裕量 = 40.5°

注意光标
时间差 = $4.225 \mu\text{s}$
在 26.5 kHz, 周期为
 $37.7 \mu\text{s}$ 。
 $(4.225/37.7) \times 360$
= 40.5



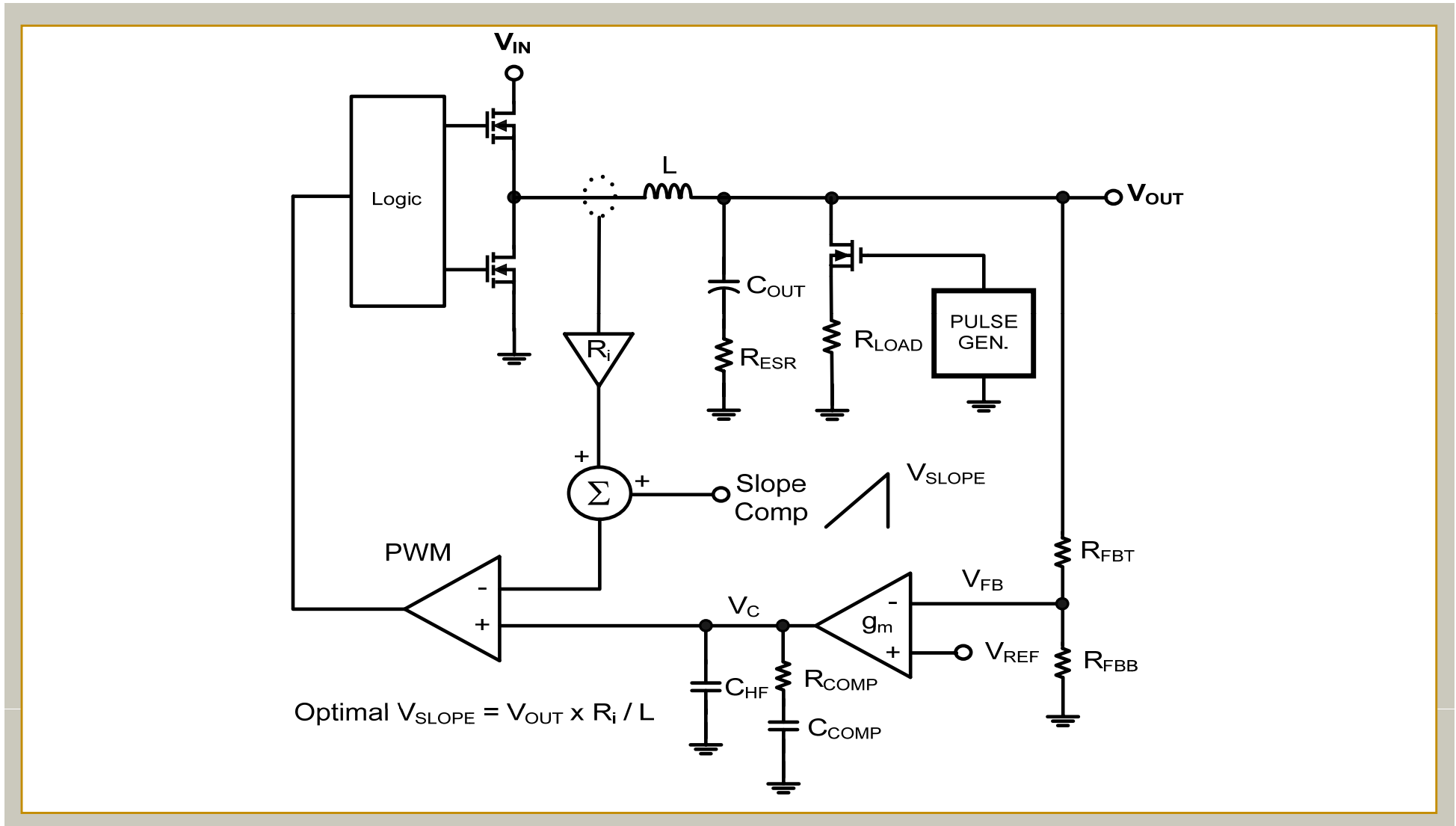
动手实验

采用负载阶跃补偿降压稳压器

运用信号注入得到穿越频率和相位裕量

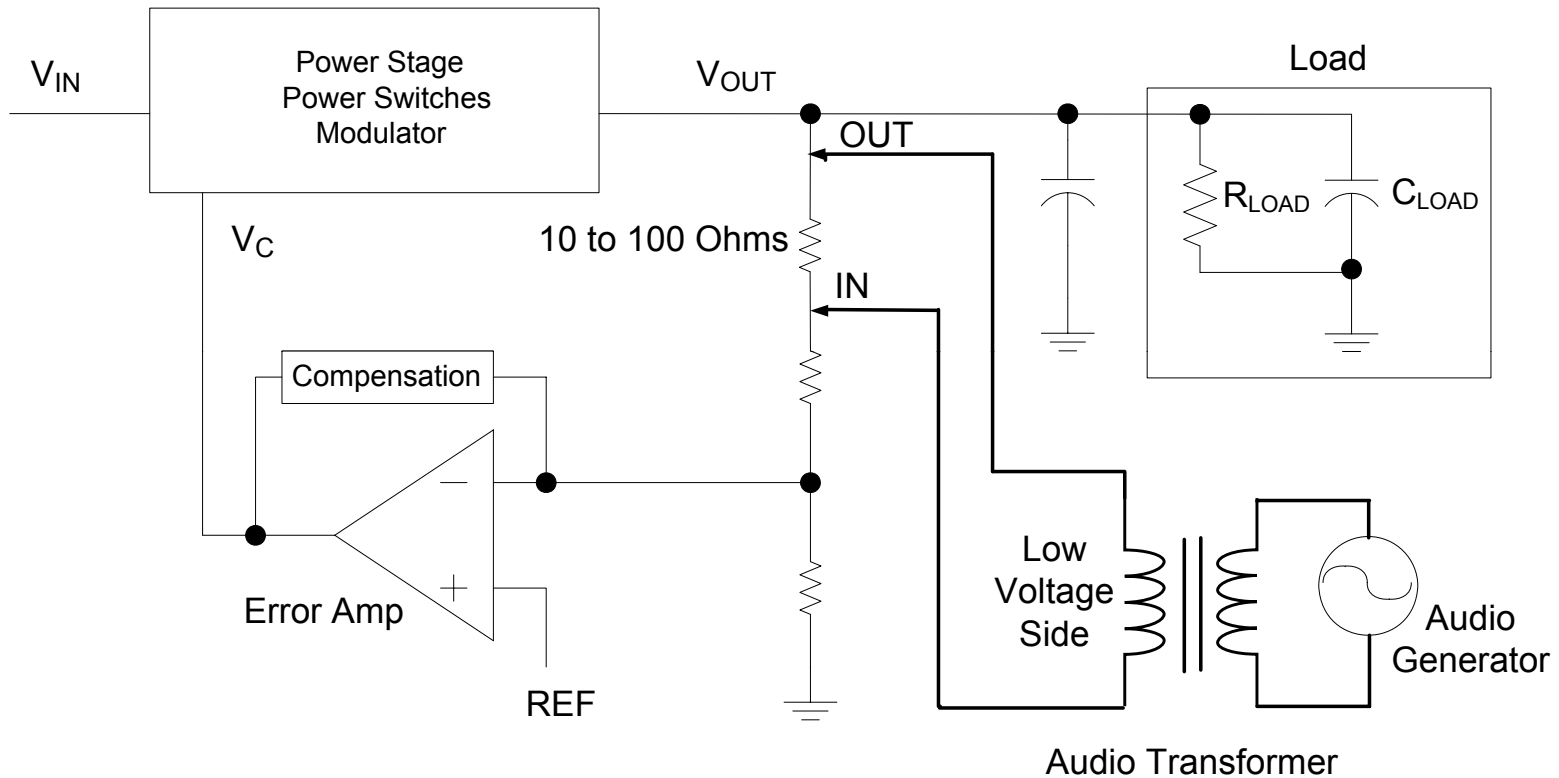


带负载阶跃的电流模式降压





单位增益和相位测量



Connect oscilloscope channel 1 to OUT, channel 2 to IN. Both relative to the local controller ground.



Excel 补偿器设计工具

峰值电流模式降压 – **Type II** 跨导放大器

峰值电流模式控制 – **Type II** 电压放大器

电压模式降压 – **Type III** 电压放大器

电流模式简化频率补偿



电流模式降压

Type II 跨导放大器

Compensator Design - Peak Current-Mode Buck - Transconductance Amplifier

Enter parameters in shaded cells

Version 2.0

Revision date: 9 May 2010

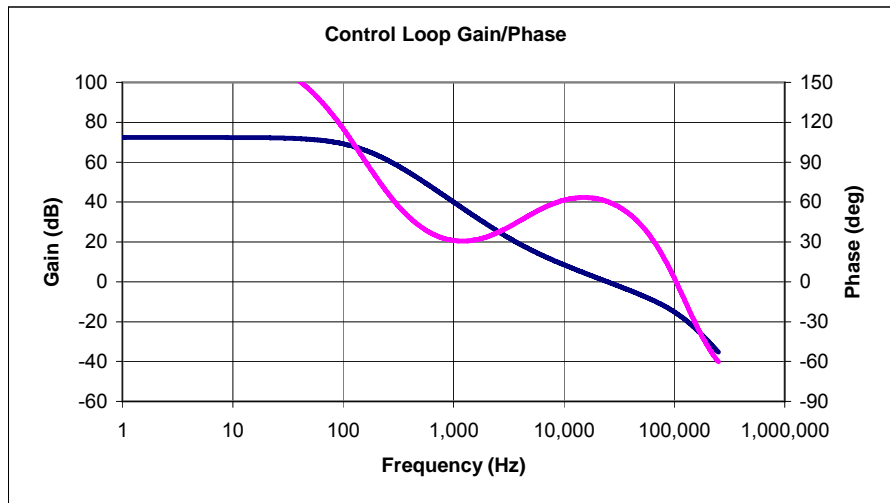
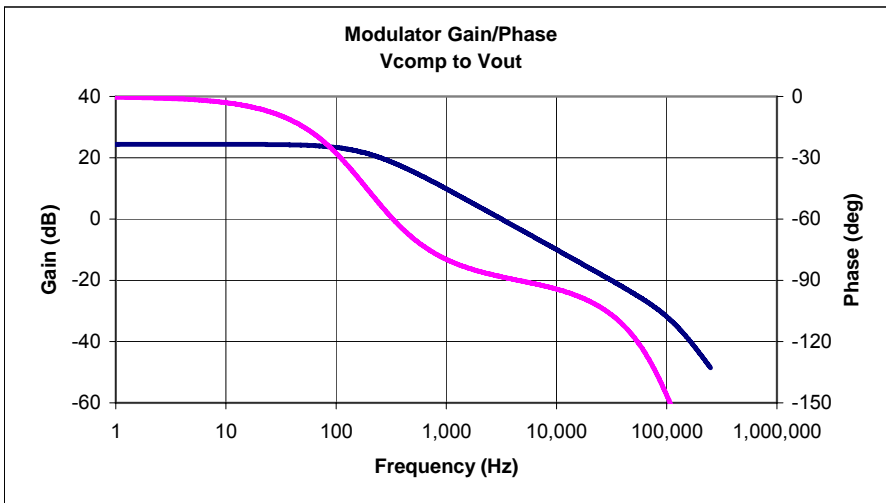
Vin (V)	10
Vout (V)	5
Load Current Iout (A)	1
Switching Frequency Fsw (kHz)	250
Current Sense Resistor Rs (mΩ)	10.0
Current Sense Gain A (V/V)	10
Slope Comp Multiplier SLM (V/V)	1
Output Inductor L (μH)	5.0
Output Capacitor Cout (μF)	500
Output Capacitor ESR (mΩ)	1.0
Error Amplifier gm (μA/V)	1,000
Error Amplifier Rea (kΩ)	1,000

PCM1 Frequency Compensation Parameters

Error Amplifier - Single Pole Transconductance Amplifier

Reference Voltage Vref (V)	1.25
Bottom Feedback Divider Rfbb (Ω)	1,250
Top Feedback Divider Rfbt (Ω)	3,750
Modulator Scale Factor SFM (V/V)	1.00
Modulator Gain Gm(mod) (A/V)	10.00
Modulator Crossover Fc(mod) (kHz)	3.18
Error Amp Zero (kHz)	4.02
Target Loop Bandwidth Fc (kHz)	25.00
Error Amplifier Aol (V/V)	1,000
Error Amplifier UGB (MHz)	10.0
Error Amplifier Cbw (pF)	16

Modulator	Error Amp
D = 0.5000	Kfb = 0.2500
Rout = 5.00	Avm = 8.250
Ri = 0.1000	khf = 1.010
Vsl = 0.4000	wzea = 25,253
Km = 25.00	whf = 2,550,505
Kd = 3.000	wbw = 62,831,853
Av = 16.667	Slope Comp
wp = 1,200	Se = 100000
wz = 2,000,000	Sn = 100000
wc = 157,080	wn = 785,398
	Q = 0.6366





电流模式降压

Type II 电压放大器

Compensator Design - Peak Current-Mode Buck - Voltage Amplifier

Enter parameters in shaded cells

Version 2.0

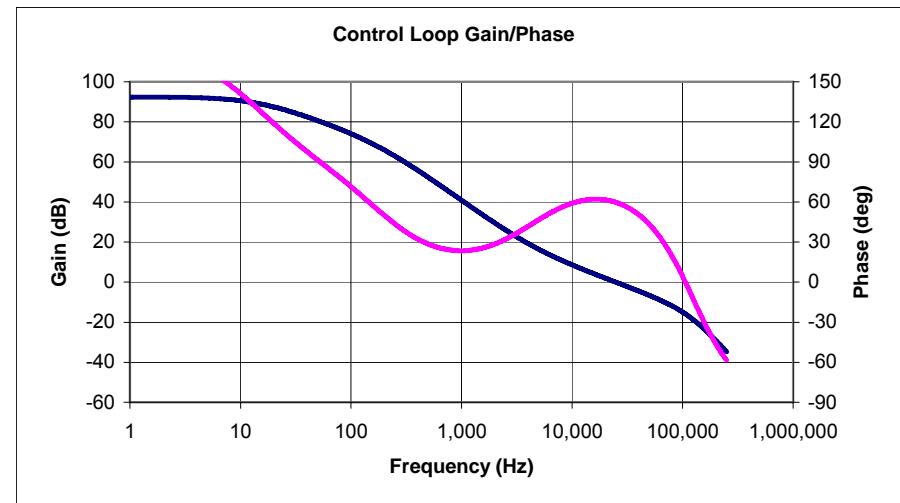
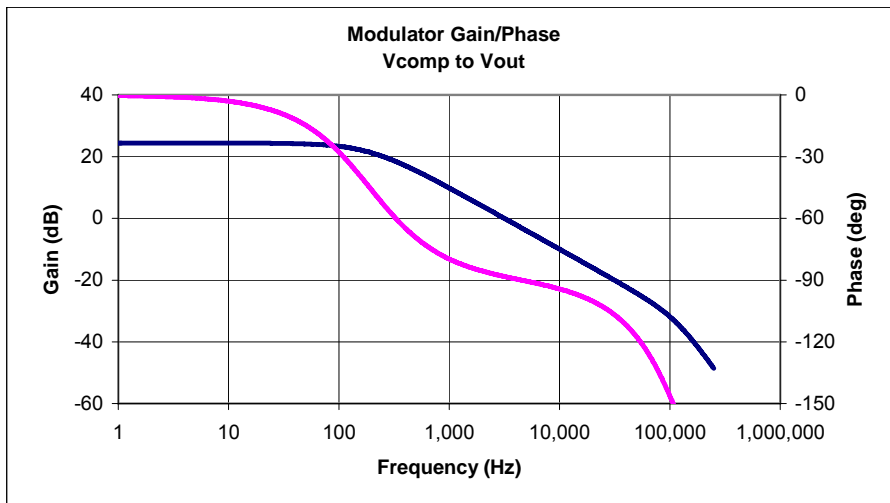
Revision date: 9 May 2010

Vin (V)	12
Vout (V)	5
Load Current Iout (A)	1
Switching Frequency Fsw (kHz)	250
Current Sense Resistor Rs (mΩ)	10.0
Current Sense Gain A (V/V)	10
Slope Comp Multiplier SLM (V/V)	1
Output Inductor L (μH)	5.0
Output Capacitor Cout (μF)	500
Output Capacitor ESR (mΩ)	1.0
Error Amp Aol (V/V)	10,000
Error Amp UGB (MHz)	10.0

PCM1 Frequency Compensation Parameters Error Amplifier - Single Pole Operational Amplifier

Reference Voltage Vref (V)	1.25
Bottom Feedback Divider Rfbb (Ω)	1,250
Top Feedback Divider Rfbt (Ω)	3,750
Modulator Scale Factor SFM (V/V)	1.00
Modulator Gain Gm(mod) (A/V)	10.00
Modulator Crossover Fc(mod) (kHz)	3.18
Error Amp Zero (kHz)	4.42
Target Loop Bandwidth Fc (kHz)	25.00

Modulator		Error Amp
D =	0.4167	Kfb = 0.2500
Rout =	5.00	Rth = 937.5
Ri =	0.1000	Avm = 8.000
Vsl =	0.4000	khf = 1.008
Km =	25.00	wzea = 27,778
Kd =	3.000	whf = 3,361,111
Av =	16.667	wbw = 62,831,853
wp =	1,200	Slope Comp
wz =	2,000,000	Se = 100000
wc =	157,080	Sn = 140000
		wn = 785,398
		Q = 0.6366





电压模式降压

Type III 电压放大器

Compensator Design - Voltage-Mode Buck - Voltage Amplifier

Enter parameters in shaded cells

Version 2.1

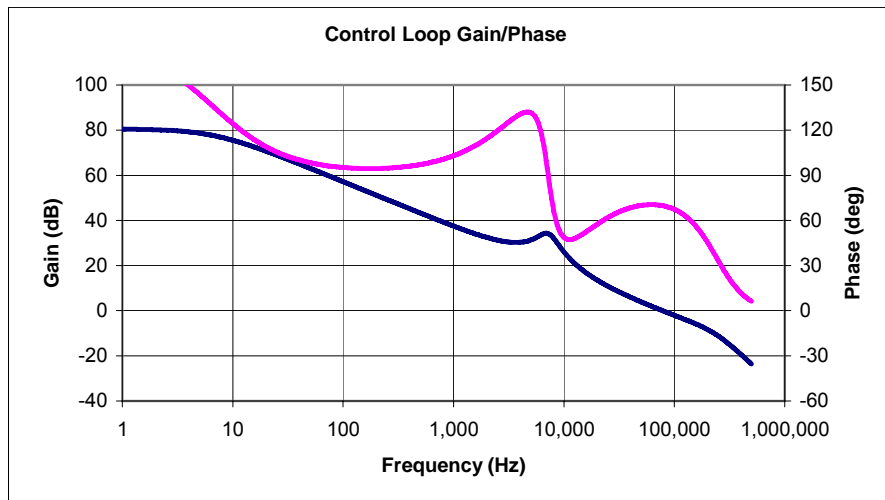
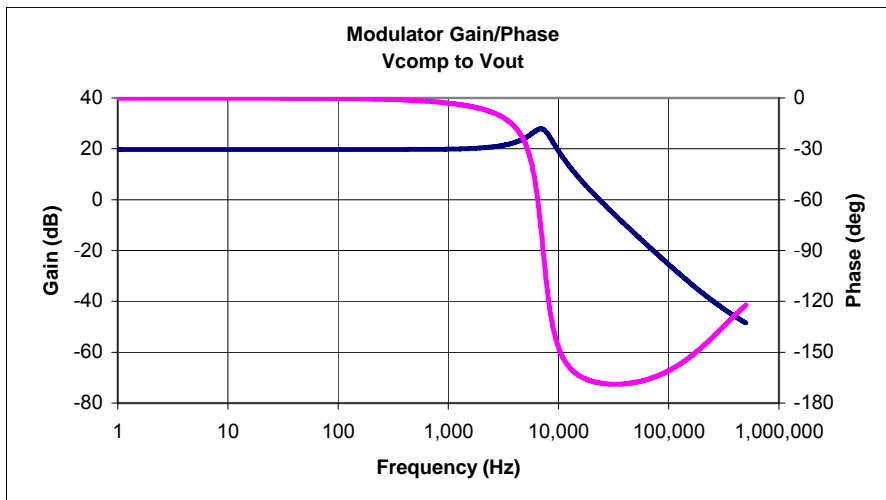
Revision date: 10 May 2010

Vin (V)	12
Vout (V)	1.8
Load Current Iout (A)	10
Switching Frequency Fsw (kHz)	500
Output Inductor L (μH)	1.0
Output Capacitor Cout (μF)	500
Output Capacitor ESR (mΩ)	1.0
Modulator Scale Factor SFM (V/V)	1.00

Input Voltage Feed-Forward Kff (V/V)	0.100
Equivalent Ramp Voltage Vramp (V)	1.200
Reference Voltage Vref (V)	0.600
Bottom Feedback Divider Rfbb (Ω)	1,500
Top Feedback Divider Rfbt (Ω)	3,000
Error Amp Aol (V/V)	3,300
Error Amp UGB (MHz)	15.0
Target Loop Bandwidth Fc (kHz)	75.00

Frequency Compensation Parameters Error Amplifier - Single Pole Operational Amplifier

Modulator		Error Amp
D =	0.1500	Kfb = 0.3333
Rout =	0.18	Rth = 1000.0
Km =	10.00	Avm = 1.069
Gc =	1.054	khf = 1.014
wp =	44,721	wfz = 44,721
wc =	471,239	wzea = 44,721
wz =	2,000,000	wfp = 2,000,000
wsw =	3,141,593	whf = 3,141,593
		wbw = 94,247,780





电流模式简化频率补偿

Word 文档

嵌入式 Excel

Current-Mode Simplified Frequency Compensation

Peak Current-Mode Buck – Voltage Amplifier

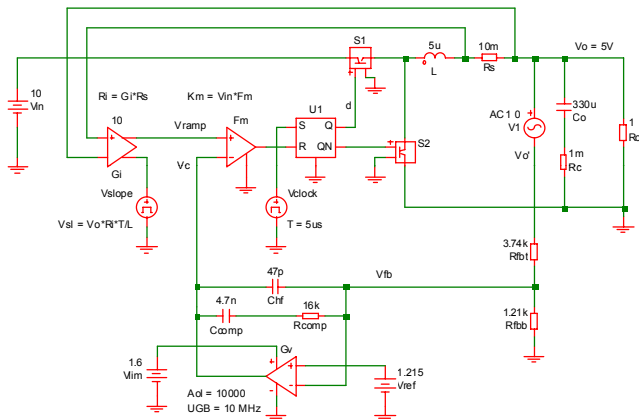


Figure 1. Current-mode buck switching model.

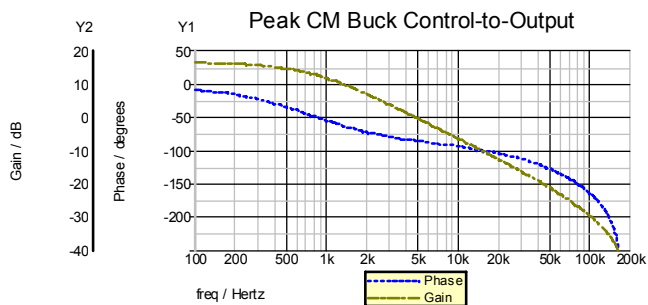


Figure 2. Control-to-output gain and phase.

-
-
-
-
-
-
-
-



结论



概要/行动倡议

1

- 采用 **Excel** 补偿器设计工具

2

- 运用瞬态负载验证性能

3

- 采用信号注入进行单位增益和相位测量