Application Note 44b

Type III Stability Program for the MIC2168/69

Stability Analysis for the MIC2168/69 Voltage Mode Converter Using a Type III Transconductance Error Amplifier

The MIC2169 is a high efficiency, simple to use synchronous buck controller IC, housed in a 10-pin MSOP package. The MIC2169 switches at 500kHz and features a high output driver capability for an all N-channel synchronous architecture. The MIC2169 operates from a 3V to 13.2V input and can be configured to generate output voltages as low as 0.8V. Thus, the MIC2169 is a voltage mode converter with an internal transconductance error amplifier.

This application note addresses stability analysis for the MIC2169 voltage mode controller based on Dean Venable's K[1]-factor method. The following analysis is based on a Type III error amplifier scheme and calculates the compensation resistor and capacitors for the MIC2169 controller, see Figure 1. Type III error amplifier compensation scheme does not rely on the output capacitor ESR to produce a Zero in the power path (input to output transfer function) and therefore, allows low ESR output capacitor such as Ceramic. For additional information on this subject, consult Reference 2.

Type III compensation analysis is done in MathCad which gives the user the flexibility to enter the output capacitance value and ESR; inductor's value and its DCR to match the actual values used on a specific MIC2169 application. This program not only calculates the Compensation values but also provides insight on how the values affect the overall open-loop response. It also has the power-path and error-amplifier transfer functions that show the location of poles and zeros. The MathCad file can be downloaded from Micrel Semiconductor's website (URL:www.micrel.com/xyz/typeIII.mcd). This program can be modified to any fit any voltage mode controller with a transconductance error amplifier by simply changing the gm (error amplifier gain) and the peak magnitude of the voltage ramp signal value.

The following values have to be entered in the program before it calculates the Compensation resistors, R1, R2 and capacitors C1, C2 and C3, see Figure 1:

1. V_{IN}
2. V_{OUT}
3. Cout
4. C_{OUT_ESR}
5. Inductor Value
6. DCR of inductor + R_{DSON} of upper MOSFET
7. Crossover Frequency (normally 50kHz)
8. Required Phase Margin (normally 45°-60°)

After entering the above values, the program calculates the Compensation values and displays the power-path gain and phase, error amplifier gain and phase and total open loop response gain and phase for the circuit. The program will also display the crossover frequency and phase margin for the calculated Compensation values.

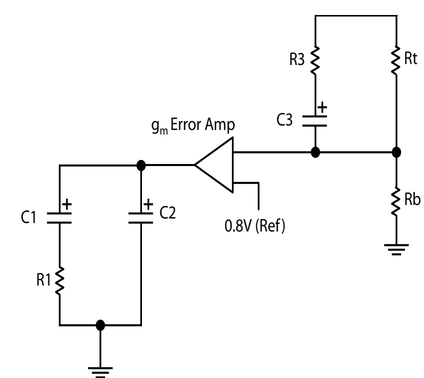

Figure 1. Type III Error Amplifier Scheme

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$L := 1\mu H$	Enter inductor value.
$C := 700\mu F$	Enter output capacitance value.
$ESR := 0.005\Omega$	Enter capacitance ESR value.
$DCR := 0.009\Omega$	Enter inductor DCR + top MOSFET's R_{DSon}.
$f_{esr} := \frac{1}{2 \times \pi \times C \times ESR}$	ESR zero.
$f_c := 150 \times kHz$	Select 100kHz plus as crossover frequency.
$\phi_m := 55$	Enter desired phase margin.
$V_{IN} := 12V$	Enter input voltage.
$V_{OUT} := 3.3V$	Enter your desired output voltage; check page 5 to see if this is achievable.

$$D := \frac{V_{OUT}}{V_{IN}}$$

Reference voltage = 0.8V

$$G_s := 20 \times \log\left(\left(\frac{0.8V}{V_{OUT}}\right)\right) \quad G_s = -12.308$$

Feedback divider attenuation.

$$G_m := 20 \times \log\left(\frac{V_{IN}}{1V}\right)$$

Modulator gain.

$G_m = 21.584$

$$G_{(s)} := \frac{\left(\frac{1}{s \times C} + ESR\right)}{\left(DCR + s \times L + \frac{1}{s \times C} + ESR\right)}$$

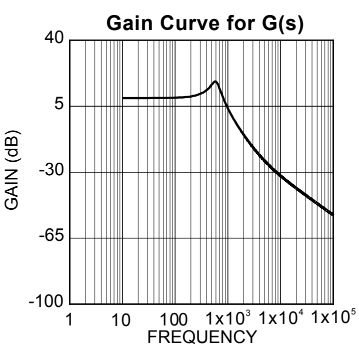
Power path transfer function.

$$G_{(s)} := \frac{(1 + ESR \times s \times C)}{\left(DCR \times s \times C + s^2 \times L \times C + 1 + ESR \times s \times C\right)}$$

Power path transfer function simplified.

Transfer function used for plotting gain curve in dB.

$$G(f) := G_s + Gm + 20 \times \log\left[\sqrt{1 + (ESR \times C \times 2 \times \pi \times f)^2}\right] - 20 \times \log\left[\sqrt{\left[1 - (2 \times \pi \times f)^2 \times L \times C\right]^2 + \left[2 \times \pi \times f \times C \times (ESR + DCR)\right]^2}\right]$$



$Mag := G(f_c)$ Mag is the amplitude of gain required at crossover from the error amplifier.

$Mag = -35.836$

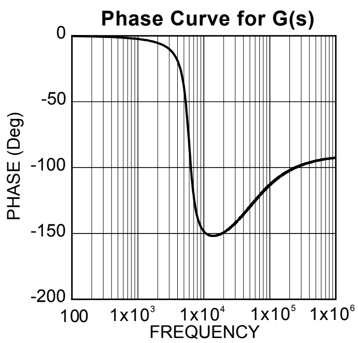
Phase Denominator- due to the LC of the output stage.

$$\phi(f) := \begin{cases} \left[57.3 \times \operatorname{atan}\left[\dfrac{2\times\pi\times f\times C\times(ESR + DCR)}{\left|1-(2\times\pi\times f)^2\times L\times C\right|}\right]\right] & \text{if } \left[(2\times\pi\times f)^2\times L\times C\right] < 1 \\ \left[180 - 57.3\times\operatorname{atan}\left[\dfrac{2\times\pi\times f\times C\times(ESR + DCR)}{\left[\left|1-(2\times\pi\times f)^2\times L\times C\right|\right]}\right]\right] & \text{if } \left[(2\times\pi\times f)^2\times L\times C\right] > 1 \\ 90 \text{ otherwise} & \end{cases}$$

Phase Numerator- due to the ESR of the output capacitor.

$\phi 1(f) := 57.3 \times \operatorname{atan}(2 \times \pi \times f \times ESR \times C)$

$\phi tot(f) := \phi 1(f) - \phi(f)$



$g_m := 0.001 \times \Omega^{-1}$ Transconductance gain.

$\theta_{lc} := 180 - 57.3\operatorname{atan}\left(\dfrac{f_c}{f_{esr}}\right) \qquad \theta_{lc} = 106.859$

K-Factor Method

$P_{shift} := 360 - \phi_m \qquad P_{shift} = 305$

$P_{errorpermitted} := P_{shift} - \theta_{lc} \qquad P_{errorpermitted} = 198.141$

$K_{fac} := \tan\left(\dfrac{450 - P_{errorpermitted}}{4} \times \dfrac{\pi}{180}\right) \quad K_{fac} = 1.96 \quad K := K_{fac}$

$F_z := \dfrac{f_c}{K} \qquad F_z = 7.654 \times 10^4 \text{Hz}$ Zero location.

$F_p := f_c \times K \qquad F_p = 2.939 \times 10^5 \text{ Hz}$ Pole location.

$Mag = -35.836$

$$\frac{Rtop}{Rbottom} > \frac{F_p}{F_z} - 1$$

You have to impose this condition for ensuring +ve transfer function, otherwise will get -ve value for R3- see type3_new for more information.

$Rtop := 10k\Omega$ $Rt := Rtop$

$$Rbottom := \frac{Rtop}{\frac{F_p}{F_z} - 1}$$

$Rbottom := Rbottom - 100 \times \Omega$

$Rb := Rbottom$ $Rb = 3.421 \times 10^3 \Omega$

$$V_{OUT\_MIN} := 0.8V \times \left(1 + \frac{Rt}{Rb}\right)$$

Absolute min output voltage for this scenario is:

$V_{OUT\_MIN} = 3.139V$ This is the V_{OUT_MIN} that is possible to achieve type III compensation.

$$Rb := \left(\frac{V_{OUT}}{.8V} - 1\right)^{-1} \times Rt \qquad Req := Rb \times \frac{Rt}{Rb + Rt}$$

$Rb = 3.2 \times 10^3 \Omega$ Bottom feedback resistor.

$Rt = 1 \times 10^4 \Omega$ Top feedback resistor.

$Req = 2.549 \times 10^3 \Omega$ Parallel equivalent resistance for Rt ad Rb.

$$nmag := |Mag| - 20 \times \log\left(\left(\frac{f_c}{F_z}\right)\right) \qquad nmag = 29.993$$

$$R1 := \frac{10^{\frac{nmag}{20}}}{g_m}$$

$$C1 := \frac{1}{2 \times \pi F_z \times R1}$$

$R1 = 3.16 \times 10^4 \Omega$ Compensation resistor.

$C1 = 6.581 \times 10^{-11} F$ Compensation capacitor.

$$C2 := \frac{1}{2 \times \pi F_p \times R1}$$

$C2 = 1.714 \times 10^{-11} F$ Compensation capacitor.

If V_{OUT_MIN} V_{OUT} >"Not Possible","***Possible***",( ) "***Possible***"= Stop!!!!

If you are getting a "Not Possible" message, otherwise continue. You will get a negative resistor value for R3!!!! Call Micrel factory for support.

$$R3 := \frac{Rt^2 + Rb \times Rt \times \left(1 - \frac{F_p}{F_z}\right)}{(Rb + Rt) \times \left(\frac{F_p}{F_z} - 1\right)}$$

$R3 = 243.108\Omega$ Compensation resistor.

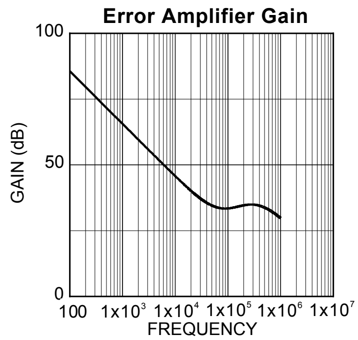
$$C3 := \frac{1}{2 \times \pi \times (Rt + R3) \times F_z}$$

$C3 = 2.03 \times 10^{-10} F$ Compensation capacitor.

Error amplifier transfer function.

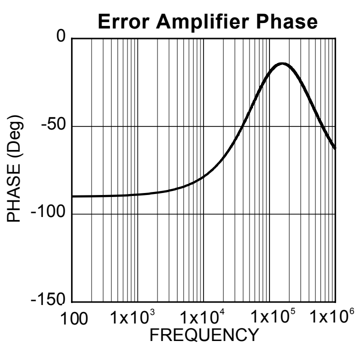
$$E(z) := g_m \times \left[\frac{(1 + R1 \times S \times C1) Rb [1 + (Rt + R3) \times S \times C3]}{s \times (C1 + C2) \times \left(1 + R1 \times \frac{C1 \times C2 \times S}{C1 + C2}\right) \times (Rb + Rt) \times [1 + S \times C3 \times (Req + R3)]}\right]$$

$$\mathrm{Error}(f) := \left[\begin{array}{l} 20 \times \log\left[\dfrac{g_m}{(C1 + C2)}\right] + 20 \times \log\left[\sqrt{1 + (2 \times \pi \times f \times R1 \times C1)^2}\right] - 20 \times \log\left[\sqrt{1 + \left(2 \times \pi \times f \times R1 \times \dfrac{C2 \times C1}{C1 + C2}\right)^2}\right] - 20 \times \log\left[\sqrt{(2 \times \pi \times f)^2}\right] \\ + 20 \times \log\left[\sqrt{1 + \left[(Rt + R3) \times C3 \times 2 \times \pi \times f\right]^2}\right] - 20 \times \log\left[\sqrt{1 + \left[\left[2 \times \pi \times f \times (Req + R3) \times C3\right]^2\right]}\right] \end{array}\right]$$



$$\mathrm{ErPhase}(f) := 57.3 \times \left[\begin{array}{l} \left(\mathrm{atan}(2 \times \pi \times f \times R1 \times C1) - \mathrm{atan}\left(\dfrac{2 \times \pi \times f \times R1 \times C1 \times C2}{C1 + C2}\right) - \mathrm{atan}(2 \times \pi \times f)\right) \\ + \mathrm{atan}\left[(Rt + R3) \times C3 \times 2 \times \pi \times f\right] - \mathrm{atan}\left[\left[2 \times \pi \times f \times (Req + R3) \times C3\right]\right] \end{array}\right]$$

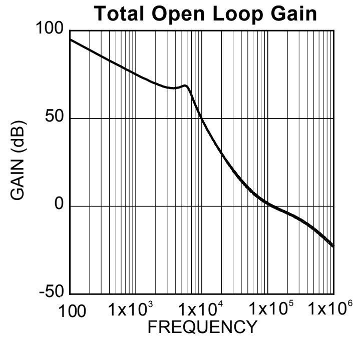
$$\mathrm{ErPhase1}(f) := \mathrm{ErPhase}(f) - 180$$

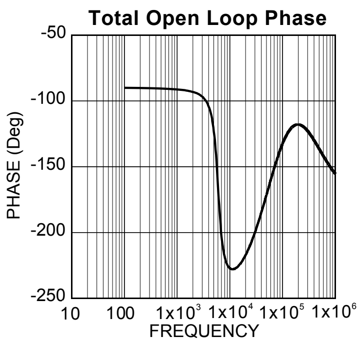


Total open loop.

Cl(f) := G(f) + Error(f)

Clphase(f) := ErPhase1(f) + ϕtot(f)





$R1 = 3.16 \times 10^{4}\Omega$

$C1 = 6.581 \times 10^{-11}F$

$C2 = 1.714 \times 10^{-11}F$

$R3 = 243.108\Omega$

$C3 = 2.03 \times 10^{-10}F$

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