Accurate Point-of-Load Voltage Regulation Using Simple Adaptive Loop Feedback

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Introduction

Accurate point of load (PoL) voltage control is essential for highly dynamic electronic loads. 'Adaptive loop' is a technique for efficient, feed-forward compensation of isolated power-management systems based on PRM™ Regulator and VTM™ Voltage Transformer combinations.

This application note describes the design methodology for optimal DC set point compensation of PRM and VTM combinations[a], including small arrays of two identical VTMs driven by one PRM.

For your reference, an Adaptive Loop Calculator is available at:

http://spicewebprd.vicorpower.com/apps/PRM_VTM_Calculator/Calculator.php.

Adaptive Loop Regulation Concept

Adaptive loop is a model-based, positive-feedback compensation technique that can easily complement negative feedback, voltage mode regulation. Figure 1 shows the conceptual block diagram.
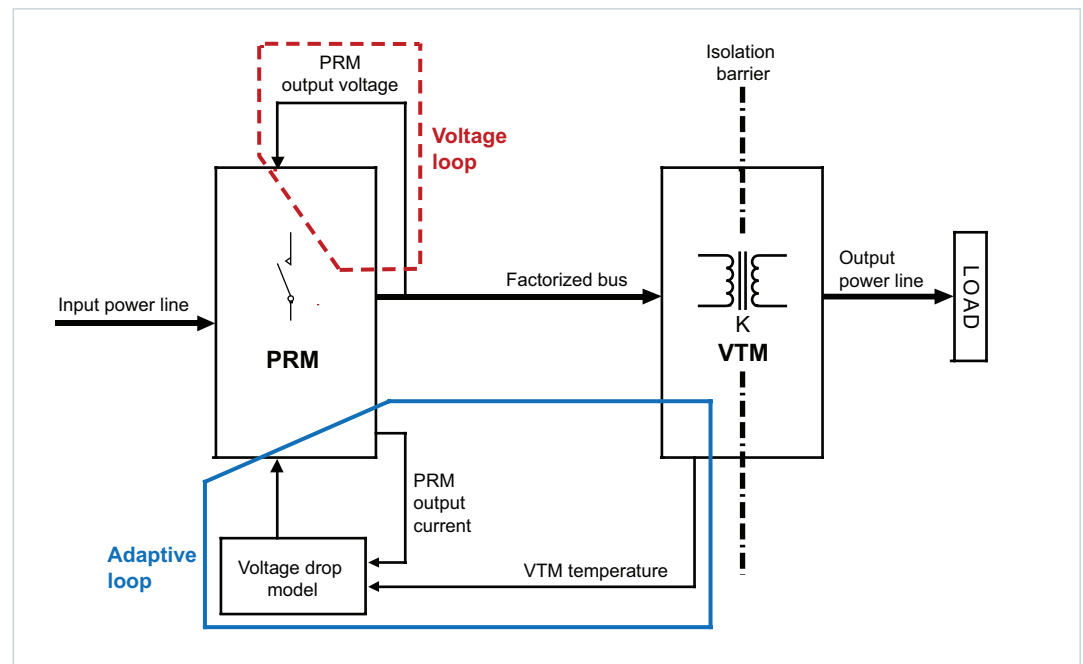

Figure 1
Adaptive Loop Regulation
Conceptual Diagram

While the local voltage feedback loop maintains regulation at the PRM output, the adaptive loop (AL) provides compensation for the voltage drops that occur from the PRM output to the actual load. As stated before, AL is based on a model that requires VTM temperature and factorized bus current as inputs. The resistive behavior of power lines (factorized bus and output line) as well as the VTM, enables accurate modeling of their voltage drops.

Note: The calculations represented in this application note apply to 24V, 36V and 48V input PRMs. Though the same methodology applies to 28V input MIL-COTS PRMs, care should be taken to apply the correct values. For further assistance, please contact a Field Applications Engineer via your local Technical Support Center.

Major benefits of this approach are:

- No signals need to be transmitted across VTM's™ isolation barrier
- Simpler circuit, lower component count

Regulation accuracy is affected by the accuracy of this model; this application note explains how to optimize the model for a given system, and how to estimate the obtained accuracy.
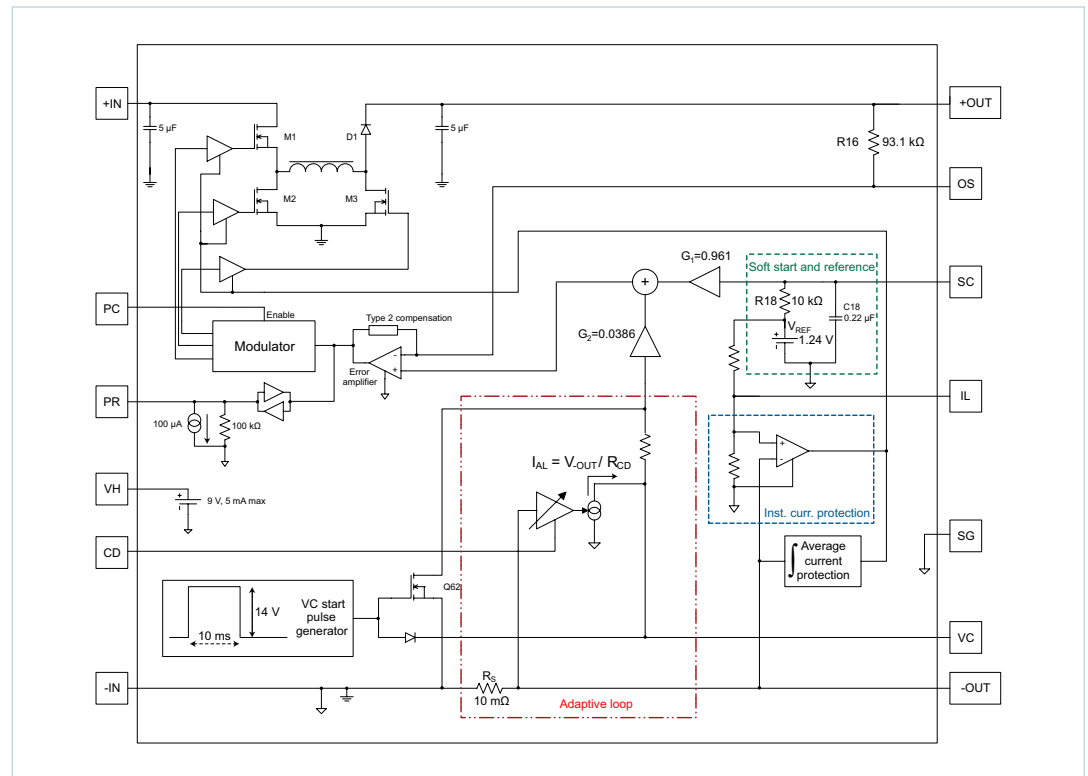
Standard regulation techniques are based on direct observation and integral error compensation of PoL voltage, and the steady state error (compared to the reference) is therefore forced to be zero. AL only asymptotically approaches the zero error state, therefore widening the total distribution of the PoL voltage.

PRM-AL Block Diagram

Figure 2 shows the functional block diagram for a full-chip PRM-AL regulator (e.g. P045F048T32AL). The OS and SC pins provide for local voltage feedback loop setting, while the VC and CD pins provide for settings and connections of the downstream system model.

Figure 2
PRM-AL Functional Block Diagram

In summary:

Local Voltage Feedback Loop:

- V_{REF}, through R18, provides a reference voltage source on the SC pin. This is routed to the non-inverting input of the error amplifier, through the gain stage G1.
- The factorized bus (+OUT) voltage is fed back to the inverting input of the error amplifier through R16.
- SC and OS provide for the connection of the external resistor dividers.

Adaptive Loop Circuit:

- The voltage controlled current source has variable gain, controlled by the resistance connected between CD and signal ground (SG) pins. The current injected on the VC line by the variable gain transconductance amplifier is:

  - directly proportional to the voltage across the sense resistor RS
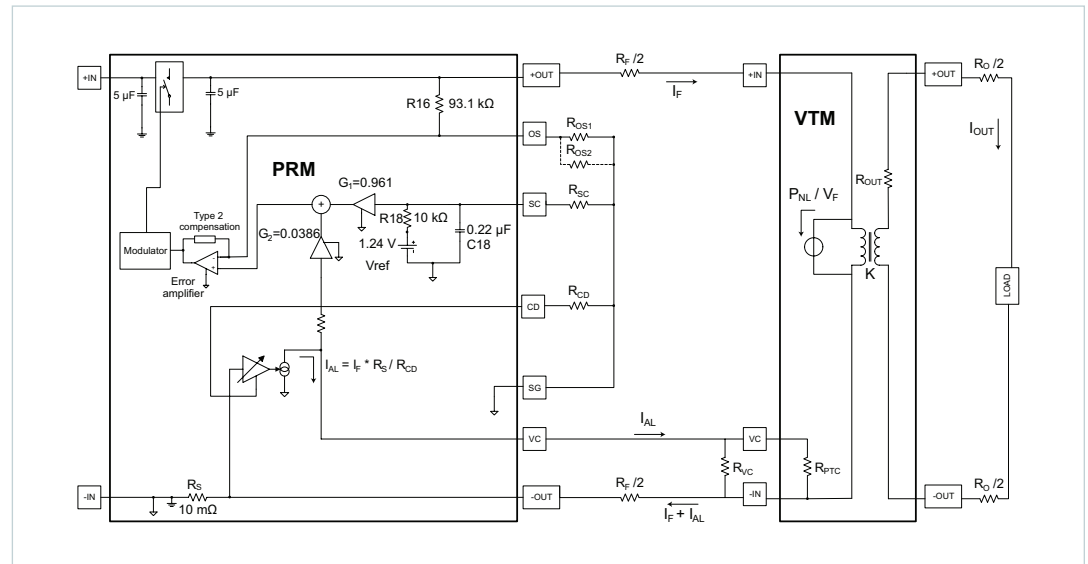 - inversely proportional to the resistor connected between CD and SG according to the following relationship:

$$I_{AL} = \frac{V_{-OUT}}{R_{CD}} = \frac{R_S I_F}{R_{CD}} \qquad (1)$$

where I_F is the factorized bus (PRM™ output) current and V_{-OUT} is the voltage drop across RS.

- The VC pin voltage is added to the reference pin voltage SC through the gain stage G2.

A PRM™ and VTM™ system is considered, as shown in the block diagram in Figure 3. The system PCB adds further voltage drops from the PRM output to the load: the factorized bus resistance, R_F, and the output line resistance, R_O, which are assumed to be constant and equally divided on the positive and negative trace / wire. In order to account for them, these resistances must be estimated or measured.

Figure 3
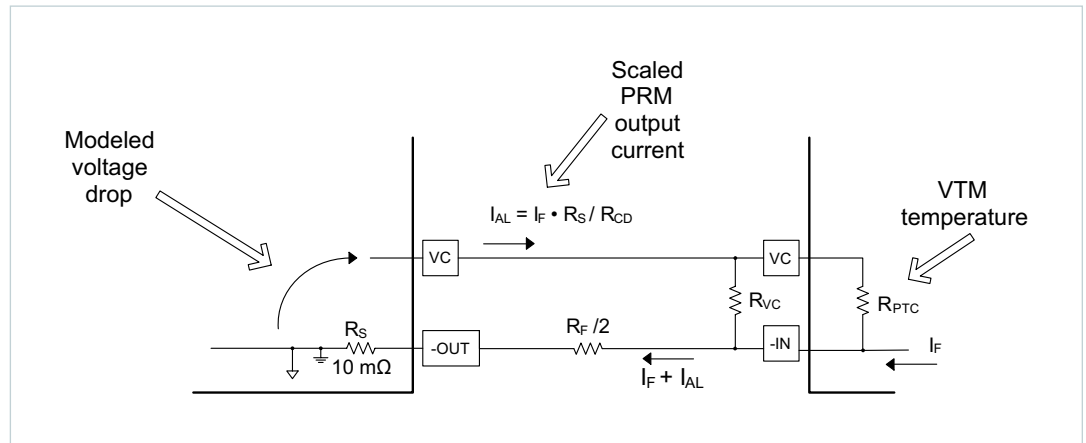*Factorized Power Architecture (FPA™) System with Adaptive Loop Control Block Diagram*

It is important to correctly identify the total voltage drop parameters, which are R_F, R_{OUT} and R_O in this specific case. Their compensation model must therefore be resistive, and temperature dependent.

Such a model is easy to implement, thanks to:

- The PTC resistor embedded in the VTM module, which will change its value according to the VTM temperature.
- R_{VC} resistor, which allows precise match of R_{PTC} to VTM R_{OUT} temperature characteristic.

The parallel of R_{VC} and R_{PTC} resistors, in series with $R_F/2$ and R_S resistors constitutes the voltage drop model. The AL circuitry forces a scaled version of the PRM™ output current (I_{AL}) in the VC line, which then merges with the factorized bus current IF on its return path (as shown in Figure 4).

The voltage obtained on the VC pin, with some scale factor, is the model of the total voltage drop in the system.

DC Set Point Calculation

The necessary inputs to the procedure are shown in Table 1.

Standard Full-Chip Characteristics	Power System Characteristics
■ R_{OUT_25} (R_{OUT_AMB} in datasheet): 25°C output resistance	■ V_{F_NOM}: nominal factorized bus voltage at no load
■ R_{OUT_100} (R_{OUT_HOT} in datasheet): 100°C output resistance	■ I_{OUT}: maximum system (VTM) output current
■ K: transformer ratio	■ R_F: factorized bus (PRM to VTM) total resistance
■ R_{VC-INT}: VTM VC pin internal resistance	■ R_O: output bus (VTM to point load) total resistance
■ T_{VC_COEFF}: VC internal resistor temperature coefficient	
■ P_{NL}: no load power dissipation at nominal input voltage	

The inputs listed in Table 1 can be found in each individual VTM's datasheet; see the Adaptive Loop Calculator tool for more information:

http://spicewebprd.vicorpower.com/apps/PRM_VTM_Calculator/Calculator.php.

With reference to Figure 3:

A. Calculate the maximum voltage drop (at 25ºC and 100ºC) due to VTM™ output resistance R_{OUT}.

$$\Delta V_{ROUT\_25} = R_{OUT\_25} \bullet I_{OUT} \qquad (2)$$

$$\Delta V_{ROUT\_100} = R_{OUT\_100} \bullet I_{OUT} \qquad (3)$$

B. Calculate the maximum current flowing on the factorized bus.

$$I_F = K \bullet I_{OUT} + \frac{P_{NL}}{V_{F\_NOM}} \qquad (4)$$

Although the no load power (P_{NL}) required by the VTM is input voltage dependent, the variation has only a minor influence on the AL compensation, and will therefore be neglected in the following steps.

C. Calculate the total PRM™ output voltage increase that will compensate all the drops (factorized bus resistance, VTM output resistance and output bus resistance).
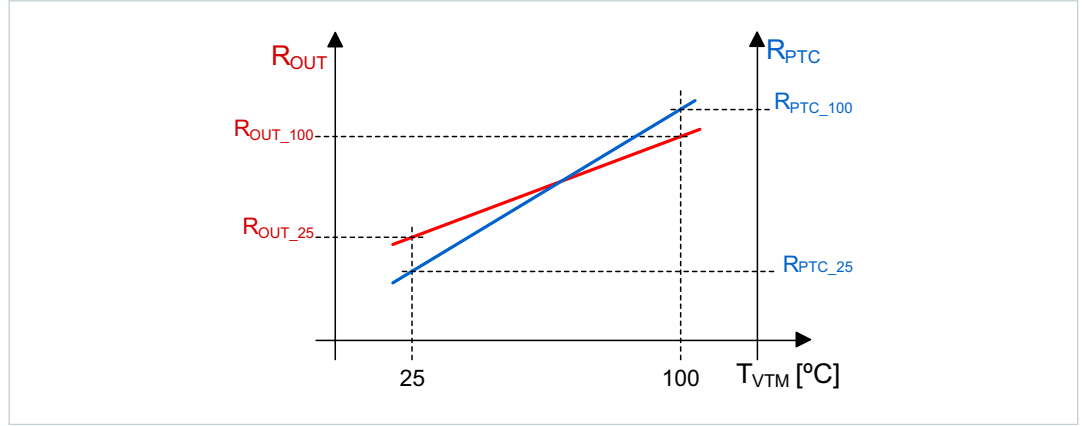
$$\Delta V_{F\_25} = \frac{\Delta V_{ROUT\_25} + R_O I_{OUT}}{K} + (R_F + R_S) \bullet I_F \qquad (5)$$

$$\Delta V_{F\_100} = \frac{\Delta V_{ROUT\_100} + R_O I_{OUT}}{K} + (R_F + R_S) \bullet I_F \qquad (6)$$

VICOR *PowerBench*

D. Calculate the total temperature coefficient of the power circuit and the R_{VC} resistor needed to match it.

The PTC resistor and the VTM™ R_{OUT} resistance are subject to the same temperature, but they have different rates of change, as shown in Figure 5.

In order for the model to precisely match the voltage drop over temperature, its slope must match the system slope. The R_{VC} resistor in parallel to R_{PTC} can be calculated in order to meet this condition.

$$\Delta R_{TOT} = \frac{\Delta V_{F\_100}}{\Delta V_{F\_25}} = \frac{\dfrac{R_{VC} \bullet R_{PTC\_100}}{R_{VC} + R_{PTC\_100}}}{\dfrac{R_{VC} \bullet R_{PTC\_25}}{R_{VC} + R_{PTC\_25}}} \quad \Rightarrow \qquad\qquad (7)$$

$$R_{VC} = (1 - \Delta R_{TOT}) \frac{R_{PTC\_25} \bullet R_{PTC\_100}}{\Delta R_{TOT} \bullet R_{PTC\_25} - R_{PTC\_100}}$$

There is an important reason for choosing a parallel rather than a series resistor to match the system temperature coefficient. At start up, the PRM™ issues a 14V, 10ms pulse on the VC line to synchronously start the VTM. A series resistor would cause significant amplitude change on this signal, avoided by the parallel arrangement. However, the designer should exercise judgment and avoid extreme cases, where the temperature dependency might be so low as to cause the R_{VC} value to fall below 200Ω (which would cause overload during the 14V, 10ms startup pulse).

E. Calculate the maximum VC pin voltage for the given system at 25°C (100°C should provide the same value, given the temperature dependency has been taken care of through R_{VC}, Equation 7):

$$V_{C\_MAX\_25} = I_{AL} \bullet \frac{R_{PTC\_25} \bullet R_{VC}}{R_{PTC\_25} + R_{VC}} + (I_F + I_{AL}) \bullet \left(\frac{R_F}{2} + R_S \right) = \qquad (8)$$

$$= R_S \frac{I_F}{R_{CD\_MIN}} \bullet \frac{R_{PTC\_25} \bullet R_{VC}}{R_{PTC\_25} + R_{VC}} \bullet \left(I_F + R_S \frac{I_F}{R_{CD\_MIN}} \right) \bullet \left(\frac{R_F}{2} + R_S \right)$$

Minimum allowable R_{CD} value for current products is 20Ω.

F. Calculate the needed (if any) V_{SC} trim that allows enough AL dynamic range under the worst case: $V_{C\_MAX\_25}$ and ΔV_{F_100} (this will allow enough design margin).

The voltage on VC, through the gain stage G_2, is summed to the reference voltage SC in order to compensate for the voltage drop ΔV_F. Because the VC voltage dynamic range is set, V_{SC} might be reduced in order to match the relative changes of factorized bus and adaptive loop compensation.

$$\frac{\Delta V_{F\_100}}{V_{F\_NOM}} \leq \frac{G_2 \bullet V_{C\_MAX\_25}}{G_1 \bullet V_{SC}} \implies V_{SC} \leq \frac{G_2 \bullet V_{C\_MAX\_25}}{G_1 \dfrac{\Delta V_{F\_100}}{V_{F\_NOM}}} \qquad (9)$$

G_1 and G_2 gains are 0.961 and 0.0386 respectively.

If $V_{SC} \leq V_{REF} = 1.24V$, the external resistor to be connected on SC will be easily calculated as following:

$$R_{SC} = R_{18} \frac{V_{SC}}{V_{REF} - V_{SC}} \qquad (10)$$

The absolute minimum value for V_{SC} is 0.25V, because of the characteristic of the internal error amplifier. The minimum resistance value for R_{SC} is therefore 2550Ω.

G. Calculate the voltage feedback divider resistor needed to set the nominal output voltage.

$$V_{F\_NOM} = G_1 \bullet V_{SC} \frac{R_{16} + R_{OS}}{R_{OS}} \implies R_{OS} = G_1 \bullet R_{16} \frac{V_{SC}}{V_{F\_NOM} - G_1 \bullet V_{SC}} \qquad (11)$$

R_{OS} defines the gain on the voltage feedback, which accommodates for the chosen reference voltage V_{SC}. It is recommended to calculate its value using the V_{SC} voltage obtained with a standardized value resistor as R_{SC}. Moreover, if a standard value resistor is not available to match (within 0.2%) the calculated R_{OS} value, it is strongly recommended to use a parallel configuration.

H. Calculate the R_{CD} resistor that allows AL to compensate for the drops (25°C or 100°C will give the same result, because of R_{VC}).

First, substitute the VC line voltage at full I_F current (room temperature):

$$V_{C\_25} = \frac{R_S \bullet I_F}{R_{CD}} \bullet \frac{R_{PTC\_25} \bullet R_{VC}}{R_{PTC\_25} + R_{VC}} + \left(\frac{R_S \bullet I_F}{R_{CD}} + I_F \right) \bullet \left(\frac{R_F}{2} + R_S \right) \qquad (12)$$

into the expression for the related factorized bus increase:

$$\Delta V_{F\_25} = G_2 \bullet V_{C\_25} \frac{R_{16} + R_{OS}}{R_{OS}} =$$

$$= G_2 \bullet \frac{R_S \bullet I_F}{R_{CD}} \bullet \frac{R_{PTC\_25} \bullet R_{VC}}{R_{PTC\_25} + R_{VC}} + \left(\frac{R_S \bullet I_F}{R_{CD}} + I_F \right) \bullet \left(\frac{R_F}{2} + R_S \right) \frac{R_{16} + R_{OS}}{R_{OS}}$$

Then solve for R_{CD}:

$$R_{CD} = \frac{G_2 \dfrac{R_{16} + R_{OS}}{R_{OS}} R_S I_F \left(\dfrac{R_{PTC\_25} \bullet R_{VC}}{R_{PTC\_25} + R_{VC}} + \dfrac{R_F}{2} + R_S \right)}{\Delta V_{F\_25} - G_2 \dfrac{R_{16} + R_{OS}}{R_{OS}} \left(\dfrac{R_F}{2} + R_S \right) I_F} \qquad (13)$$
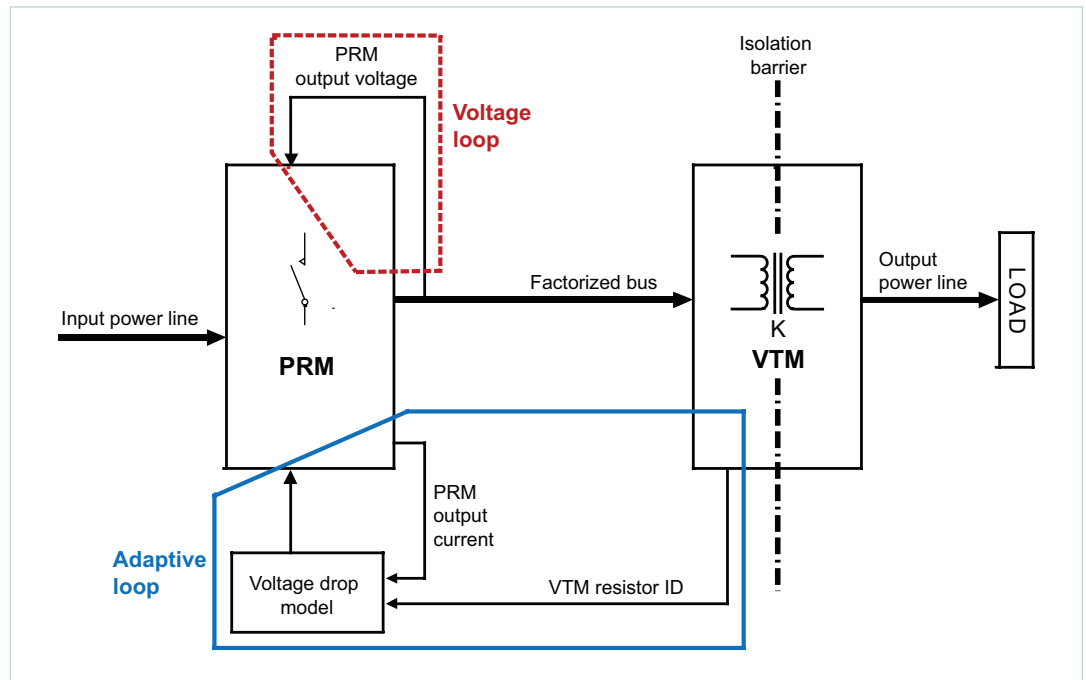
Considerations

In order to improve regulation accuracy, the following guidelines should be followed:

■ Discrepancy between the model and the system will directly affect regulation accuracy. System characterization is strongly recommended during the design phase, specifically factorized bus (R_F) and output line (R_O) resistances.

■ Statistical distribution of components values plays also a key role on accuracy distribution. To this end, 'Monte Carlo' (or similar) analysis and optimization is strongly encouraged. It should include all the components directly affecting regulation; i.e., setting resistors, model resistors and component characteristics. Any extra component designed in the system; i.e., filter inductors, connectors, etc., should also be included if affected by variability.

■ While the impact of R_S and R_F on VC voltage may be neglected in a few cases, it normally affects accuracy distribution. In order to evaluate it, both resistors should be included in the analysis.
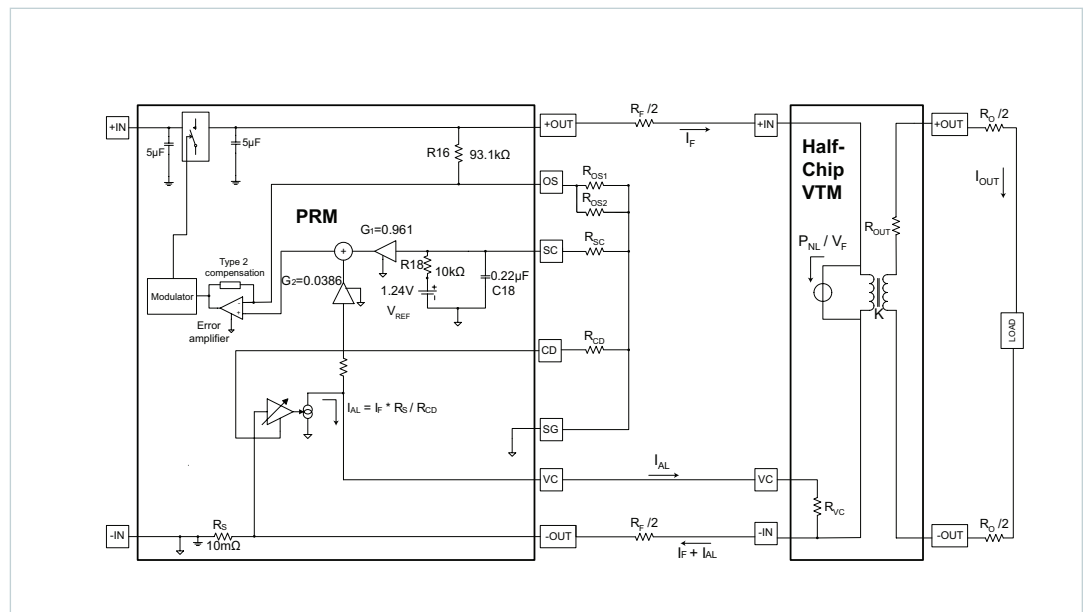
Adaptive Loop with Half-Chip VTMs

The major difference between full- and half-chip VTMs™ is the absence of temperature feedback. While the full-chip VTMs implement a PTC resistor, the half-chip modules use a simple precision resistor, as shown in Figure 6.

Figure 6
Adaptive Loop Regulation
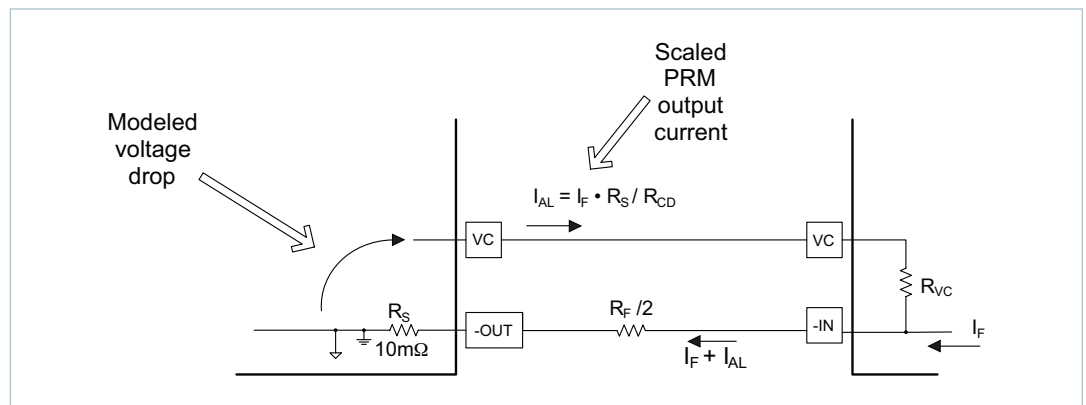*Concept without*
Temperature Feedback

The absence of temperature feedback slightly degrades the regulation accuracy; however, the half-chip units have tighter parameter distributions, which partially compensate for the reduced model accuracy. The control configuration in this case is shown in Figure 7.

Figure 7
Adaptive Loop Control
with Half-Chip VTM

The voltage drop model also differs with the one for the full-chip version (Figure 3), resulting in the simpler one shown in Figure 8.

Having explained the differences, it is now possible to revise the design procedure in this specific case. Table 2 shows the necessary inputs.

Table 2

Adaptive Loop Calculation Procedure Inputs for Half-Chip VTMs

Standard Full-Chip Characteristics	Power System Characteristics
■ R_{OUT_25} (R_{OUT_AMB} in datasheet): 25°C output resistance ■ R_{OUT_100} (R_{OUT_HOT} in datasheet): 100°C output resistance ■ K: transformer ratio ■ R_{VC} (R_{VC-INT} in datasheet): VTM™ VC pin internal resistance ■ P_{NL}: no load power dissipation at nominal input voltage	■ V_{F_NOM}: nominal factorized bus voltage at no load ■ I_{OUT}: maximum system (VTM) output current ■ R_F: factorized bus (PRM to VTM) total resistance ■ R_O: output bus (VTM to point load) total resistance

The inputs listed in Table 2 can be found in each individual VTM's™ datasheet; see the Adaptive Loop Calculator tool for more information:

http://spicewebprd.vicorpower.com/apps/PRM_VTM_Calculator/Calculator.php.

For sake of clarity, only the steps that differ from the procedure already explained for the full-chip VTMs are reported.
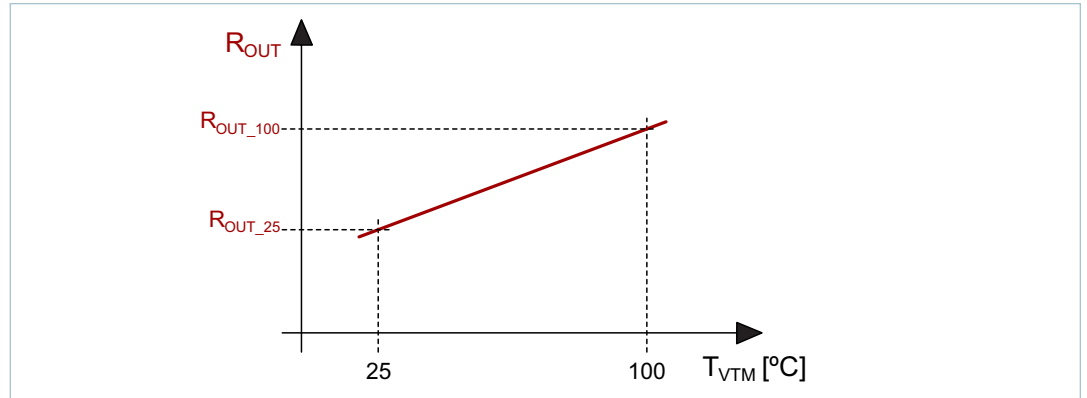
Step(s):

A., B., C. unchanged

D. Calculate the total temperature coefficient of the power circuit at the estimated VTM™ working temperature.

The VTM R_{OUT} resistance is temperature dependent, as shown in Figure 9.

Figure 9
Half-Chip VTM R_{OUT} vs.
Module Internal Temperature

In order for the model to match the system voltage drop better, the VTM operating temperature should be estimated. In cases where temperature is unknown, a conservative approach would be to assume the module will operate at half of its temperature range, for example 75°C:

$$\Delta V_{F\_75} = \Delta V_{F\_25} + \frac{\Delta V_{F\_100} - \Delta V_{F\_25}}{75} \bullet 50 \qquad (14)$$

Linear interpolation used in Equation 14 is acceptable in this case, as R_{OUT} temperature dependency is linear.

E. Calculate the maximum VC pin voltage for the given system.

$$V_{C\_MAX} = I_{AL} \bullet R_{VC} + (I_F + I_{AL}) \bullet \left(\frac{R_F}{2} + R_S \right) = \qquad (15)$$

$$= R_S \frac{I_F}{R_{CD\_MIN}} \bullet R_{VC} + \left(I_F + R_S \frac{I_F}{R_{CD\_MIN}} \right) \bullet \left(\frac{R_F}{2} + R_S \right)$$

F., G. unchanged

H. Calculate the R_{CD} resistor that allows AL to compensate for the drops.

First, substitute the VC line voltage at full I_F current (ambient temperature):

$$V_C = \frac{R_S \bullet R_S}{R_{CD}} \bullet R_{VC} + \left(\frac{R_S \bullet I_F}{R_{CD}} + I_F \right) \bullet \left(\frac{R_F}{2} + R_S \right) \qquad (16)$$

into the expression for the related factorized bus increase:

$$\Delta V_{F\_75} = G_2 \bullet V_C \frac{R_{16} + R_{OS}}{R_{OS}} =$$

$$= G_2 \bullet \frac{R_S \bullet I_F}{R_{CD}} \bullet R_{VC} + \left(\frac{R_S \bullet I_F}{R_{CD}} + I_F \right) \bullet \left(\frac{R_F}{2} + R_S \right) \frac{R_{16} + R_{OS}}{R_{OS}}$$

Then solve for R_{CD}:

$$R_{CD} = \frac{G_2 \dfrac{R_{16} + R_{OS}}{R_{OS}} R_S I_F \left(R_{VC} + \dfrac{R_F}{2} + R_S \right)}{\Delta V_{F\_75} - G_2 \dfrac{R_{16} + R_{OS}}{R_{OS}} \left(\dfrac{R_F}{2} + R_S \right) I_F} \qquad (17)$$

Design Example with VI Chip® Customer Boards

System requirements:

Input: 36 – 75V
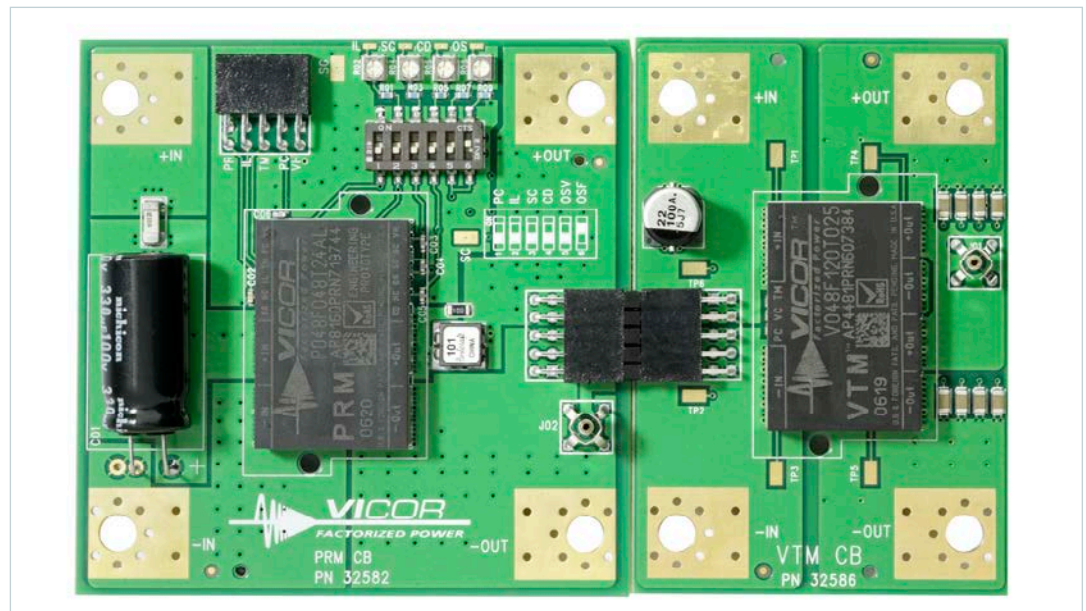Output: 5V, 36A, 180W

VI Chip selection:

PRM™: P048F048T24AL (due to the wide range input voltage and the power level).

VTM™: V048F060T040 (due to output voltage and current requirements).

Corresponding customer boards are P048F048T24AL-CB and V048F060T040-CB respectively. They come with a connector which routes factorized bus and VC line, as explained in the User Guide UG:003. Figure 10 shows the two selected boards once connected.

Figure 10
PRM and VTM
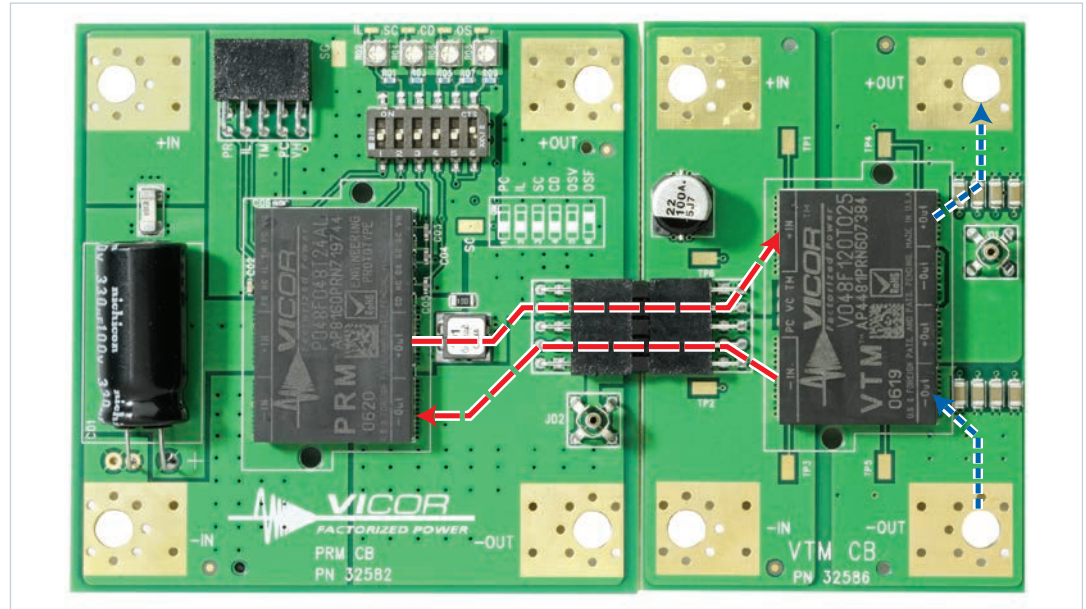*Customer Boards*

First, collect the characteristics from the VTM's data sheet and from Table 2:

- R_{OUT_25}: 5.76mΩ
- R_{OUT_100}: 6.73mΩ
- K: 1/8
- R_{PTC_25}: 1000Ω
- R_{PTC_100}: 1000 • (1+0.0039 • 75) = 1293Ω
- P_{NL}: 2.7W

Second, calculate or measure the power system characteristics:

- V_{F_NOM}: $V_{OUT}/K = 40V$

- I_{OUT}: 36A

- R_F and R_O: these values are strictly related to the board traces or cables used to route power. A convenient way to obtain these values is to identify the current paths of interest, as shown in Figure 11.

Figure 11

Factorized Bus Current Path
(Long-Dash Red)
and Output Current Path
(Short-Dash Blue)

Then, a simple DC impedance measurement from terminal to terminal will provide R_F and R_O values. In this particular case:

- $R_F = 10m\Omega$

- $R_O = 80\mu\Omega$

It is now possible to apply the proposed procedure.

A. Calculate the maximum voltage drop (at 25°C and 100°C) due to VTM™ output resistance, R_{OUT}.

$$\Delta V_{ROUT\_25} = R_{OUT\_25} \bullet I_{OUT} = 0.00576 \bullet 36 = 0.207V$$

$$\Delta V_{ROUT\_100} = R_{OUT\_100} \bullet I_{OUT} = 0.00673 \bullet 36 = 0.242V$$

B. Calculate the maximum current flowing on the factorized bus.

$$I_F = K \bullet I_{OUT} + \frac{P_{NL}}{V_{F\_NOM}} = \frac{1}{8} \bullet 36 + \frac{2.7}{40} = 4.568A$$

C. Calculate the total PRM™ output voltage increase that will compensate all the drops (factorized bus resistance, VTM™ output resistance and output bus resistance).

$$\Delta V_{F\_25} = \frac{\Delta V_{ROUT\_25} + R_o I_{OUT}}{K} + (R_F + R_S) \bullet I_F = \frac{0.207 + 80\mu \bullet 36}{\dfrac{1}{8}} + (10m + 10m) \bullet 4.568 = 1.77V$$

$$\Delta V_{F\_100} = \frac{\Delta V_{ROUT\_100} + R_o I_{OUT}}{K} + (R_F + R_S) \bullet I_F = \frac{0.242 + 80\mu \bullet 36}{\dfrac{1}{8}} + (10m + 10m) \bullet 4.568 = 2.05V$$

D. Calculate the total temperature coefficient of the power circuit and the R_{VC} resistor needed to match it.

$$\Delta R_{TOT} = \frac{\Delta V_{F\_100}}{\Delta V_{F\_25}} = \frac{2.05}{1.77} = 1.158 \quad \Rightarrow$$

$$R_{VC} = (1 - \Delta R_{TOT}) \frac{R_{PTC\_25} \bullet R_{PTC\_100}}{\Delta R_{TOT} \bullet R_{PTC\_25} - R_{PTC\_100}} = (1 - 1.158) \frac{1000 \bullet 1293}{1.158 \bullet 1000 - 1293} = 1513\Omega$$

The R_{VC} value is greater than 200Ω, therefore valid. The nearest available 1% resistor value chosen for R_{VC} is 1500Ω.

E. Calculate the maximum VC pin voltage for the given system at 25°C. From the PRM-AL data sheet, $R_{CD\_MIN} = 20\Omega$:

$$V_{C\_MAX\_25} = R_S \frac{I_F}{R_{CD\_MIN}} \bullet \frac{R_{PTC\_25} \bullet R_{VC}}{R_{PTC\_25} + R_{VC}} \bullet \left(I_F + R_S \frac{I_F}{R_{CD\_MIN}}\right) \bullet \left(\frac{R_F}{2} + R_S\right) =$$

$$= 10m \frac{4.568}{20} \bullet \frac{1000 \bullet 1500}{1000 + 1500} + \left(4.568 + 10m \frac{4.568}{20}\right) \bullet \left(\frac{10m}{2} + 10m\right) = 1.44V$$

F. Calculate the needed (if any) V_{SC} trim that allows enough AL dynamic range under the worst case: $V_{C\_MAX\_25}$ and ΔV_{F_100}.

$$V_{SC} \leq \frac{G_2 \bullet V_{C\_MAX\_25}}{G_1 \dfrac{\Delta V_{F\_100}}{V_{F\_NOM}}} = \frac{0.0386 \bullet 1.44}{0.961 \dfrac{2.05}{40}} = 1.12V$$

As $V_{SC} \leq V_{REF} = 1.24V$, R_{SC} must be installed:

$$R_{SC} = R_{18} \frac{V_{SC}}{V_{REF} - V_{SC}} = 10k \frac{1.12}{1.24 - 1.12} = 93.3k\Omega$$

R_{SC} is greater than 2550Ω, therefore acceptable. The closest 1% tolerance value is chosen, R_{SC} = 93.1kΩ, which provides for an obtained V_{SC} = 1.12V

G. Calculate the voltage feedback divider resistor needed to set the nominal output voltage.

$$R_{OS} = G_1 \cdot R_{16} \frac{V_{SC}}{V_{F\_NOM} - G_1 \cdot V_{SC}} = 0.961 \cdot 93.1k \frac{1.12}{40 - 0.961 \cdot 1.12} = 2574\Omega$$

The closest standard value would be 2550Ω, which is almost 1% off the target. In order to gain accuracy, the highest standard value is chosen, 2610Ω, and a parallel resistor is used in order to closely match the required value:

R_{OS1} = 2610Ω and R_{OS2} = 187kΩ

H. Calculate R_{CD} resistor that allows AL to compensate for the drops.

$$R_{CD} = \frac{G_2 \dfrac{R_{16} + R_{OS}}{R_{OS}} R_S I_F \left(\dfrac{R_{PTC\_25} \cdot R_{VC}}{R_{PTC\_25} + R_{VC}} + \dfrac{R_F}{2} + R_S \right)}{\Delta V_{F\_25} - G_2 \dfrac{R_{16} + R_{OS}}{R_{OS}} \left(\dfrac{R_F}{2} + R_S \right) I_F} =$$

$$= \frac{0.0386 \dfrac{93.1k + 2574}{2574} 10m \cdot 4.568 \left(\dfrac{1k \cdot 1.5k}{1k + 1.5k} + \dfrac{10m}{2} + 10m \right)}{1.77 - 0.0386 \dfrac{93.1k + 2574}{2574} \left(\dfrac{10m}{2} + 10m \right) \cdot 4.568}$$

The nearest standard value is chosen, R_{CD} = 23.7Ω.
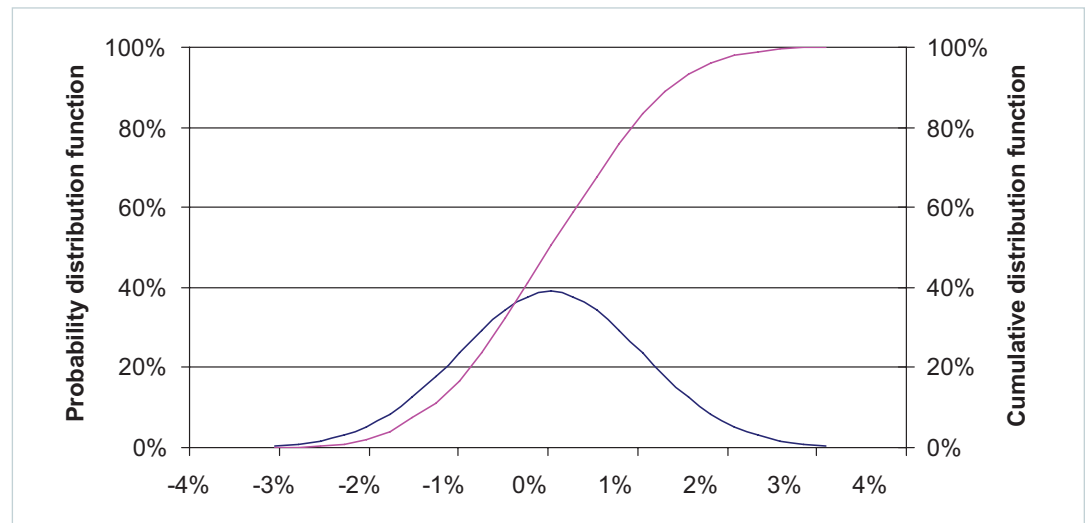
The design is now complete, the calculated resistors:
R_{SC} = 93.1kΩ, R_{OS1} = 2610Ω, R_{OS2} = 187kΩ, R_{VC} = 1500Ω and R_{CD} = 23.7Ω
can be implemented in the two customer boards and regulation accuracy verified.

Conclusion

This procedure highlights the adaptive loop regulation concept and the design procedure to achieve good voltage regulation for a simple PRM™/VTM™ combination.

Monte Carlo analysis shows that 1% regulation accuracy over line, load and temperature can be statistically achieved 82% (or greater) of the time. Figure 12 shows accuracy distribution for the design example previously illustrated.

Figure 12

Accuracy Distribution Over Line, Load and Temperature for the Design Example

The same design concepts are directly applicable to arrays of VI Chips® if proper modeling applied. It is recommended to contact VI Chip Application Engineering for any array involving two or more PRMs and three or more VTMs. For your reference, an Adaptive Loop Calculator is available at:
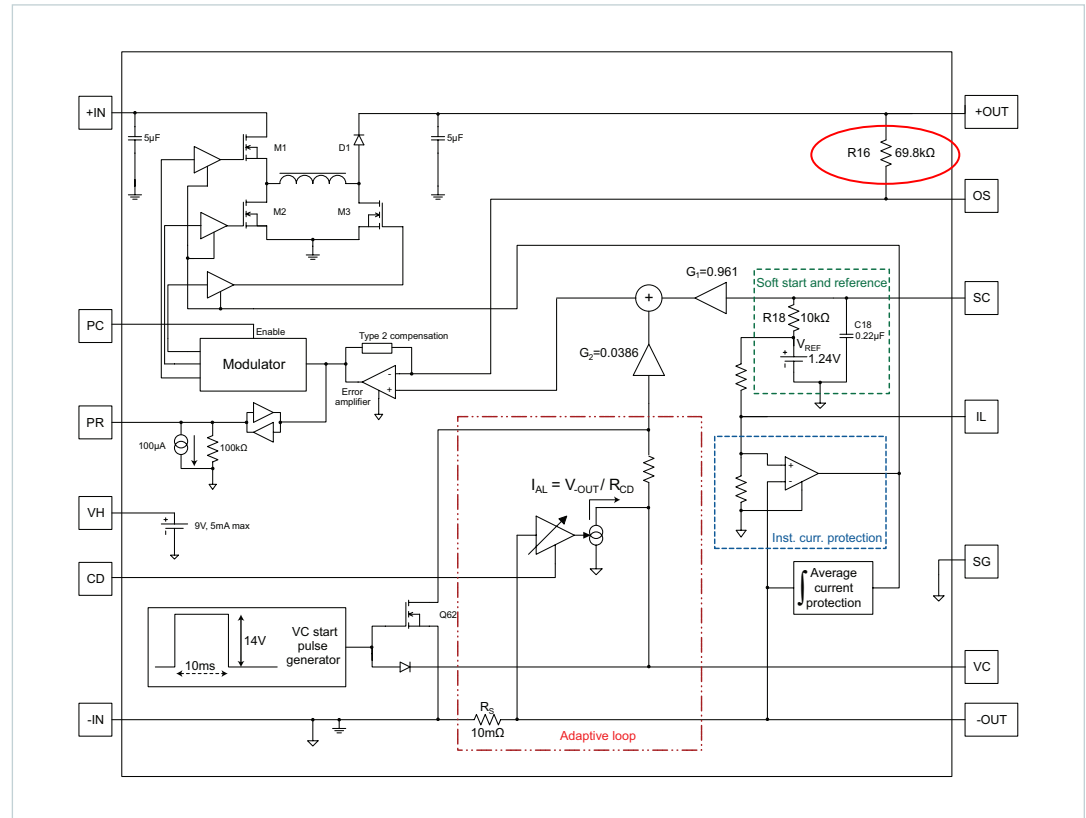
http://spicewebprd.vicorpower.com/apps/PRM_VTM_Calculator/Calculator.php.

Appendix A

Changes applicable to MIL-COTS versions of VI Chips®.

MIL-COTS VTM™: parameters and modeling of MIL-COTS VTMs are identical to the commercial counterparts with the same K factor. The AL design procedure can be applied directly.

MIL-COTS PRM™: parameters and modeling of MP028F036M12AL are identical to the commercial parts as with the only exception of R16 which changes to 69.8kΩ, as shown in the figure below.

For your reference, an Adaptive Loop Calculator for MIL-COTS products is available at:

http://spicewebprd.vicorpower.com/apps/PRM_VTM_Calculator/Calculator.php.

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