

Constant-Current (CC) Evaluation Board



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The Constant-Current (CC) Evaluation Board described in this document shows how to use a PRM regulator as a constant-current source. The CC evaluation board is not designed for installation in end-user equipment. The system demonstrates the use of a PRM™ and a VTM™ to drive light-emitting diodes (LEDs) or for general laboratory evaluation.

Please read this document before setting up a customer evaluation board.

 **IMPORTANT NOTICE:**

The User Guide is not comprehensive and is not a substitute for common sense and good practice. For example:

1. When testing electronic products always use approved safety glasses.
2. Provide a strain relief for wires and place the system on the bench in such a way as to prevent accidental dislodgment from the bench top.
3. Remove power and use caution when connecting and disconnecting test probes and interface lines to avoid inadvertent short circuits and contact with hot surfaces.
4. Never use a jumper in place of the fuse. Replace the fuse only with its equivalent type and rating.
5. Never attempt to disconnect the CC evaluation board from a VTM customer board while power is applied. This system is not designed to demonstrate hot-plug capability. Additional components would be required to implement a hot-plug capable system.

Introduction

The PRM Regulator can be set to either regulate its output in a Local-Loop mode or regulate the output of a VTM Voltage Transformer at the point of load in an Adaptive Loop. Adaptive-Loop regulation is realized through the addition of a compensation resistor to the CD pin. Please refer to the [Factorized Power Architecture \(FPA™\) white paper](#) for more details. The CC evaluation board is designed to provide a precise regulated current. This is particularly useful in LED driving applications where the intensity and brightness are controlled by regulating the current through the LED.

The VI Chip® solution provides an efficient, power dense means of powering high current optosemiconductor LEDs such as Enfis products UNO and Quattro arrays as well as OSRAM product OSTAR.

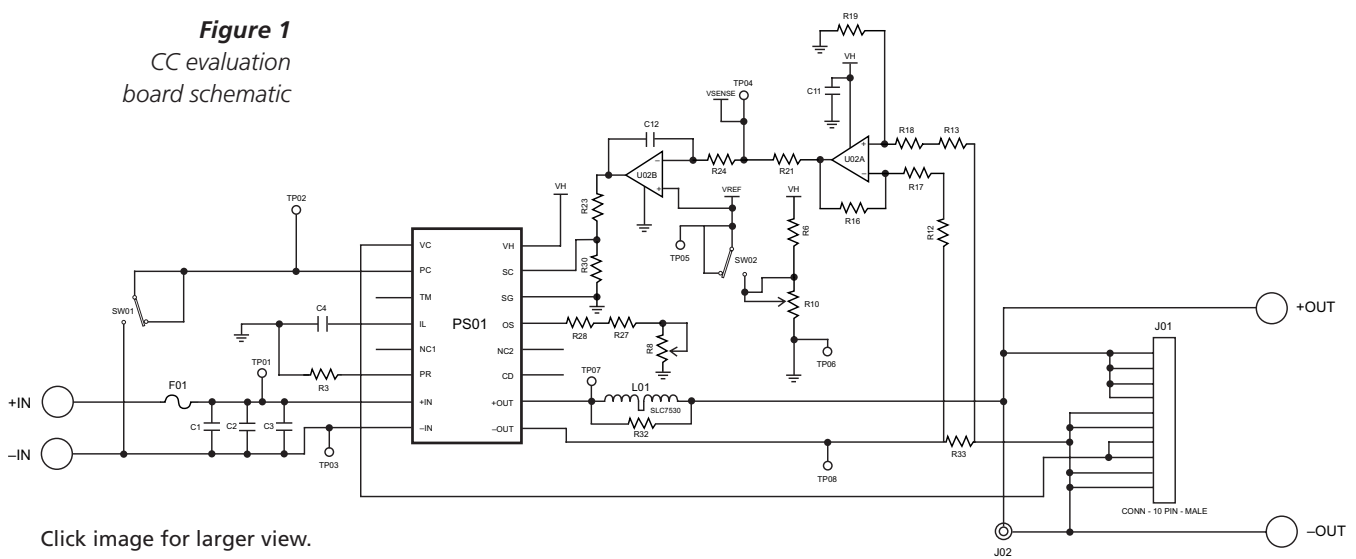
The P048F048T24AL-CC board may be used to provide up to 5A when employed as a standalone non-isolated source. A PRM-VTM combination provides isolated current multiplication up to 100A. Separate VTM boards allow customers to choose a desired output current and voltage range. To obtain a VTM customer board, simply add "-CB" to the VTM part number.

Features

The CC Evaluation Board contains the following:

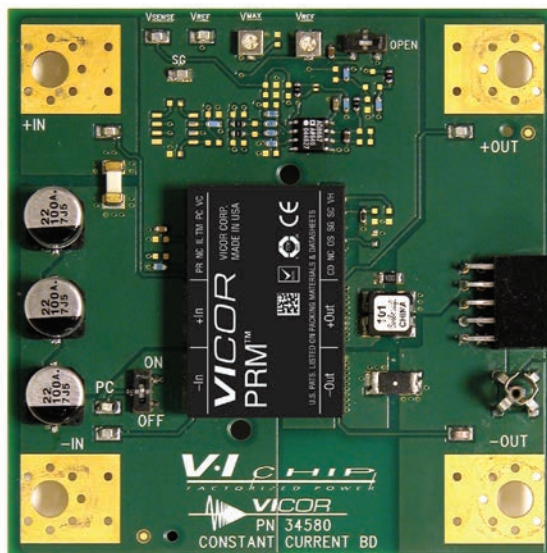
1. High-power-density PRM™.
2. Adjustable current output of up to 5A (if no VTM™ is used).
Adjustable current output of up to 100A with the use of a VTM customer board.
3. Adjustable PRM maximum output voltage.
4. Kelvin connections for measuring the efficiency of the VI Chip® components independent of load connect losses.
5. Oscilloscope probe jacks for measuring output voltage, including output voltage ripple.
6. Fused PRM input.
7. Provision for mounting optional VI Chip pushpin heat sink.
8. System enable and disable.

Figure 1
CC evaluation
board schematic



CC Evaluation Board Description

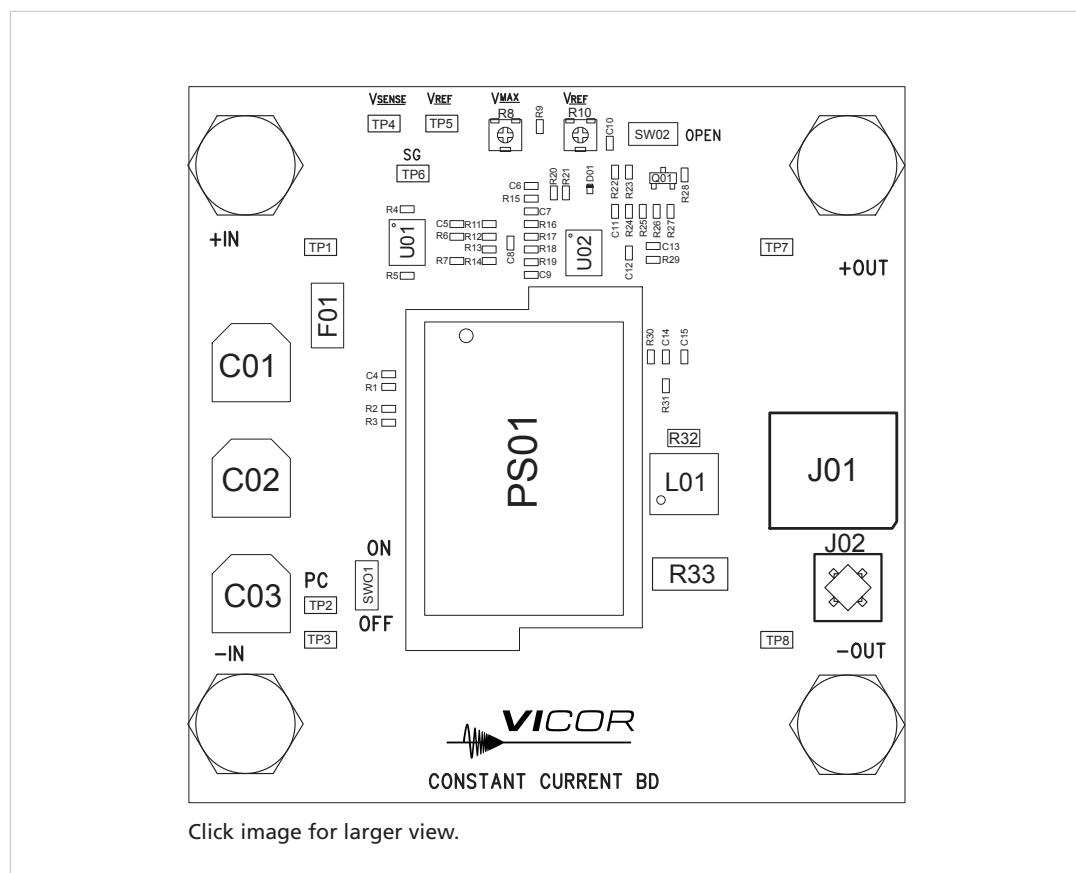
Figure 2
CC evaluation board



General

1. **Source voltage DC input points (+IN, -IN):** Designed to accommodate #10 hardware and Panduit ring lugs. The PRM has no reverse power protection so be sure to observe correct polarity.
2. **Toggle switch (SW01):** Used to enable or disable the PRM. The ON position enables the PRM by allowing the PRM PC pin to float. The OFF position disables the PRM by pulling the PRM PC to signal ground (SG).
3. **Toggle switch (SW02):** Used to open or close the connection between the reference voltage produced from the potentiometer (R10) and the positive input of the comparator op amp. This is provided as an added feature to allow the use of an external shunt regulator. The recommended component is TLV431B. For further details refer to application note: [AN:018 Providing a Constant Current for Powering LEDs using the PRM™ and VTM™](#). Make sure to turn this switch to the "open" position when a shunt regulator is in use.
4. **Output voltage points (+OUT, -OUT).**
5. **Output connector (J01):** Used for mating with VTM-CB providing V_{OUT} and VC. As shown dedicated to the +OUT, four for the -OUT, and two for the VC. Each contact is rated for 3A. The excess capacity afforded by these pins can facilitate testing multiple VTM-CBs from a single PRM-CC using appropriate wiring harness and mating connector. This may also be achieved using the large pads of the output voltage points.

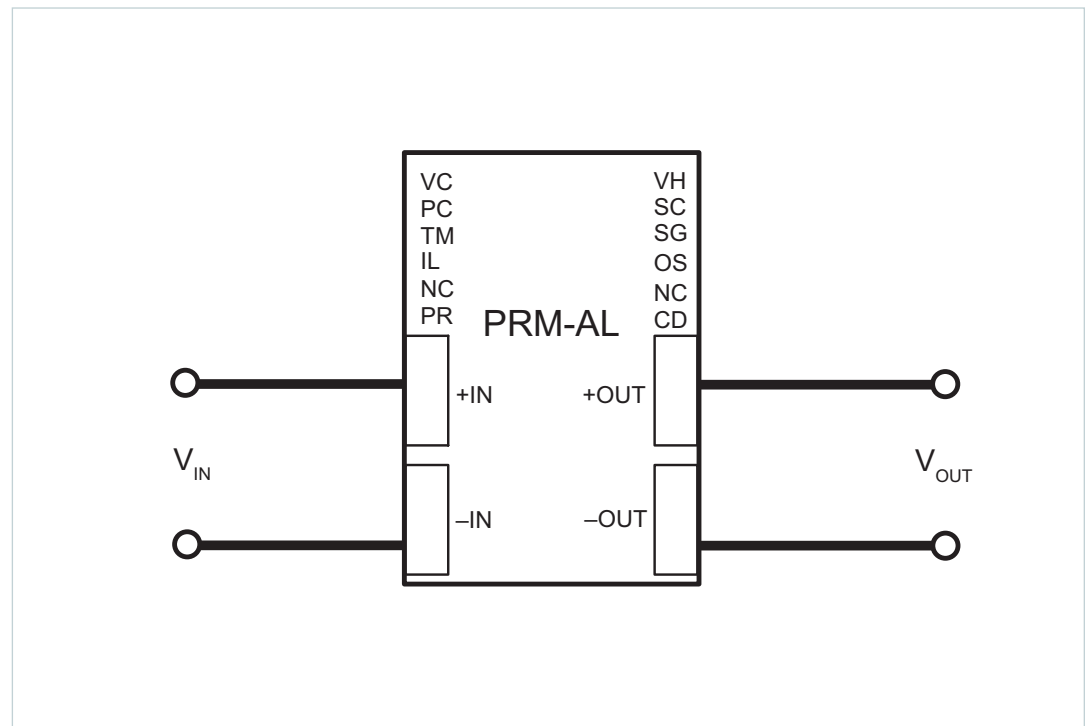
Figure 3
CC evaluation
board layout



CC Evaluation Board Components

1. **Input capacitors (C01, C02, C03):** A 22 μ F capacitance assuming a low input source impedance.
2. **Fast-acting fuse (F01):** Rated for 10A.
3. **Potentiometer V_{REF} (R10):** Provides an adjustable voltage divider in combination with (R6). This divider achieves the reference voltage used to set the value of the PRM output current. Please refer to the application note [AN:018 Providing a Constant Current for Powering LEDs using the PRM™ and VTM™](#) for more details on start up sequencing precautions.
4. **Potentiometer V_{MAX} (R8):** Combined with (R27) V_{MAX} make up the OS resistor referred to in the [PRM data sheet](#). The OS resistor is used to set the output voltage of the PRM. In this case it is used to limit the PRM maximum output voltage the CC feedback can drive in order to source more current.
5. **Dual op amp (U02):** U02A shown in Figure 1 is used as a difference amplifier sensing the voltage produced by the current flowing through the PRM output sense resistor (R33). Op amp (U02B) regulates the output of op amp (U02A) against the manually set reference using the potentiometer (R10) or an external shunt regulator.
6. **Output inductor (L01):** The PRM soft switches at a frequency greater than 1MHz while the VTM soft switches at a frequency of 1.7MHz. L01 is used to reduce the high frequency current ripple produced by the high frequency switching inside the PRM.
7. **Sense resistor (R33):** The voltage across the sense resistor is captured by the difference amplifier then fed back to the PRM SC pin through the error amplifier in order to maintain the current regulation. R33 is a 1W, $\pm 0.1\%$ tolerance, 10m Ω high precision metal strip current sense resistor positioned at the -OUT of the PRM.
8. **PRM connection highlights:**

Figure 4
PRM-AL
schematic symbol



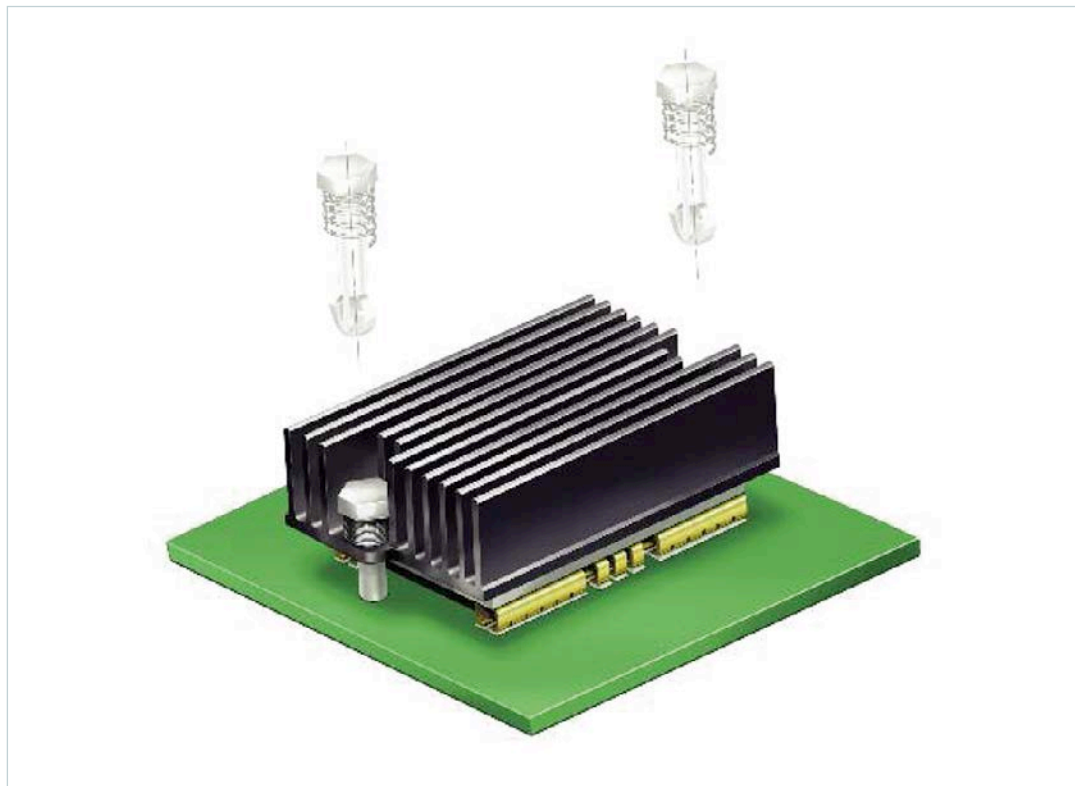
- A. Auxiliary voltage (VH):** The op amp is powered using the VH pin. This pin is a $9V \pm 0.3V$ regulated voltage capable of sourcing up to 5mA. **Do not exceed the current rating for VH.** Exceeding the current limit will render the unit inoperative. To increase VH capability an external circuit scheme using a power transistor can be used as described in application note [AN:018 Providing a Constant Current for Powering LEDs using the PRM™ and VTM™](#).
- B. Secondary control (SC):** The output of the comparator op amp (U02B) is connected to the SC pin. This pin will be driven high to drive the PRM™ output voltage high and vice versa. The resistor divider formed by (R23 & R30) controls the maximum voltage at the input of this SC pin. The output of the comparator is about 9V. Care must be taken when selecting values different than the recommended (R23 & R30). Please refer to the application note AN:018 Providing a Constant Current for Powering LEDs using the PRM and VTM.
- C. Output set resistor (R27):** This pin defines the maximum output voltage of the PRM when the error amplifier output drives the SC pin to its maximum. The combination of both resistors (R27 & R8) forms the R_{OS} resistor required to operate the PRM. Reducing the R_{OS} resistor by turning the potentiometer (R8) clockwise will increase the maximum output voltage. The fixed resistor (R27) value is chosen to ensure a maximum output voltage of 55V. Please refer to the [PRM P048F048T24AL data sheet](#) for more details on how to choose the appropriate R_{OS} value for the desired PRM maximum output voltage.
- D. VTM control pin (VC):** This PRM output pin provides a 10ms pulse during start up enabling the downstream VTM. VC is connected to pin (3 & 4) on (J01) connector.

Test Points

- 1. Input & output Kelvin test points –IN, +IN (TP1 & TP3) and –OUT, +OUT (TP7 & TP8):** These input/output access points of the PRM enable accurate efficiency measurements of the VI Chip® independent of the interconnection losses.
- 2. PC (TP3):** Test point primary control signal. During normal operation this pin is internally pulled high to 5V. Drive this pin low by moving (SW01) to the OFF position to disable the PRM output. This pin will pulsate under fault conditions.
- 3. V_{SENSE} (TP4):** Test point voltage sense serves to show the output voltage of the difference amplifier (U02A). This voltage is proportional to the actual PRM-sensed output current. The constant of proportionality is equal to the difference amplifier gain formed by the resistors (R16-R18). If the recommended gain of 100 is used in combination with the 10mΩ sense resistor the outcome is a one-to-one relationship between the measured voltage at this test point and the PRM output current. ($V_{SENSE} = R_{SENSE} \cdot Gain \times I_{OUT_PRM}$)
- 4. V_{REF} (TP5):** Test point voltage reference value is being compared with the sensed voltage V_{SENSE} . Op amp B is providing an output voltage to the SC pin in order to retain $V_{SENSE} = V_{REF} = I_{OUT_PRM}$ assuming that $R_{SENSE} \times Gain = 1$. Turn the potentiometer (R10) clockwise to increase the required output current set point.
- 5. SG (TP6):** Test point signal ground is the ground reference for the internal control IC.
- 6. Output voltage oscilloscope probe jack (J02):** Accepts most oscilloscope probes and enables precision measurement of the output voltage ripple.

Mounting a Heat Sink

Figure 5
Typical heat sink



A push pin VI Chip® heat sink is included with the CC evaluation board to allow extended bench-top testing at full power and lower airflow.

The PRM™ is equipped with an overtemperature shut-down feature. Please refer to the data sheet for more details.

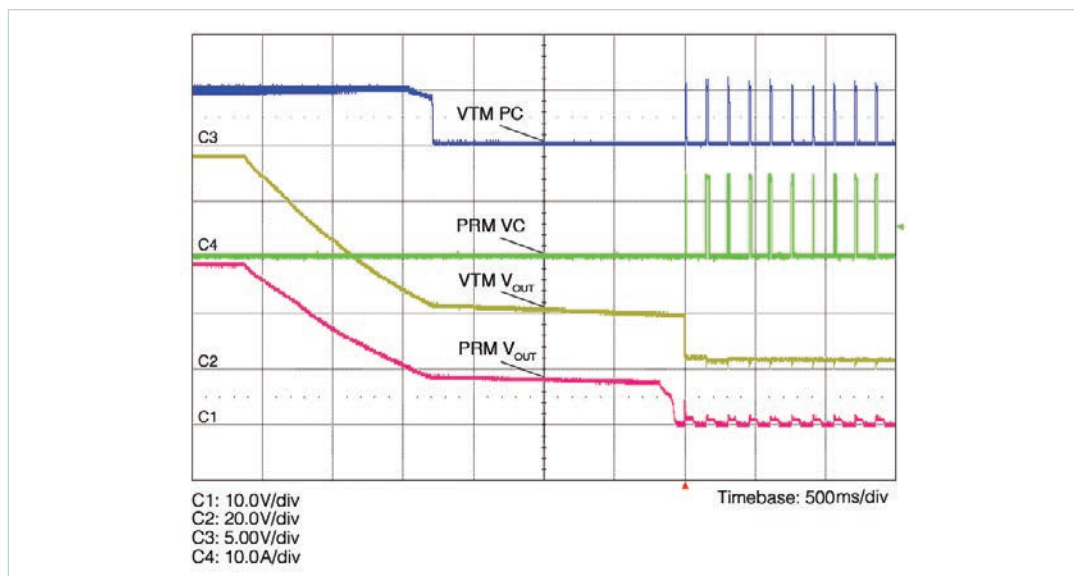
No-Load Connection

The CC evaluation board relies on the feedback provided by the current flowing through the sense resistor (R33). If no load is connected to the module output the CC loop will detect a no-current flow and will steer the SC pin accordingly to the maximum value. The output voltage of the PRM will be driven to its highest set point. The resistor (R27) can prevent the PRM from going into an output overvoltage fault during this condition by limiting the maximum PRM output voltage. The PRM is equipped with overvoltage protection. However, if the circuit drives the PRM into overvoltage with no load, the PRM may be damaged. Please refer to the appropriate section for guidelines on properly setting the maximum PRM output voltage.

VTM Shut Down

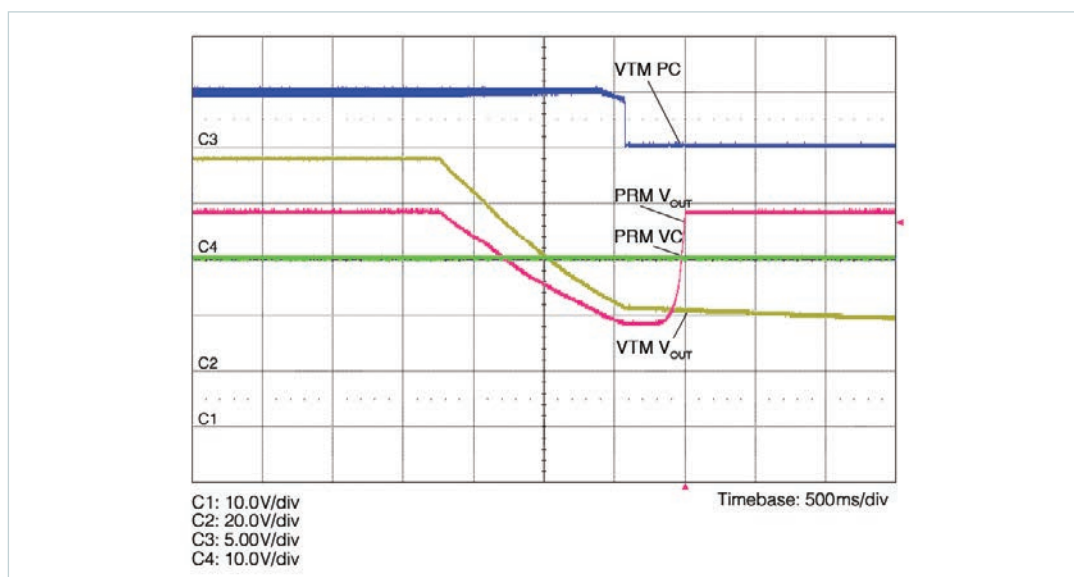
The PRM initiates a VC pulse at start up for the downstream VTM™. The VC pulse is used to synchronize the output of the VTM with the PRM output voltage. If the PRM detects a fault condition, it will initiate the 12V, 10ms pulse to the downstream VTM. Adjusting the (R10) counterclockwise to limit the output current will drive the PRM output voltage low. It is possible to manually trigger the undervoltage mechanism where the PRM goes into fault condition as shown in Figure 6.

Figure 6
PRM & VTM
undervoltage behavior



It is also possible to adjust (R10) clockwise fast enough before a PRM™ undervoltage event. The PRM will aptly recover without registering an error. However, the VTM™ may have already detected an undervoltage condition which will force it into shut down. Reset the VTM by toggling the (SW01). The VTM requires a VC voltage if its input is lower than 26V. An additional circuit is required to provide a permanent solution in the special case where the PRM recovers from a lower than 26V. This circuit will detect a VTM fault and will force a PRM restart. Please contact Vicor applications engineering for further details.

Figure 7
PRM & VTM undervoltage
abnormal behavior



Measurement Precautions

The DC current limit protection uses a shunt resistor in the path of –IN and –OUT. Although this is a non-isolated system, be advised that shorting –IN to –OUT disables this valuable feature of the PRM. This warning extends to the use of multiple scope probes on the input and output simultaneously.

The CC sense resistor (R33) is located right before the output voltage oscilloscope probe jack (J02). Probing the input pins while connecting a probe to (J02) will introduce another low resistance return path. The amount of current circulating through that path is difficult to predict. The current through the added path will not be sensed by the CC circuit. The CC circuit will require the PRM to compensate for this loss. The current through the load will be equal to the user set reference current and the unknown variable current through the scope. In short, this may damage the load and equipment used due to excess current.

Test Procedure

Recommended Equipment

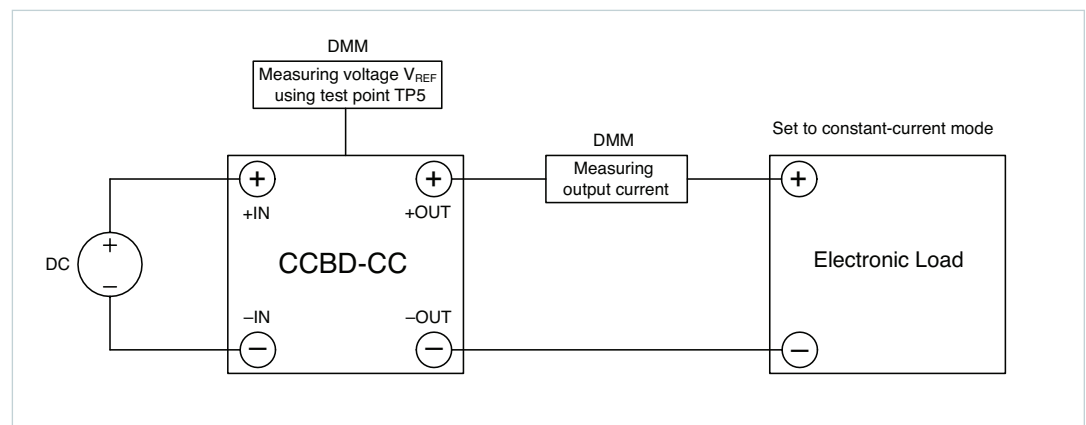
- DC power supply: 0 – 100V; 500W
- DC electronic load: pulse capable; 0 – 100V; 100A minimum
- Two digital multi-meters (DMMs)
- Oscilloscope
- Fan (if the PRM-VTM to be operated for extended periods of time or at an elevated ambient temperature we recommend the supplied heat sink be installed)
- Safety glasses
- Data sheet for the requisite PRM™ / VTM™

Prerequisites

- Maximum desired output voltage.
- Desired PRM output current.

Initial CC Evaluation Board Set Up (V_{REF} and V_{MAX} set)

Figure 8
CC no-load
functional verification



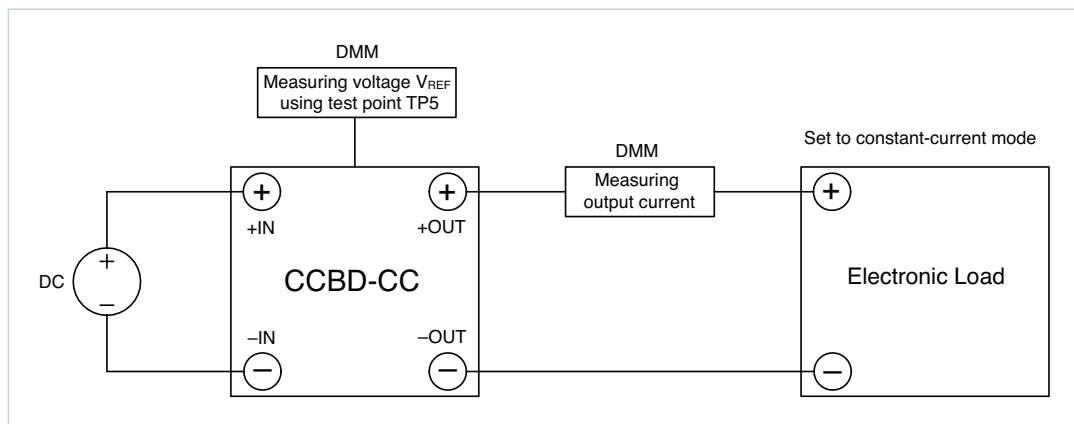
1. Have the latest PRM data sheet in hand.
2. Install heat sink if desired.
3. Assure that the DC supply is set to $0.0V_{DC}$ prior to turning the unit on.
4. Set the supply current limit to a higher value than the chosen PRM DC current limit.
5. Set the DC load to $0.0A$, constant-current mode.

-
6. Verify proper power supply to CC board connections.
 7. Connect DMM to measure the output voltage using the output Kelvin test points.
 8. Turn V_{REF} (R10) potentiometer clockwise gently until it reaches its maximum value of 100K which corresponds to $\approx 5V$ depending on its tolerance. The potentiometer has stops which indicate that it has been turned fully in one direction. Do not wind the potentiometer past the stop, as this may damage the part.
 9. Turn V_{MAX} (R8) potentiometer counterclockwise gently until it reaches its maximum value of 5K which corresponds to an output voltage of $\approx 30V$ depending on its tolerance. The potentiometer has stops which indicate that it has been turned fully clockwise / counterclockwise. Do not wind the potentiometer past the stop as this may damage the part.
 10. Connect DMM to measure V_{REF} at TP5 with reference to SG at TP6.
 11. Make sure (SW02) is in "close" position.
 12. Turn on a fan if desired.
 13. Raise the DC input voltage to the nominal value of 48V as indicated on the [PRM P048F048T24AL data sheet](#). The output voltage should read approximately 30V if the potentiometer has been turned fully counterclockwise as directed in step 9.
 14. Set the load in constant-current mode to 50% of the PRM's rated output (2.5A for the P048F048T24AL-CC). With the load in this setting, the circuit will have no control and will drive the PRM to its maximum value provided that the load current is less than the reference set point. This allows for adjusting the maximum PRM™ output voltage.
 15. Turn the potentiometer (R8) clockwise to set the maximum PRM output voltage. When setting the maximum PRM output, keep in mind that the CC feedback can drive the output voltage up to this maximum limit in order to maintain the required current. Due to component tolerances, turning (R8) fully clockwise can result in the circuit driving the PRM above its maximum voltage. If this is done with no load, the PRM may be damaged.
Do not set the maximum PRM voltage above 55V.
 16. Turn off the electronic load.
 17. Turn the potentiometer V_{REF} (R10) counterclockwise to lower the PRM output current set point to the desired value. If V_{REF} is not lowered to a reasonable value below the DC current limit, the PRM will start in a fault condition when connected to a load. It will remain in fault until the potentiometer V_{REF} (R10) is turned counterclockwise to lower the set reference. An undesirable clicking sound will be audible in this case. Although continuous operation in this mode will not damage the unit, it is not recommended.
 18. Decrease the input voltage to low line.

You have now verified the operation of the CC and set the desired output current and maximum output voltage.

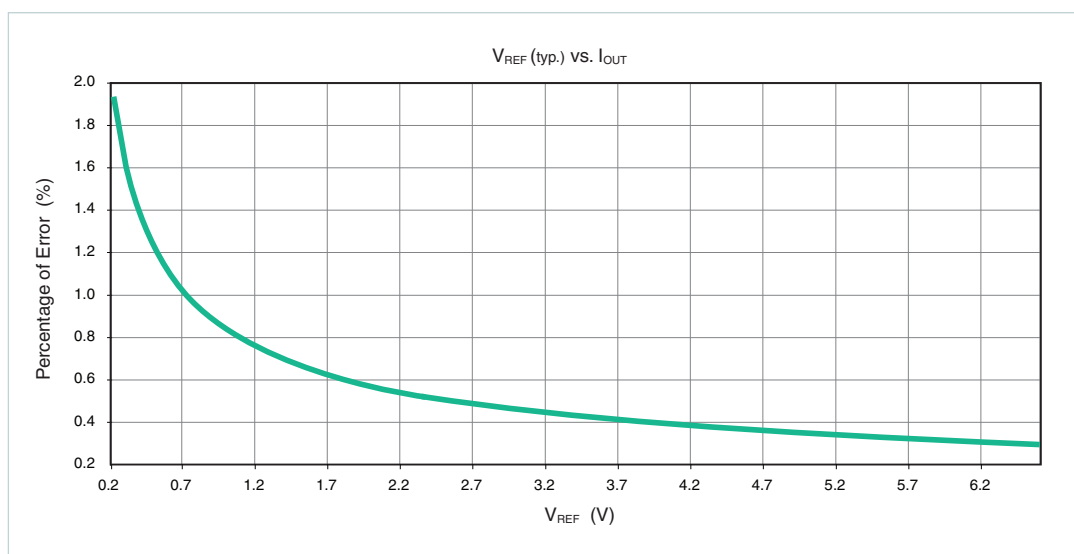
CC Evaluation Board with an Electronic / Resistive Load

Figure 9
CC electronic / resistive load



1. Make sure that the power is removed from the unit prior to making adjustment.
2. Connect DMM in series with the electronic load. Make sure DMM can handle the maximum PRM™ output current then set it to read DC current.
3. Set the electronic load to constant-resistance mode of 0.16 Siemens.
4. Verify proper DMM and electronic load connections to the CC board output.
5. Connect an oscilloscope to the test point provided to monitor output voltage. Remove the plastic cover of the scope probe and position it in the test jack (J02). The oscilloscope is now referenced to the -OUT ground. Be careful not to create a ground loop by connecting any other probes to the -IN. Shorting the -IN and -OUT of the PRM will defeat the PRM current limit feature as the current shunt is in this path. Please refer to the measurement precaution section for more details.
6. Turn on a fan if necessary.
7. Turn on the electronic load.
8. Raise the DC input voltage to the nominal value of 48V as indicated on the [PRM P048F048T24AL data sheet](#). Observe that turning the potentiometer V_{REF} (R10) clockwise increases the voltage measured on test point V_{REF} resulting output current with a max error of 2% as shown in Figure 10.

Figure 10
 V_{REF} vs. I_{OUT} PRM error margin



The following Figures 11 – 13 are a start-up comparison between what the user should see when using an electronic load and an actual equivalent power resistor. Figure 11 shows a delay in the PRM™ output current introduced by the electronic load set to 0.16S along with a current overshoot.

Note: do not set the electronic load in a constant voltage mode is not recommended for stability reasons. If the electronic load is set to a constant voltage, a lengthier delay and an unstable behavior is observed as in Figure 12. These plots are presented to inform the user of the possible occurrence of this issue when exploring the CC evaluation board.

The current overshoot occurs within that instant where the CC senses and corrects its response. Using a resistive load equivalent to 7Ω, Figure 13 shows the expected waveform where both the reference voltage and the PRM output current agree. Please refer to the start up sequencing section in the [CC application note](#) for more details on the rise-time limitations.

Figures 11 – 13 are taken in reference to –IN. Figures 15 – 19, showing the output voltage and current ripple, were captured in reference to –OUT by using the scope jack (J02) for better accuracy.

Figure 11
Electronic load
constant-resistance PRM
start-up waveform

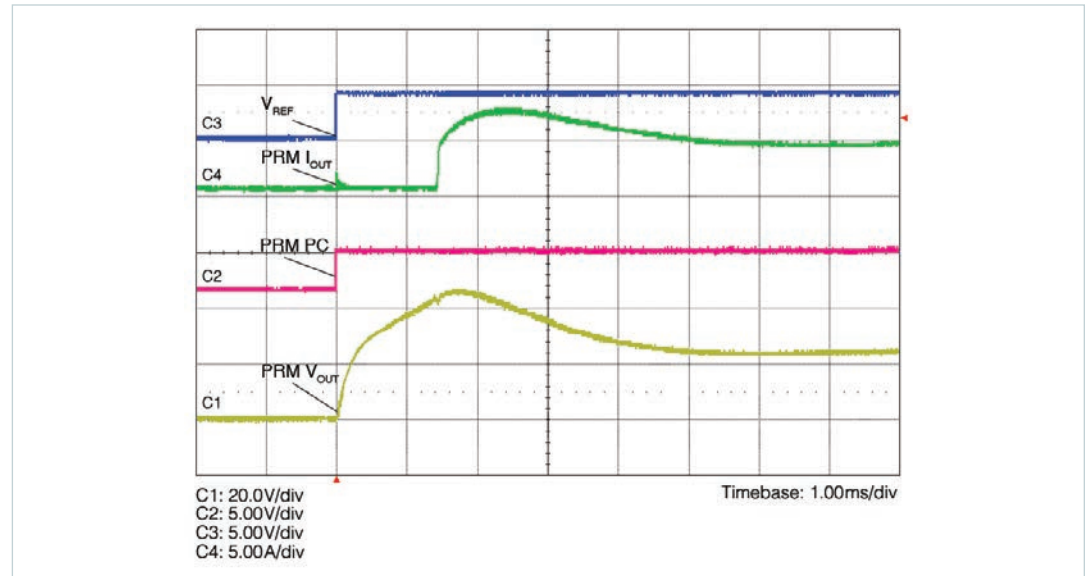


Figure 12
Electronic load
constant-voltage PRM
start-up waveform

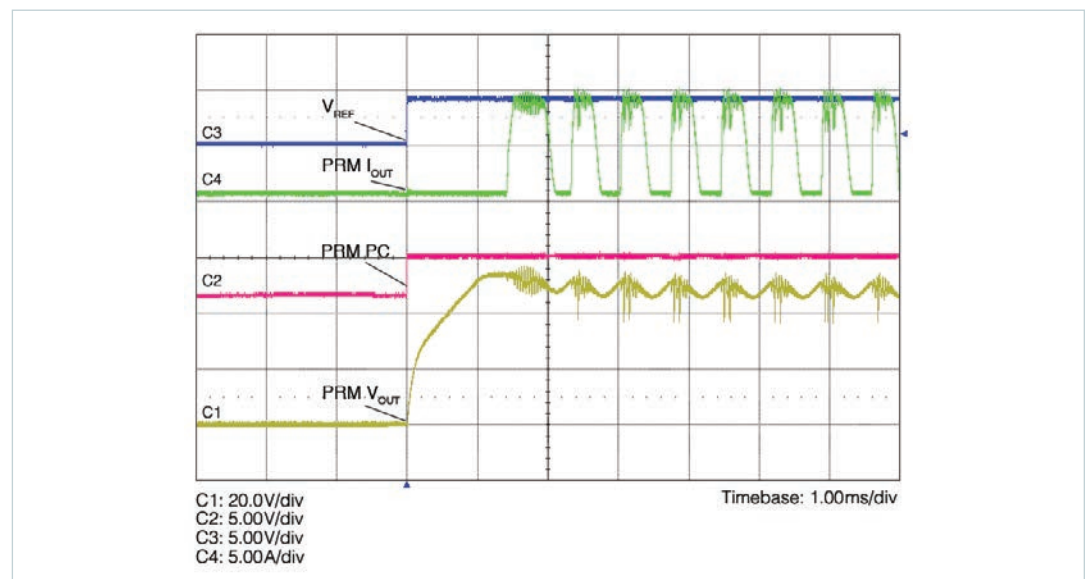
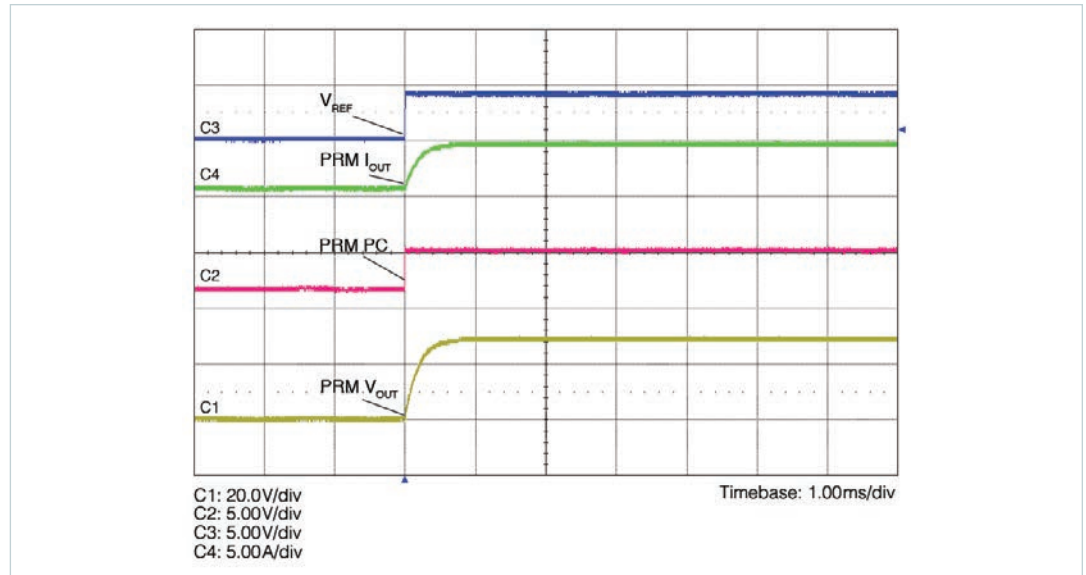
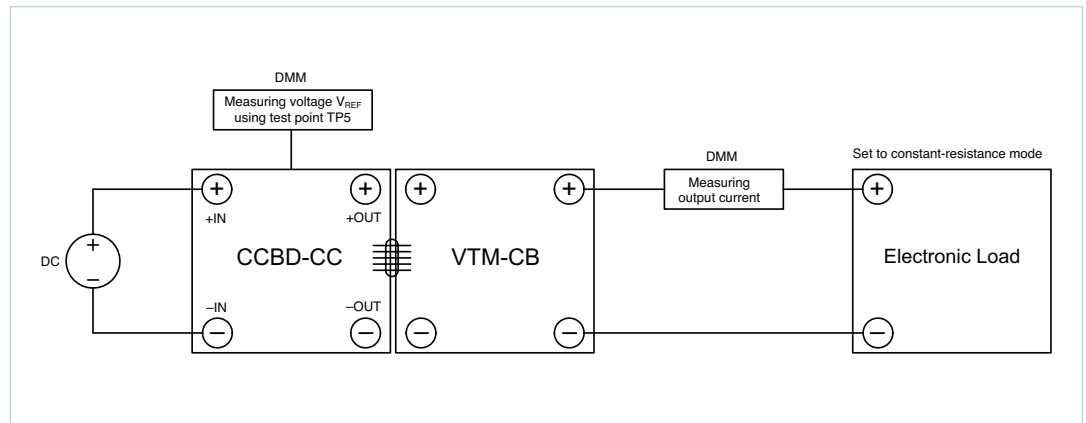


Figure 13
Resistive load PRM
start-up waveform



CC Evaluation Board / VTM with an Electronic / Resistive Load

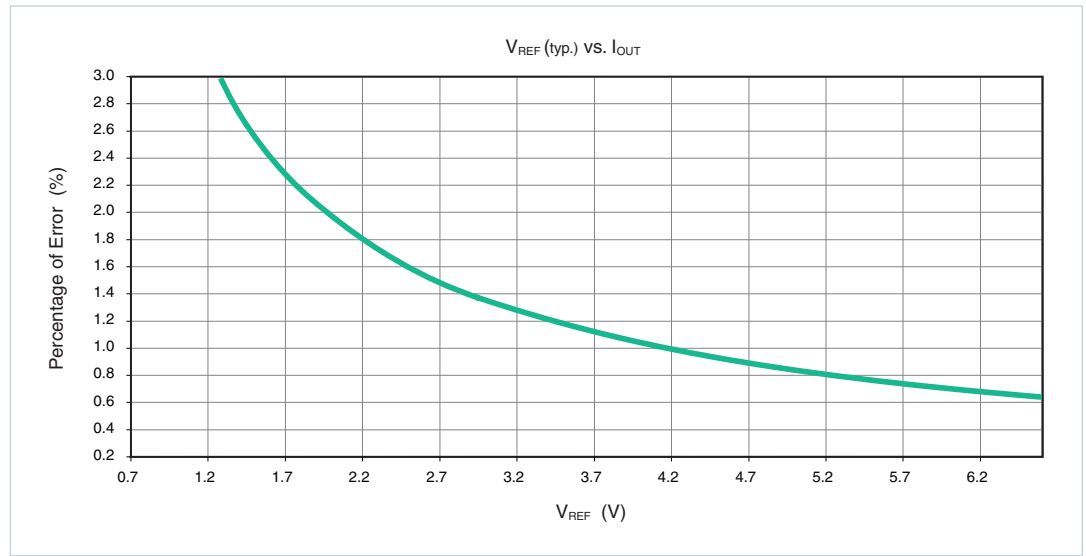
Figure 14
CC & VTM
electronic / resistive load



1. Make sure that the power is removed from the unit prior to making adjustment.
2. Use output connector (J01) to connect the CC to the VTM-CB.
3. Connect DMM and a resistor network or electronic load in series with the output of the VTM™ customer board. Make sure DMM can handle the maximum PRM™ output current then set it to read DC current.
4. Verify proper electronic load and VTM connections.
5. Connect an oscilloscope to the test point provided to monitor output voltage on the VTM-CB. The VTM provides current multiplication and source isolation. Grounding the oscilloscope probe at the VTM -OUT and the PRM -IN will only provide a short path for the AC current which will not affect the functionality of the system.
6. Turn on a fan if necessary.
7. Turn on the electronic load.
8. Raise the DC input voltage to the nominal value indicated on the data sheet. It was observed that in some cases the VTM does not start due to a low V_{REF} set point. Please refer to the start up sequencing section in the [CC application note](#) for more details on the rise time limitations.

Figure 15 shows the accuracy of the PRM™ output current as seen at the VTM™ output versus the set reference. The measured VTM output current is divided by the typical VTM K factor and then compared to the set reference V_{REF} .

Figure 15
 V_{REF} vs. $I_{OUT PRM-VTM}$
 error margin



Figures 16 – 19 show current and voltage ripple at start up in both a pure resistive and electronic load. Again, note the delay introduced in the VTM I_{OUT} wave in the constant-resistance mode. If these plots are observed using an electronic load, it is possible to experience an unacceptable wave such as the ones in Figure 18. This slight fluctuation is due to the electronic load enhancing or opposing the work of the CC control loop.

The resistive load, Figures 17 and 19, show the accurate constant-current waveforms.

Figure 16
 Electronic load
 constant-resistance
 PRM™-VTM™
 start-up waveform

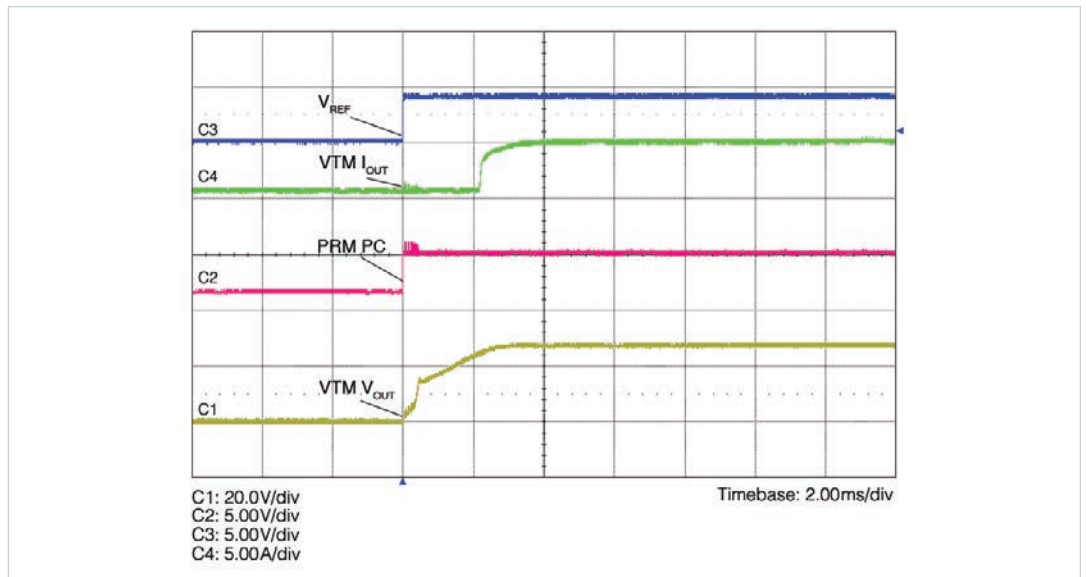


Figure 17
 Resistive load PRM-VTM
 start-up waveform

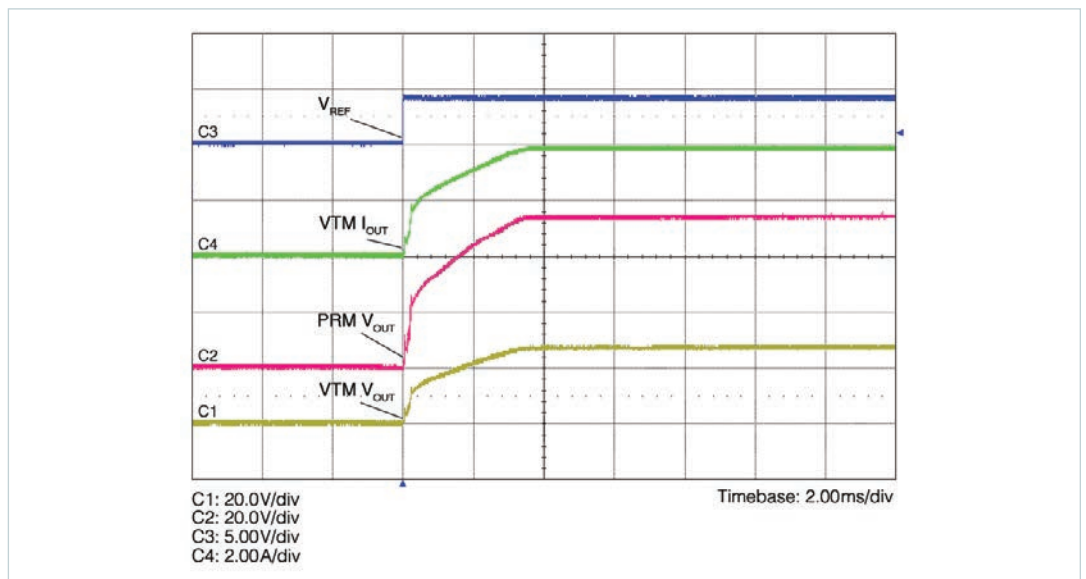


Figure 18
 Electronic load CV
 PRM™-VTM™
 V_{OUT} & I_{OUT} ripple

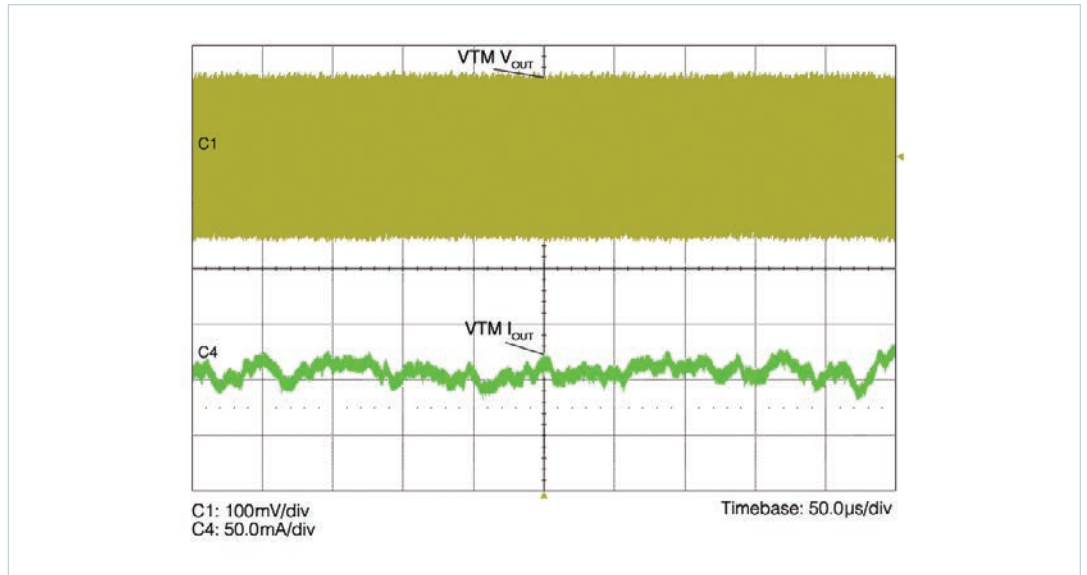
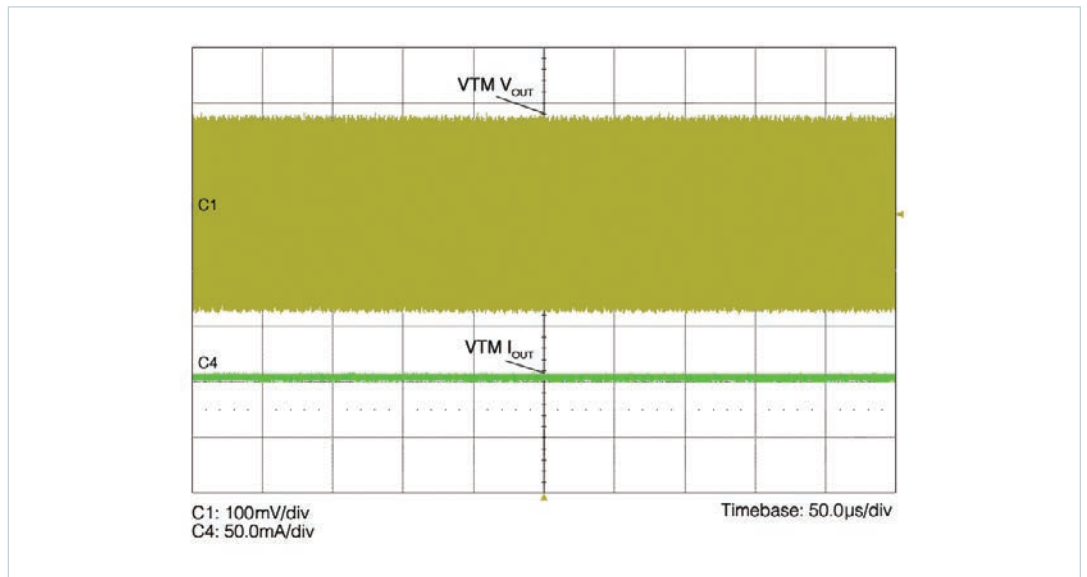


Figure 19
 Resistive load PRM-VTM
 V_{OUT} & I_{OUT} ripple



Bill of Materials

Reference Designator	Value	Supplier	Supplier Part Number	Description
R3	10kΩ	Digi-Key	P10.0KHDKR-ND	RES 10kΩ 1/10W 1% 0603 SMD
R6	63.4kΩ	Digi-Key	P63.4KHCT-ND	RES 63.4kΩ 1/10W 1% 0603 SMD
R8	5kΩ	Digi-Key	490-2655-6-ND	TRIMPOT 5kΩ 1 TRN 3MM SMD
R10	100kΩ	Digi-Key	490-2645-6-ND	TRIMPOT 100kΩ 1 TRN 3MM SMD
R12, R13, R21, R25, R28	0Ω	Digi-Key	P0.0GDKR-ND	RES 0Ω 1/10W 5% 0603 SMD
R16, R19	100kΩ	Digi-Key	P100KHDKR-ND	RES 100kΩ 1/10W 1% 0603 SMD
R17, R18	1kΩ	Digi-Key	P1.00KHDKR-ND	RES 1.00kΩ 1/10W 1% 0603 SMD
R23	2.15kΩ	Digi-Key	P2.15KHDKR-ND	RES 2.15kΩ 1/10W 1% 0603 SMD
R24	16.2kΩ	Digi-Key	P16.2KHDKR-ND	RES 16.2kΩ 1/10W 1% 0603 SMD
R27	5kΩ	Digi-Key	P4.99KHCT-ND	RES 4.99kΩ 1/10W 1% 0603 SMD
R30	1.24kΩ	Digi-Key	P1.24KHDKR-ND	RES 1.24kΩ 1/10W 1% 0603 SMD
R32	10Ω	Digi-Key	P10.0FDKR-ND	RES 10Ω ¼W 5% 1206 SMD
R33	10mΩ	Vishay	CSM25120R010B	10mΩ SMD Shunt
C1, C2, C3	22μF	Digi-Key	PCE3207CT-ND	CAP 22μF 100V ELECT VS SMD
C4, C11	0.01μF	Digi-Key	478-1227-1-ND	CAP CERM 0.01μF 10% 5 0V X7R 0603
C12	0.1μF	Digi-Key	490-4779-1-ND	CAP CER 0.1μF 50V X7R 0603
U02	AD8667	Analog Devices	AD8667ARZ	Low noise, Precision, 16V, CMOS, Rail-to-Rail operational amplifier
SW01, SW02		Digi-Key	563-1024-1-ND	Switch Slide SPDT SMD GULL
F01	10A	Digi-Key	F1150TR-ND	Fuse 10A 125V Fast Nano 2 SMF
L01	0.1μH	Coilcraft	SLC7530D-101MLC	IND 0.1μH / 20% / 20A dual 3026
J01				CONN 10POS 90° through hole female 0.100 SPC
J02				Jack vertical mech through hole
PS01		Vicor	P048F048T24AL	48 – 48V 240W PRM

Note: Abovementioned components are populated parts only.

Summary

In this user guide we have discussed the impact of adding the CC circuit to a PRM™ regulator output (the factorized bus rail). The PRM-VTM combination provides a high-current-accuracy, high-efficiency, high-power-density solution for high-power LED applications.

Ordering Information

The PRM Constant-Current demo part number is P048F048T24AL-CC. The relevant VTM™ board (if required) is specified by adding the suffix “-CB” to the chosen VTM model number. For any questions, comments or further design support, please contact your local field applications engineer.

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