Single DCM™ as an Isolated, Regulated DC-DC Converter

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Introduction

The DCM DC-DC Converter Module encapsulates isolation, regulation, thermal management, and fault monitoring in a single module. Its wide input voltage range, high output power, high density, and high efficiency enable its use in a variety of industrial and military applications. The DCM is offered in two different packages: Converter housed in Package (ChiP) and Vicor Integrated Adapter (VIA) package, which delivers high power density through its superior thermal performance. This application note mainly focuses on ChiP based DCM. ChiP platform products use advanced magnetic structures that are integrated within high density interconnect (HDI) substrates, together with power semiconductors, control ASICs and a microcontroller. For more information on DCM capabilities and options, please see the Vicor web page for DCMs:
www.vicorpower.com/dc-dc-converter-board-mount/dcm-dc-dc_converter

The DCM operates on the same high frequency, double-clamped zero voltage switching (DC-ZVS) topology as the Vicor PFM™ and the PI31xx Isolated DC-DC Converter Modules.
The DC-ZVS topology provides a revolutionary increase in density and efficiency compared to other complete DC-DC converter solutions.

Support Circuitry

Referring to Figure 1, the DCM simplifies the design of the input, output, and control circuitry.
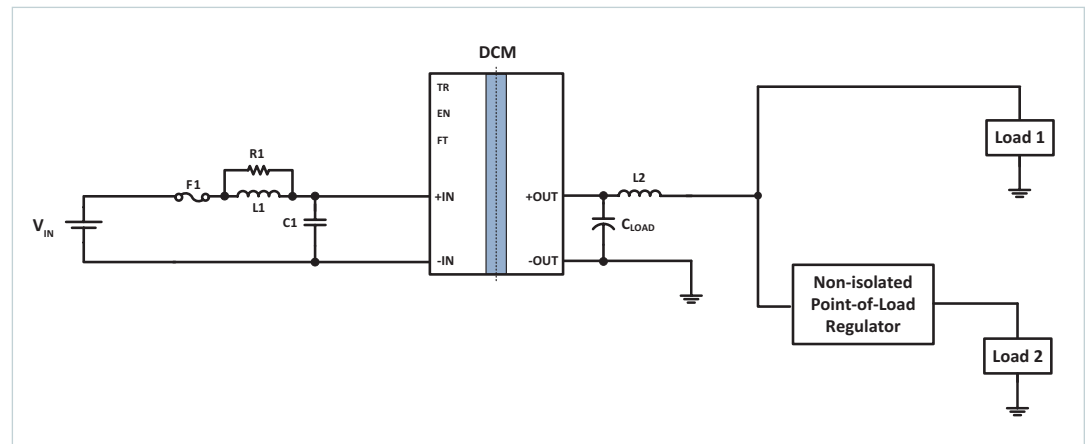

Figure 1
Block Diagram of a
Single DCM Circuit

Input Circuitry

DCMs feature on-board protection for input overvoltage and overcurrent, so the fuse F1 shown in Figure 1 is only needed for applications that must pass safety approvals, such as CE Mark or UL60950. For more information on fuse selection and recommendations, refer to the data sheet for the DCM™ model of interest.

The effective input impedance of the DCM is V_{IN}^2/P_{IN}. This form of the equation is the most relevant because for a given load, the DCM presents a constant power load to its input power source (up to the control loop bandwidth, which is up to 20kHz).

To guarantee stability of the DCM control loop, the impedance of the source that supplies V_{IN} must be less than ½ the effective input impedance of the DCM at the expected minimum input line condition, over the control loop bandwidth. If the source cannot satisfy this requirement alone, the input filter circuit must compensate for the excessive impedance. A large electrolytic capacitor can be used: for example, at least 1000μF is recommended for a 320W DC-DC converter operating with line voltages down to 16V, such as the DCM3623T50M31C2M00 (model specific values are provided in the corresponding DCM data sheet). However, in cost-sensitive or space-limited applications, a more efficient solution may be possible. The theory behind the input impedance requirement is given in the Vicor tech tip:

powerblog.vicorpower.com/wp-content/uploads/2009/10/tech_tip_input_source_impedance.pdf

For an additional optimization to minimize ringing and provide additional margin between the DCM's rated low line and its input undervoltage fault protection threshold (UVLO), the source impedance of V_{IN} should be further limited to be no more than 1/10 the effective input impedance of the DCM.

If the application circuit is designed such that the DCM is not inhibited using the EN pin, the DCM output voltage will become active during the input voltage ramp, when it reaches the input undervoltage fault protection (UVLO) voltage $V_{IN-UVLO+}$. The input filter needs to be designed according to this extreme low line condition. As the DCM starts near UVLO+, the source impedance must be low enough that input voltage transients caused by inrush current do not trigger UVLO.

DCM efficiency is slightly impacted by high frequency ripple voltage developed on the DCM input due to switching currents. Ceramic input filter capacitors in close proximity to the +IN and –IN leads can form a resonant tank with the package lead inductance and the internal input capacitors. When the DCM is operating near its maximum switching frequency (approximately 1MHz), the resonant tank can amplify ringing voltage, leading to a slight increase in losses within the DCM. This effect can be minimized by avoiding the placement of ceramic capacitors directly across the DCM input, or by reducing the Q of this resultant resonant tank by adding resistors in series with those capacitors.

Information on the design of the input filter can be found in the following application note, which emphasizes designing DC-DC converters for low EMI:

http://www.vicorpower.com/documents/application_notes/vichip_appnote23.pdf

Vicor supplies a design tool to assist the user in designing a stable filter, with minimal peaking:

app2.vicorpower.com/filterDesign/intiFilter.do

Control Pins

The three DCM™ control pins are EN, TR and FT. Internally, they are implemented as GPIOs, each with a pull-up resistor to a constant 3.3V rail. Each control pin has a simple internal bias and drive structure, which is maintained throughout the various operating modes. The logic thresholds, bias levels and bias strengths for the input pins do not change during startup or fault protection conditions. In general, the control pins can all be left unconnected to select their default function.

EN is a digital input that enables the powertrain. The powertrain is disabled when EN is less than the EN disable threshold and enabled when EN is pulled above its enable threshold; if EN is left open, an internal 10kΩ pull-up resistor keeps the powertrain enabled.

TR selects the trim mode and sets the trimmed output voltage of the DCM. The TR pin is sampled one time at power-up, after V_{IN} exceeds $V_{IN-UVLO+}$; its voltage at that time determines the function of TR for as long as the DCM is supplied an input voltage. If TR is greater than $V_{TRIM-DIS}$ when it is sampled, the DCM will be in non-trim mode. This is the case when TR is left open: an internal 10kΩ pull-up resistor pulls TR up to V_{CC}, selecting the non-trim mode of operation. In this mode, the programmed trim condition will simply be the rated nominal Vout of the DCM model.

If TR is sampled below $V_{TRIM-DIS}$ at power-up, the internal trim circuitry will be enabled and TR will control the output voltage setting as long as V_{IN} is applied. If the powertrain is disabled with EN or stopped by a fault condition, it retains the trim mode which was previously latched in when it resumes operation. The trim mode is re-evaluated only after removing and reapplying the input voltage to the DCM.

The nominal relationship between a trim resistor and the trim pin voltage is given by:

$$V_{TR} = V_{CC} \cdot R_{TRIM} / (R_{TRIM} + 10k\Omega)$$

A sample circuit to control TR is shown in Figure 2.

Figure 2
Example of a Circuit to Set TR
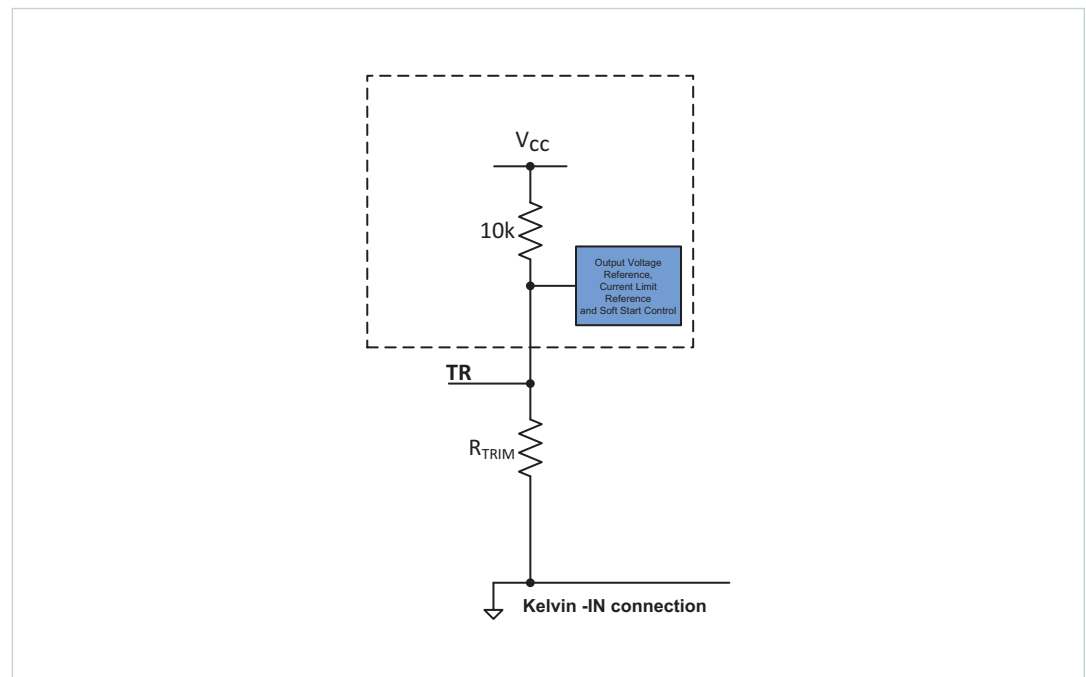
When trim mode is active, the programmed V_{OUT} of the DCM™ maps linearly to the TR pin voltage. For the example DCM3623T50M31C2M00 product, the transfer function is:

$$V_{OUT\text{-}FL} \ @ \ 25^o C \ = \ 9.98 + (18.780 \bullet V_{TR}/V_{CC})$$

at full load and room temperature. Each DCM model data sheet provides constants for this transfer function.

When V_{TR} is set such that the programmed trim value is above the nominal output voltage rating, the internal current limit threshold will be decreased proportionally thus maintaining a roughly constant maximum average output power. (See the DCM data sheet.)

Any time V_{TR} is set such that V_{OUT} is outside the rated output voltage trim range $V_{OUT\text{-}TRIMMING}$, the DCM will function, but it may not operate as expected, and none of the performance specifications in the data sheet are in force. For example, trimming the V_{OUT} above the high trim threshold decreases the margin before overvoltage protection (OVP) is activated; depending on the DCM model, output capacitor, and dynamic load profile, a load dump could trigger OVP. Conversely trimming V_{OUT} below the low trim threshold may result in excessive ripple on the output, or even shutdown of the DCM in response to load transients due to output undervoltage fault protection.

FT is the positive-true output generated by the internal Fault Monitoring circuit. When the DCM activates fault protection, the FT pin is driven high (to 3.3V) by a low impedance driver. This configuration helps avoid the need for the system to generate a separate low voltage supply for powering the fault pin monitoring circuit, since a simple opto-coupler can be entirely driven from the FT pin.

In Figure 3, the R_{SERIES} resistor acts as a current limiter to keep the maximum current below the 4mA limit of the FT pin. With a single DCM, a 560Ω resistor will limit the current to about 2mA, sufficient to light an LED.

Figure 3
FT pin driving an LED
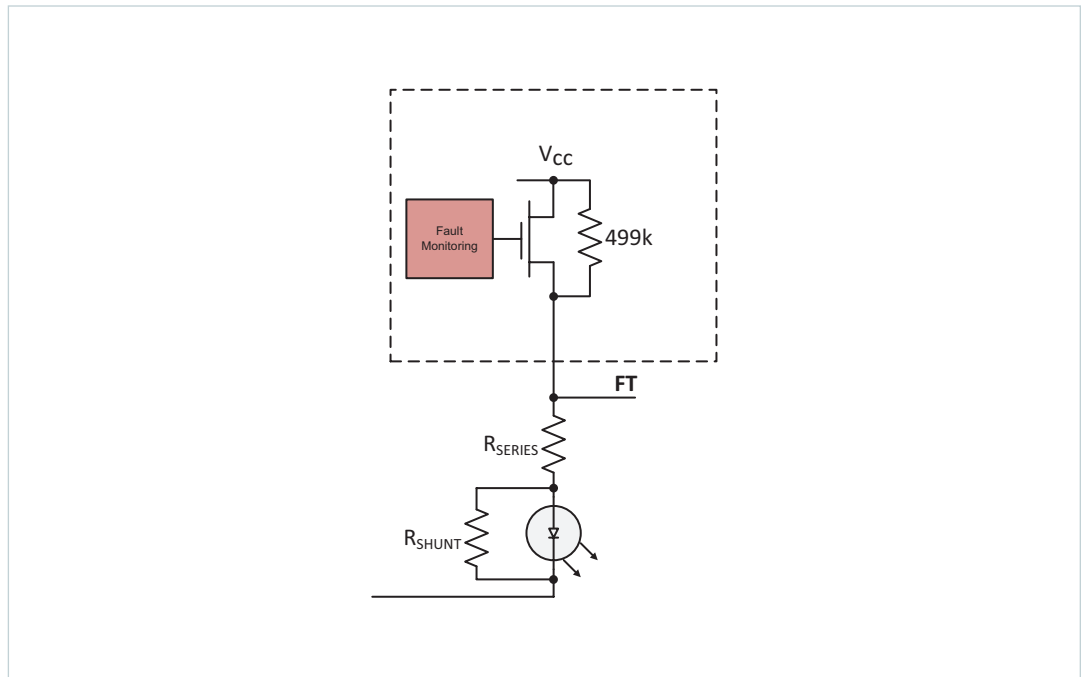
Under normal conditions, the FT pin is internally biased to 3.3V by a 499kΩ resistor, but can easily be held low by an external pull-down resistor. In the fault indicating LED circuit above (Figure 3), R_{SHUNT} is part of a voltage divider that holds the diode voltage in the OFF state when no fault is detected; a 47kΩ resistor is sufficient for a single DCM.

Light Load Boosting

The DCM™ enters Light Load Boosting under light loading conditions, when the internal power consumption of the converter plus the external output load is less than the minimum conversion power. This scenario is most pronounced when the DCM input voltage is high, the trim voltage is low, and there is no output load. During Light Load Boosting, the DCM alternates between two operating conditions: initially the error amplifier attempts to regulate V_{OUT} by enabling the converter powertrain, but the minimum energy per pulse that the powertrain can supply is greater than the power needed to maintain output regulation, so the output voltage climbs. As a result of that slight excess output voltage, the error amplifier momentarily inhibits the powertrain, allowing the output voltage to fall again. Once the output voltage falls below the error amplifier setpoint, the error amplifier starts the converter powertrain switching again. The second condition, when the powertrain is not switching, will typically last for tens or hundreds of times that of a regular switching period.

Due to the primary-referred method of sensing output voltage (see the Functional Block Diagram in the DCM data sheet), the accuracy with which the error amplifier senses V_{OUT} is greatly reduced while the powertrain is momentarily inhibited. This results in an effective boosting of the actual V_{OUT} during Light Load Boosting operation.

For most DCM models, output voltage boosting can occur when the external output load is 10% or less of the DCM rated load. The output voltage can rise by V_{OUT-LL} above its set point. The boosting of the output voltage is described by the ΔV term of the Overall Output Voltage Transfer Function. For the example DCM3623T50M31C2M00 DCM, ΔV is 5.01V in the transfer function:

$$V_{OUT} = 9.98 + (18.780 \cdot V_{TR}/V_{CC}) + 1.26 \cdot (1 - I_{OUT}/13.40) - 3.200 \cdot 0.001 \cdot (T_{INT} - 25) + \Delta V$$

To calculate V_{OUT} for other DCMs, see the relevant DCM data sheet.

Another result of the primary-sensed output voltage is that if an output load is suddenly applied during the momentary inhibit time, there may be an increased delay before V_{OUT} returns to its regulated level. The choice of output capacitor minimizes this, as covered in the next section.

Output Circuitry

The output circuit must be designed and laid out to minimize conducted emissions. As with any high power, high density circuit, thermal management may also be a special concern. See the Thermal Considerations section below.

Output Capacitor

To ensure proper operation of the DC-DC Converter, the capacitance of the load must be within the limits that are defined in the data sheet by $C_{OUT-EXT}$ for normal operation. The maximum limit is required to avoid excessive startup time, which could trigger output undervoltage fault protection. The minimum limit for $C_{OUT-EXT}$, as well as the minimum ESR of the external capacitor, $R_{COUT-EXT}$, are needed to ensure control loop stability.

For applications where the DCM sees very light loading, certain DCM models have increased minimum allowed external output capacitor values. The higher values depend on the load transients and the trim transients that the application imposes on the DCM. During Light Load Boosting, a sudden change in the load – for instance, a step increase from a light load condition – may not be tracked by the control loop, as explained above. If there is not enough capacitance on the output, this could cause the output voltage to drop below the undervoltage fault protection threshold $V_{OUT-UVP}$, causing shutdown. (See Output Undervoltage Fault Protection (UVP) in the DCM data sheet.) To prevent this from happening, the minimum allowed output capacitance value must be increased so that it falls in the range given by $C_{OUT-EXT-TRANS}$. This effect is amplified for applications which dynamically trim the DCM output at the same time these load transients are occurring. In this case, the minimum allowed output capacitance may be further increased, per the limits of $C_{OUT-EXT-TRANS-TRIM}$, to prevent the load transient and dynamic trim event from triggering fault protection.

Thermal Considerations

The Thermal Specified Operating Area in Figure 1 of the DCM™ datasheet relates the maximum load power permissible versus environment temperature for different heat extraction paths. Figure 1 extends up to the maximum rated output power of the DCM. It assumes the worst case efficiency from the data sheets specifications. (Also see the efficiency curves in the data sheet, under Typical Performance Characteristics.) Data sheet Figure 1 shows the maximum output power that can be delivered to the load for a given ambient temperature if the package temperature is controlled at the top of the package; at the top and leads; and at the top, leads and bottom of the package. Some DCM data sheets don't have the "top only" curve because cooling only the top isn't sufficient for those modules. (See the analysis in the data sheet, under Thermal Design.)

The DCM is also capable of sustained operation above rated power, up to the current limit threshold with no derating or overstress to the module, provided it is sufficiently cooled. Figure 25 "Thermal Specified Operating Area: Max Power Dissipation vs. Case Temp for arrays or current limited operation" is an extension of Figure 1, which relates maximum dissipated power to environmental temperature for the same three heat extraction paths. Any time the DCM is used above rated power, for example at current limit, the thermal design must be based on the operating efficiency and the appropriate Figure 25 curve.

Vicor offers a selection of DCM-specific heat sinks. Check with your Vicor sales team for the solution that best fits your needs.

Vicor provides a suite of online tools, including a simulator and thermal estimator, a thermal calculator, application notes, and white papers. These simplify the task of developing a DCM thermal configuration that is sufficient for a given set of conditions. These tools can be found at: www.vicorpower.com/powerbench.

Layout and Routing

Please reference Application Note AN:005 "FPA Printed Circuit Board Layout Guidelines" for a detailed discussion of PCB layout. Application Note AN:005 details board layout recommendations using VI Chip® components, with details on good power connections, reducing EMI, and shielding of control signals and techniques. While this application note is not written specifically for DCMs, many of the concepts and recommendations still apply.

Avoid routing the trim and enable control signals directly underneath the DCM. It is critical that all control signals are referenced to –IN, both for routing and for pull-down and bypassing purposes.

Conclusion

A single DCM can provide regulation, isolation and fault protection for applications that require high power while optimizing space requirements. The ChiP platform allows for a small circuit footprint while enabling flexibility in the thermal design. Vicor's power component design methodology, along with the minimal support circuitry required help engineers to develop systems quickly and efficiently.

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