Parameters to Consider when Specifying DC/DC Converters

De-Xiang Huang, Chief Engineer, Calex Mfg. Co., Inc.

Abstract

Telecommunication, industrial and consumer applications require high performance switching power supplies. This paper describes the performance of high-end commercially available DC/DC converters. This paper mainly uses half brick type converters as examples.

I. Introduction

The performance of DC/DC converters has been improved significantly over the years. The use of DC/DC converters is increasing in new electronic designs for various applications. The telecommunication industry and other industries have demanding technical requirements for power supplies used in their applications. Requirements such as accurate and very stable output voltages, excellent load regulation, fast transient response, limited short circuit current, very low noise, and very low EMI. The performance of the Calex HE Series single output Half Brick DC/DC converters provides the basis for this discussion.

II. High Electrical Performance

Accurate Output Voltage

The performance of an electronic device may vary with the DC power supply voltage used in that device. It is necessary to keep the power supply voltage accurate and constant to reduce variations in performance. The maximum initial set-up voltage error of the HE Series, at room temperature is 1 %. Typically it is less than 0.5%.

Potentiometers are widely used in DC/DC converters for output voltage adjustment. The temperature coefficient (T.C.) of many commercial trim potentiometers is not clearly identified. The manufacturers usually have the T.C. for the resistor, but not for the wiper portion of the potentiometer. The T.C. of the wiper could be low, or it could be as high as several hundred ppm/ ^{o}C, as compared to the resistor of the potentiometer which may be 20 or 100 ppm/ ^{o}C. The T.C. of a potentiometer is mainly dependent on the mechanical structure of the potentiometer, and its thermal linear expansion [1]. The T.C. of the resistor is an additional error source. The T.C. of a potentiometer is also different than that of other fixed resistors used in the voltage divider. The use of a potentiometer for output voltage adjustment is no longer used in most new designs at Calex. This allows for high reliability, low temperature coefficient, and long term stability. No adjustment is required in production. The temperature coefficient of the output voltage is typically 20 ppm/^{o}C, with a maximum of 50 to 100 ppm/^{o}C[2]. Some competing converters may have an initial set-up voltage error of a few percent, and a 500 ppm/^{o}C temperature coefficient. This can cause an output voltage drift of a few percent during the operational profile.

Excellent Load and Line Regulation

The output voltage should remain constant at various input line voltages and output load currents. With the Calex HE Series typical line regulation from a minimum input voltage (e.g. 36 V) to a maximum input voltage (e.g. 75 V) is 0.002% at maximum and minimum load currents. Typical load voltage regulation from a minimum output current (e.g. 0.75 A) to a maximum output current (e.g. 15 A) is 0.01%. This is very important for variable load applications.

Due to the heavy current, any lead resistance, and/or contact resistance will cause a relatively large voltage drop. Therefore a remote sensing function is available in Calex HE Series in order to maintain constant voltage at a point the user selects. Improper remote sensing design will degrade line and load regulation significantly. It is necessary to test line and load regulation under remote sensing if remote sensing is used for your application. The typical and maximum line and load voltage regulations are shown in Table 1. A voltage drop of 0.5 V on the two output leads is applied for remote sensing test.

Table 1. Line & Load Regulations of HE Series

	Typical	Maximum
Line Regulation (36 V to 75 V)	0.002%	0.1%
Line Regulation under Remote Sensing (36 V to 75 V)	0.002%	0.1%
Load Voltage Regualtion (5% to 100% Load)	0.01%	0.2%
Load Voltage Regulation under Remote Sensing (5% to 100% Load)	0.015%	0.2%

Some competing DC/DC converters may have line regulation and load voltage regulation of a few percent. Also they may not have a specification for line regulation and/or load regulation under remote sensing conditions. This may cause problems for voltage sensitive applications.

Very Small Load Transient Overshoot and Fast Transient Response

In real applications sudden large load current changes that can cause large output voltage fluctuations are not uncommon. The large output voltage changes may trigger logic circuits or interfere with analog circuits. Therefore, it is necessary to reduce the peak voltage changes and their duration. When the output load current changes from 50 % to 75% or 25%, the typical output voltage overshoots (called load transient overshoot, or dynamic load regulation) of the HE Series is only 2%, the load transient recovery time is approximately 100 uS, both are examples of excellent performance. Performance at this level makes operation in most logic and analog circuit problem free. The load transient waveform is shown in Fig. 1.

The load transient overshoot of some competing converters may exceed 10 % and may cause interference problems for some applications. For example, if the output voltage is 24 V, the load transient overshoot voltage may reach 2.4 V and that is not acceptable for many applications. The load transient recovery time of some commercial converters may be ten milliseconds or more.

Very Low Turn on Overshoot

The turn on overshoot voltage for HE series is held to zero by using soft start technology and proper control in the feedback loop. Some competing products may exceed 10 % of the output voltage. This specification is likely not listed in those cases.

High Efficiency

The efficiency of the HE Series for 5 V to 24 V output voltage are from 87 to 89 % at full load. This is accomplished without using zero voltage switching, zero current switching or synchronous rectification for lower noise, lower EMI and higher reliability. The efficiency of many commercial Half Bricks with similar topology are several percent lower, and the temperature rise when using the same heat sink would be higher. A 5 % efficiency difference of a Half Brick DC/DC converter at 75 W output without a metal heat sink can cause a 35 ^{o}C temperature difference. The no load input current of the HE Series is only 12 mA. Some competing converters may have more than 20 or 40 mA for no load input current.

Ultra Low Noise

Compared to linear regulators, DC/DC converters have much higher efficiency. However, they also have higher peak to peak noises that have restricted their use in the past. Low noise levels are critical for telecommunication and precision control applications. The periodic and random deviation (PARD) is the sum of all ripple and noise components measured over a specified bandwidth and stated, unless otherwise specified, in peak to peak values [3]. PARD for the HE converter at 48 V input, 5 V 15 A output is only 16 mV. This is due to design considerations and careful printed circuit board layout. Calex has measured some 5 V output commercial Half Bricks with more than 100 mV noise under the same test conditions. The noise measurement for the HE Series also can be seen in Fig. 1.

When measuring noise it is very important to reduce the pick-up noise due to the ground lead of the scope probe. Adding a common mode choke to the probe cable can reduce the common mode noise. Matching the impedance of cable (eg. 50 ohm) at the input of the test instrument can also reduce the measurement error of high frequency noise voltage due to the transmission line effect [4]. If a RMS noise value is needed, then use multi-meters or oscilloscopes with wide-band. If this is not done your reading may be lower than the actual noise voltage.

The loop area of the output path in the application should be minimized to reduce the EMI problem due to the emission of AC ripple current in the output path and to reduce the noise pick up from the environment.

Low Reflected Input Ripple Current

Input reflected (also called induced) ripple current is the AC current portion flowing in the path from and back to the battery or the DC supply. If the loop area of this path is large, the reflected ripple current will generate a magnetic field that may cause an EMI problem. It is necessary to reduce the loop area of this path and select a DC/DC converter with lower reflected ripple current and lower EMI. The reflected ripple current of the HE Series is typically only 10 mA. Calex has measured other commercial Half Brick with more than 100 mA ripple current under same test condition. If EMI is an important issue for the application, such as to meet the FCC Class A and B, then it is necessary to add differential filters and common mode filters to further reduce EMI.

The input ripple from the DC supply will be typically rejected 60 dB (120Hz) by HE Series converters.

Loop Stability

It is very common for users to add additional capacitors or LC filters to the output that will change the feedback loop response of DC/DC converters. This may cause oscillation if the converter does not have enough design margin. It is necessary for the converter design engineer to test the phase margin and gain margin of DC/DC converters using Bode plots to ensure the integrity of the feedback loop. The phase margin and gain margin of the HE Series converters were tested under different application conditions; with and without remote sensing, and with and without additional capacitors. For example, the phase margin of 48S5.15HE (output 5 V, 15 A converter) is 73-degrees, and the gain margin is 20dB under remote sensing condition with external 5,000 µF Capacitors made with 50 pieces of 100 µF tantalum capacitors in parallel connected by several Litz wires in parallel.

III. Fault Protection

Lower Short Circuit Current to Full Scale Current Ratio

Many DC/DC converter users require limited short circuit current under fault conditions for protection. The performance of short circuit protection varies widely due to differing designs. Commercially available Pulse Width Modulation (PWM) controller have built in current limits under overload conditions. But it is very difficult to limit the current to below 150% or 180% of rated current under a dead short circuit condition. Under short-circuit conditions, many designs have a short circuit current several times higher than rated output current. This type of design may cause converter overheat or fail under dead short circuit, and may not meet UL requirements.

Calex HE Series converters use several short circuit protection techniques, such as PWM current limits, volt-seconds clamps, frequency fold-back and shutdown under dead short. The distance between two output pins is 1.4”. If the output of HE Series converters is shorted by 1.4” or 1.5” copper wire for hours, the converter will survive and still be cool without activating the thermal shutdown circuit. The converter will recover immediately once the short circuit wire is removed. In order to quantify the short circuit current, a current probe or electronic load with negative voltage pull down can be used to test the dead short circuit current especially for lower output voltages and higher output currents. For example, the 48S5.15HE maximum short circuit current is less than 22.5 A, 150 % of rated current. The typical curve is shown in Fig. 2,when the output current reaches a certain current level (19.5A in the plot) the converter operates in hiccup mode, and maximum peak current is still less than 19.5 A. Another typical curve of short circuit current for the Calex Quarter brick 48S5.15QH is shown in Fig. 3. The short circuit current is less than 23.5 A, 157 % of rated current even when the output voltage is below 10 mV.

If the power supply has current fold-back characteristics as shown in Fig. 4, under some conditions, the output voltage may not turn on, because the voltage could be high or could be low for the same output current.

Thermal Shutdown

Due to fault conditions, DC/DC converter temperatures may reach higher than 100 ^{o}C. In addition to short circuit protection, there is a thermal shutdown function in Calex HE and QH Series. When the temperature of the metal base plate of the converter is higher than 112 ^{o}C, the converter will shut off and automatically recover when the temperature is lower.

Over-Voltage Protection

The HE Series has built in output over-voltage shutdown and auto-start when over-voltage condition is removed. The volt-second clamp function in the HE Series will limit the output voltage in case two feedback loops inside the converter are both damaged.

Under-Voltage Lockout

When input voltage is low, the input current will be high and the duty cycle will be high which may create magnetic core reset problems. Therefore, there is an under-voltage lockout circuit in Calex HE and QH Series to shut off the converter to avoid excessive input current or internal voltage stress when the input voltage is below the working range. Hysteresis is built-in to avoid bouncing due to input line voltage changes when the converter is turned on and off.

High Reliability

It is common to use Bell Labs' Bellcore Methods to calculate MTBF. Many companies may use a simplified MTBF calculation method, Bellcore method 1, Case 1 to save calculation time. If you look at the MTBF number on the specification from different DC/DC manufacturers, it maybe similar, but the actual reliability may well be very different.

For long-term reliability it is very important to have optimized circuit and magnetic design to reduce steady state and transient voltage and current stress on the MOSFET, rectifiers, magnetics and other components. It is also very important to have a good printed circuit board layout to reduce parasitic inductance and resistance, unwanted distributed capacitance and electromagnetic coupling. Derating of components is also very important for high reliability. Design verification testing over a wide temperature range and various conditions including short circuit testing is a must for a new product design.

A few of the hottest components usually have the highest failure rate. Therefore it is critical to lower the temperature rise of these hottest components by electrical design and thermal design. Although the cost of an aluminum based printed circuit board is higher, the aluminum plate can be easily attached to a heat sink or metal enclosure with proper pressure. The heat can be conducted away much faster than for converters without a metal base plate. Encapsulating (soft potting) a DC/DC converter with high thermal conductivity and low mechanical stress material is the preferred way to lower the temperature rise of the hottest components comparing to open frame structure, although the cost of potting is also added. Encapsulating can damp the thermal variation and shock, mechanical vibration and shock of the components, and also be a moisture barrier.

It is very important to reduce the voltage stress, current stress, thermal stress and mechanical stress on all the components. As a result of the high reliability design, component derating and strict manufacturing processes Calex Mfg. Co., Inc. can provide a 5 year warranty on all our DC/DC converters.

IV. Useful Functions

Remote On/Off Control

The HE Series has the option of a positive or negative logic level ON/Off control function. When the converter is off, the idle input current is only 1 to 2 mA for energy saving and cool operation. Turn on time from start up to 1% error of output voltage is typically 20 mS. Some competing converters may have more than 10 mA for idle input current.

Output Voltage Trim

The output voltage of the HE Series can be easily trimmed to +/-10% . Only one resistor between the trim pin and output pin is required. When output voltage is trimmed, the T.C. of output voltage is still typically +/- 20ppm.

Cold Start at –40 °C

The outdoor units of microwave wireless telecommunication systems set on the roof of many buildings may have to start and continue working at –40 °C during winter. Therefore, it is necessary to guarantee the DC/DC converter will turn on at –40 °C. Sufficient design margin is needed to tolerate the temperature coefficient of ICs and discrete semiconductor components in order to work in wide operating temperature ranges. Calex has verified full operation at low temperatures. This ensures that the user won't have system issues at low temperature.

Isolation between Input and output

Telecom and other industrial applications often require input to output isolation. The HE Series has 1544 V isolation voltage for 48 V and 700 V isolation for 24 V input. Isolation resistance is typically higher than 100 Mohm. Input to output capacitance is typically 1700 pF.

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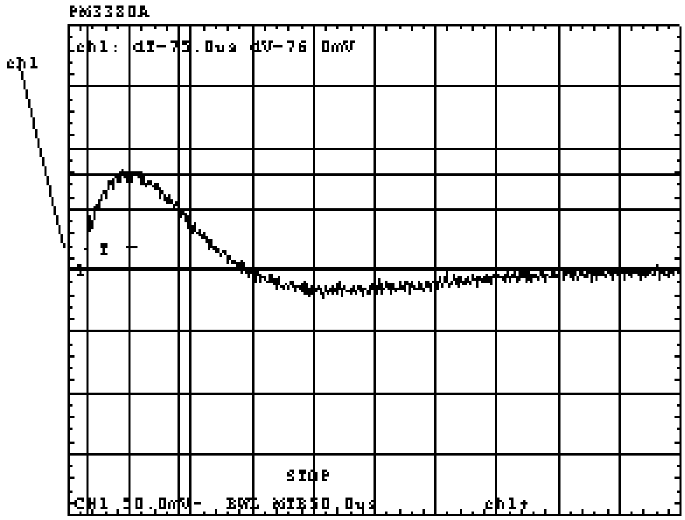
Reference

[1] "Performance of Wiper of Potentiometer", De-Xiang Huang, Calex Technical Note, July 1997.
[2] Calex Catalog at www.calex.com.
[3] IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods", IEEE Std 1515-2000.
[4] De-Xiang Huang, Joseph R. Kinard and Greg Rebuldela, "RF-DC Differences of Thermal Voltage Converters Arising from Input Connectors," IEEE Trans. Instrumentation & Measurement, Vol. 40, Apr. 1991, pp.360-365.

Figure 1



48S5.15HE: Load transient overshoot is 1.5% when output current changes from 11.25 A to 7.5 A, load transien t recovery time to 1 % error band is 75 uS.

Figure 2

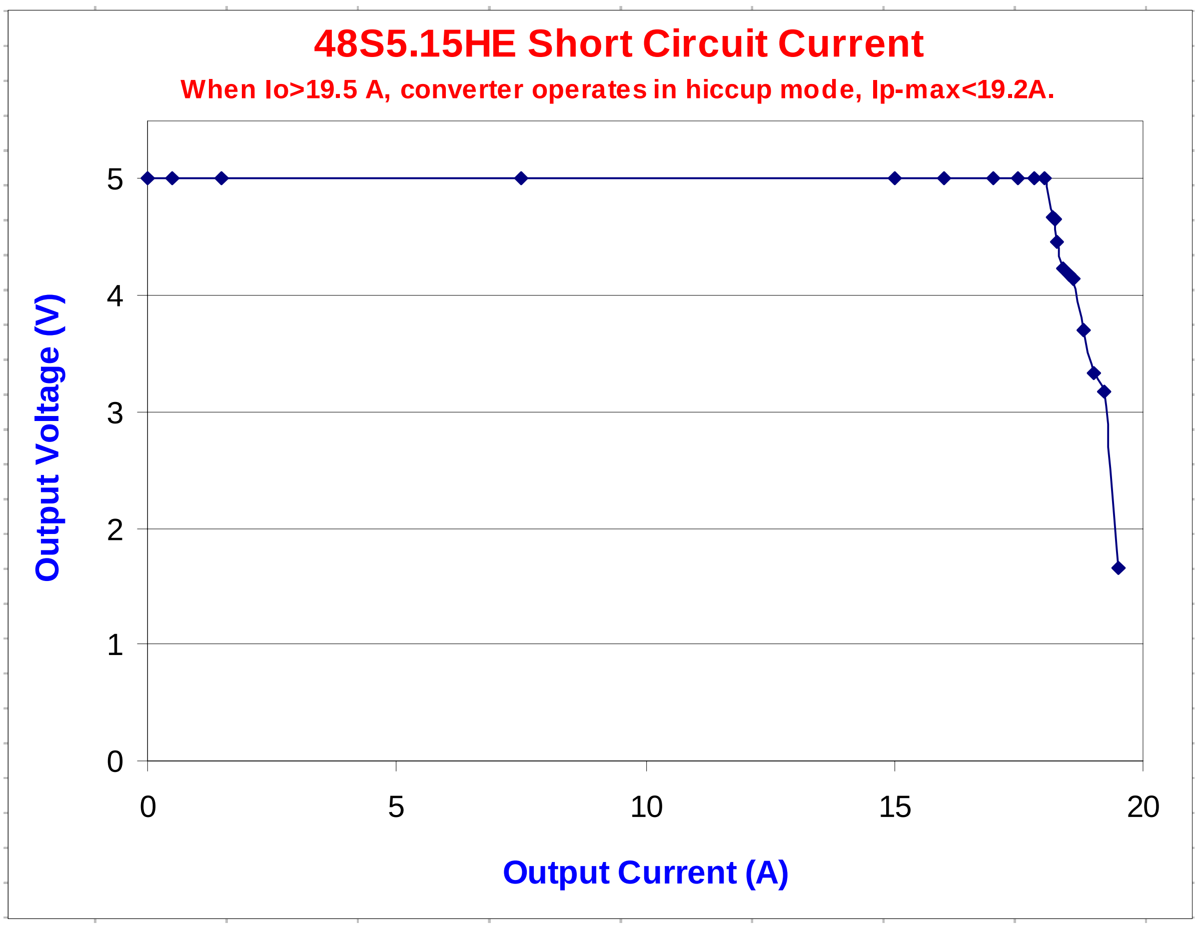


Figure 3

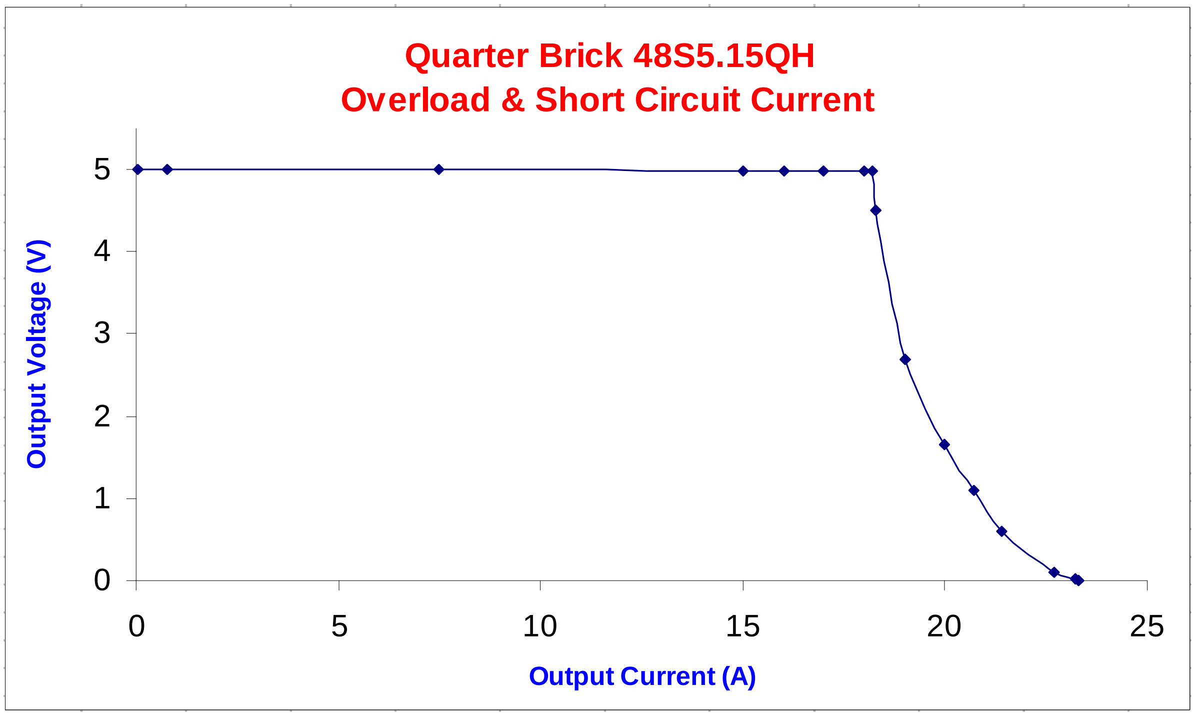


Figure 4