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1.2MHz 1.5A Synchronous Step-Down Converter

CE8515 Series

Preliminary

■ INTRODUCTION

The CE8515 is a 1.2MHz constant frequency, slope compensated current mode PWM synchronous step-down converter. The internal synchronous switch increases efficiency and eliminates the need for an external Schottky diode. It is ideal for portable equipment requiring very high current up to 1.5A from single-cell Lithium-ion batteries while still achieving over 90% efficiency during peak load conditions. 100% duty cycle provides low dropout operation, extending battery life in portable systems. Low output voltages are easily supported with the 0.6V feedback reference voltage. The device is available in a Pb-free, 3x3mm 10-lead DFN package and is rated over the -40°C to +85°C temperature range.

■ FEATURES

- High efficiency : Up to 95%
- Output Current: 1.5A (Typ.)
- 1.2MHz Constant Switching Frequency
- Input Voltage: 2.5V to 5.5V
- 0.6V Reference Allows Low Output Voltage
- Low Dropout: 100% duty Cycle
- Low $R_{DS(ON)}$ Internal Switches: 130mΩ(P-CH), 90mΩ(N-CH)
- Shutdown Current: <1μA
- Current Mode Operation for Excellent Line and Load Transient Response
- Short Circuit and Thermal Fault Protection
- Soft Start
- Allows Use of Ceramic Capacitors
- Package: DFN3×3-10

■ APPLICATIONS

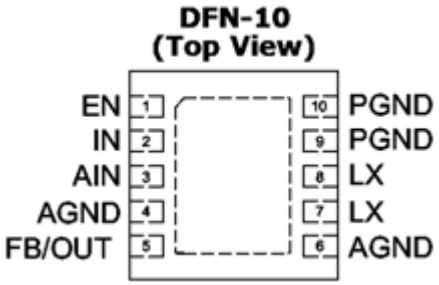
- Cellular and Smart Phones
- Laptop, Palmtops and PDA
- Digital Still and Video Cameras
- MP3, MP4 Player
- Radio control systems
- Battery-Powered Equipment

■ ORDER INFORMATION

CE8515①②③④

DESIGNATOR	SYMBOL	DESCRIPTION
①	A	Standard
②③	Integer	Output Voltage e.g.1.8V=②:1, ③:8 Adj=②:, ③:
④	D	Package： DFN3×3-10

■ PIN CONFIGURATION



PIN NUMBER	SYMBOL	FUNCTION
1	EN	Enable pin. Active high. In shutdown, all functions are disabled drawing <1μA supply current. Do not leave EN floating.
2	IN	Power supply input pin. Must be closely decoupled to AGND with a 10μF or greater ceramic capacitor.
3	AIN	Analog supply input pin. Provides bias for internal circuitry.
4,6	AGND	Analog ground pin
5	FB/OUT	FB pin (CE8515 Adj): Adjustable version feedback input. Connect FB to the center point of the external resistor divider. The feedback threshold voltage is 0.6V. OUT pin (CE8515-1.8): Fixed version feedback input. Connect OUT to the output voltage, VOUT.
7,8	LX	External Inductor Connection Pin
9,10	PGND	Power ground pin
	EP	Power ground exposed pad. Must be connected to bare copper ground plane.

■ ABSOLUTE MAXIMUM RATINGS

(Unless otherwise specified, Ta=25°C)

PARAMETER		SYMBOL	RATINGS	UNITS
Input Voltage		IN,AVIN	-0.3~ 7	V
EN,LX,FB Voltage		V_{EN},V_{LX},V_{FB}	-0.3~V_{IN}+0.3	V
Peak LX Sink and Source Current		I_{SWMAX}	2500	mA
Power Dissipation	DFN3×3-10	Pd	2200	mW
Operating Temperature		T_{opr}	-40~+85	℃
Junction Temperature		T_j	125	℃
Storage Temperature		T_{stg}	-40~+125	℃
Soldering Temperature & Time		T_{solder}	260℃, 10s	

■ ELECTRICAL CHARACTERISTICS

CE8515 Series **(V_{IN}=3.6V, Ta=25℃, unless otherwise specified)**

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Output Voltage	$V_{OUT(F)}$ (1)	I_{OUT} =100mA	V_{OUT}×0.98	V_{OUT}	V_{OUT}×1.02	V
Feedback Voltage	V_{FB}	T_A=25℃	0.5880	0.600	0.6120	V
		0℃≤T_A≤85℃	0.5865	0.600	0.6135	
		-40℃≤T_A≤85℃	0.5850	0.600	0.6150	
Input Voltage	V_{IN}		2.5		5.5	V
Supply Current	I_{SS}	V_{FB}=0.5V		300	400	μA
Shutdown Current	I_{SHDN}	V_{CE}=V_{SS}		0.1	1.0	μA
Feedback Current	I_{FB}	V_{FB}=0.65V			±30	nA
Maximum Output Current	I_{OUT}	—	1.5			A
V_{FB} Line Regulation	ΔV_{FB}	V_{IN}= 2.5V~5.5V		0.10	0.40	%/V
Output Voltage Line Regulation	ΔV_{OUT}	V_{IN}= 2.5V~5.5V I_{OUT}=10mA		0.10	0.40	%/V
Output Voltage Load Regulation	ΔV_{LOAD}	I_{OUT} =10mA ~1500mA		0.001		%/mA
Oscillator Frequency	f_{osc}	V_{FB}=0.6V or V_{OUT}=100%	0.96	1.2	1.44	MHz
Peak Inductor Current	I_{PK}			2.5		A
Start Time	Tstart	From Enable to Output Regulation		1.3		ms
Over-Temperature Shutdown Threshold	T_{SD}			170		℃
Over-Temperature Shutdown Hysteresis	T_{HYS}			10		℃
Peak Switch Current	I_{LIM}			2.5		A
$R_{DS(ON)}$ OF P-CH FET	R_{PFET}	V_{IN}=3.6V		130	200	mΩ
$R_{DS(ON)}$ OF N-CH FET	R_{NFET}	V_{IN}=3.6V		90	150	mΩ
CE "High" Voltage(2)	V_{CE}"H"		1.5		V_{IN}	V
CE "Low" Voltage(3)	V_{CE}"L"				0.3	V
CE Leakage Current	I_{CE}			±0.1	±1	μA

NOTE :

1. $V_{OUT(F)}$:The fixed voltage version effective output voltage.
2. High Voltage：Forcing CE above 1.5V enables the part.
3. Low Voltage：Forcing CE below 0.3V shuts down the device. In shutdown, all functions are disabled drawing <1μA supply current. Do not leave CE floating.

■ TYPICAL APPLICATION

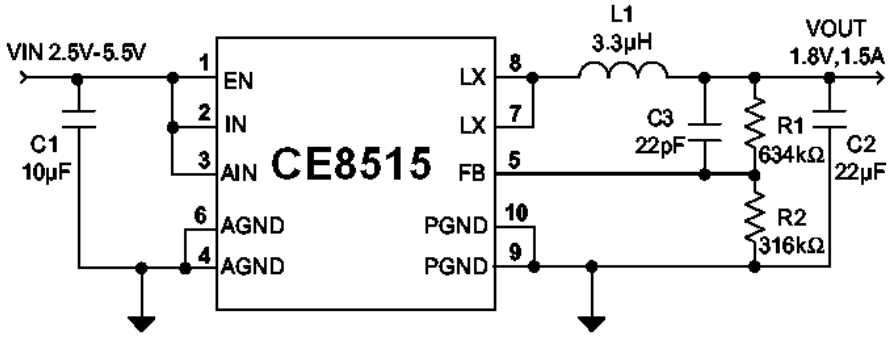
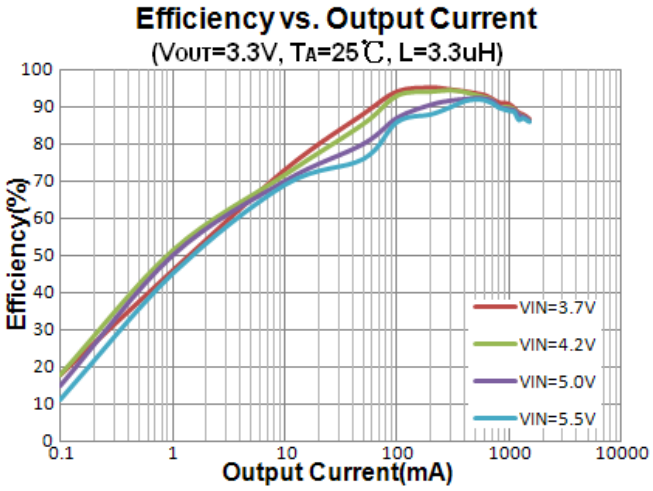
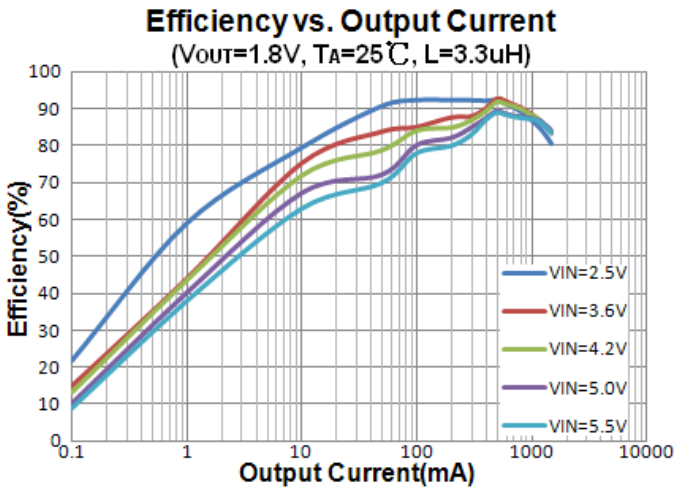
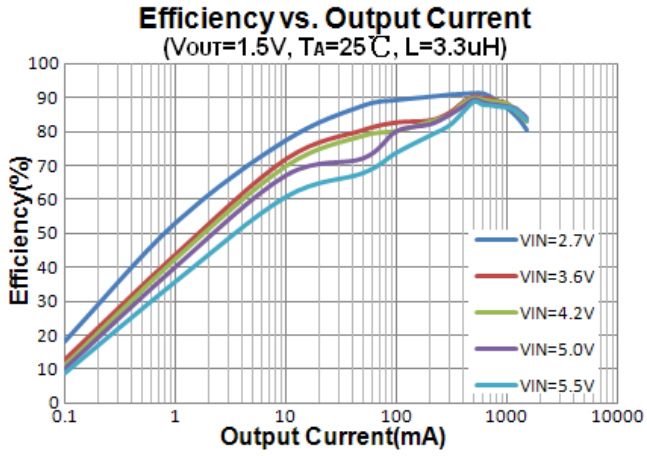


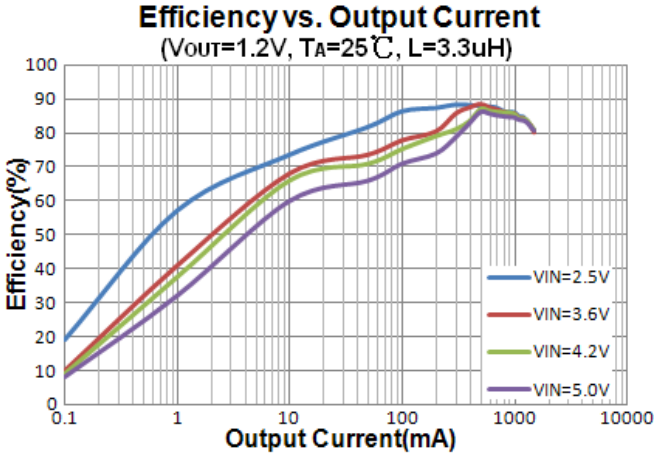
Figure1 Basic Application Circuit

■ TYPICAL PERFORMANCE CHARACTERISTICS









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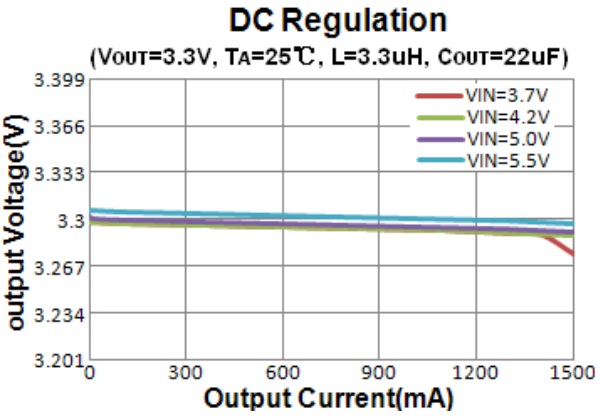

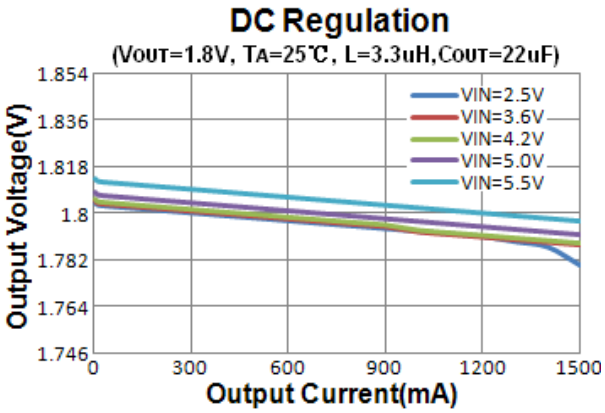

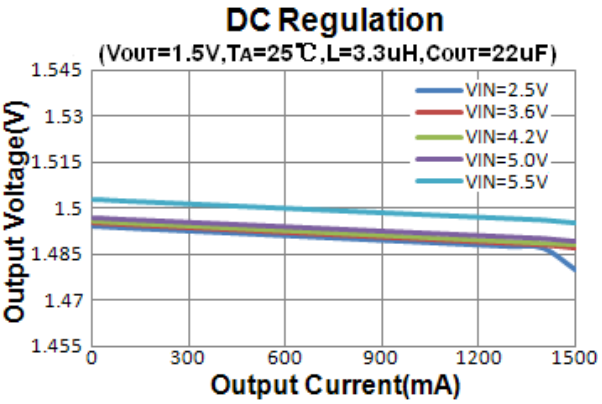

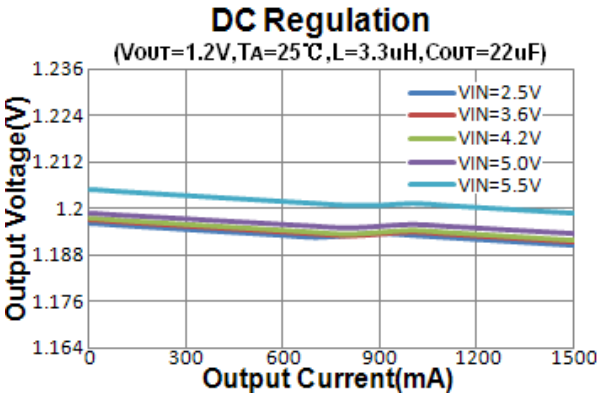

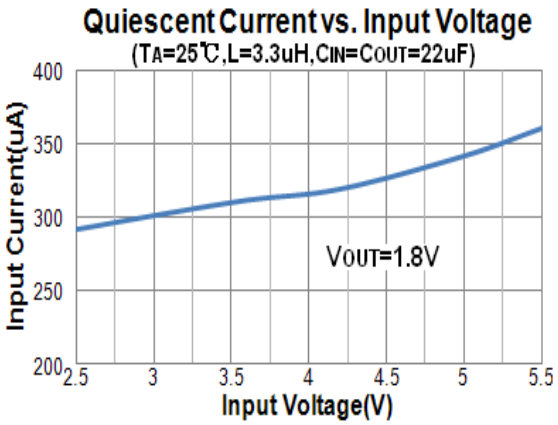

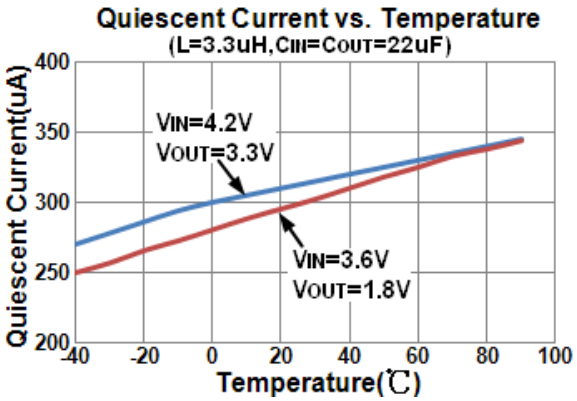

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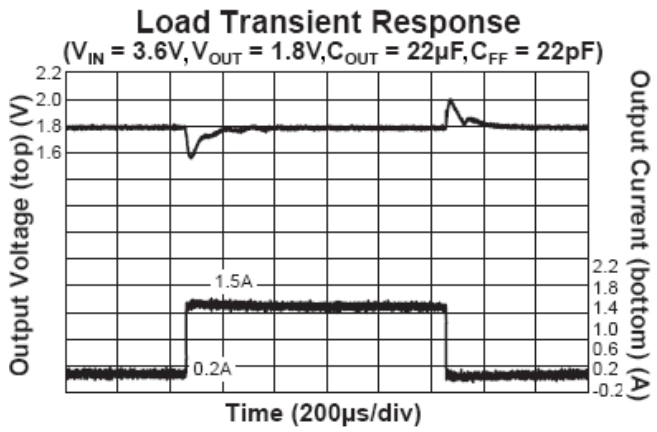
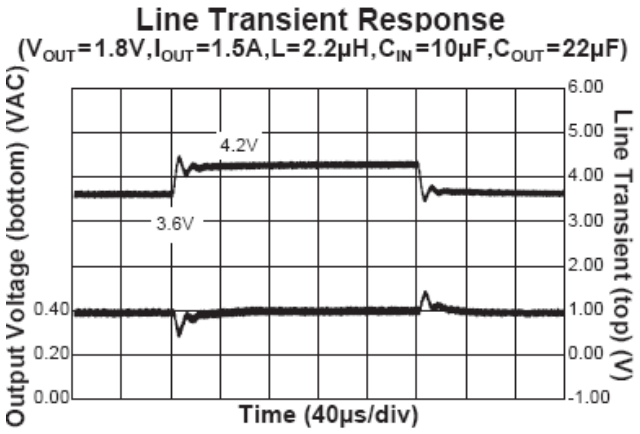
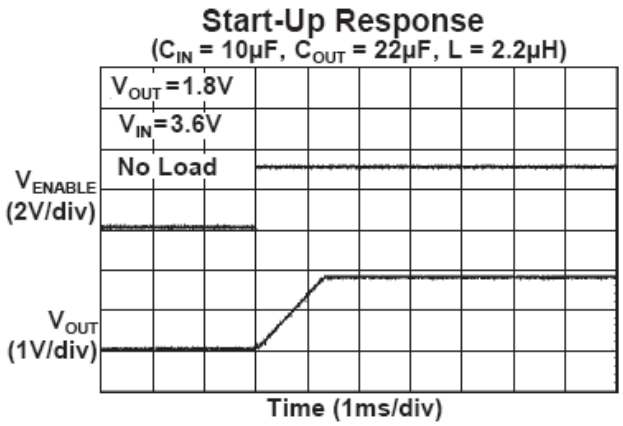
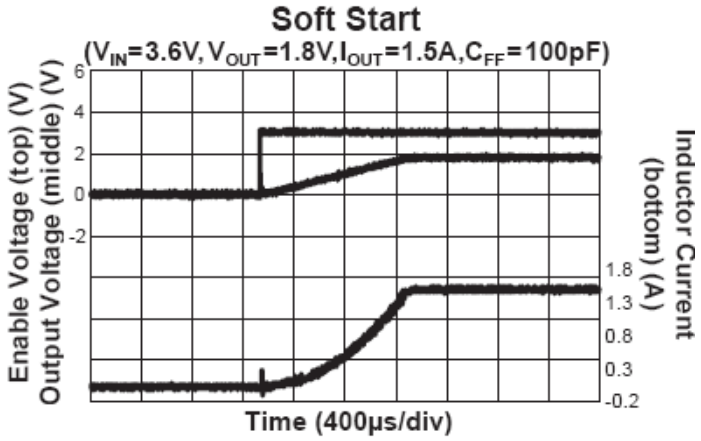
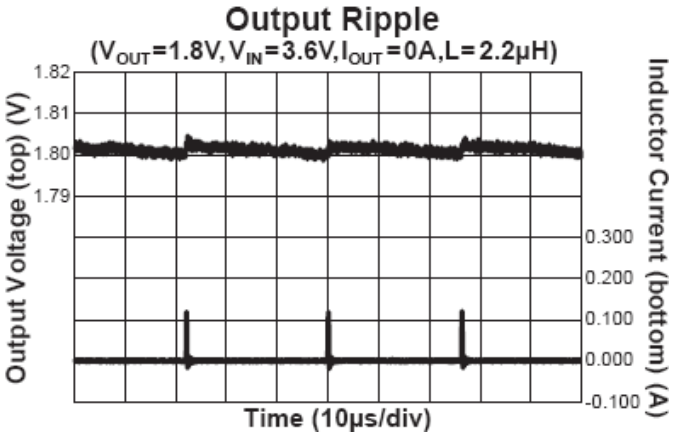
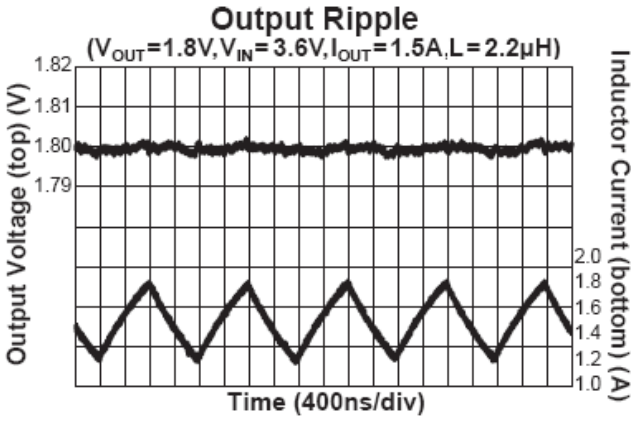




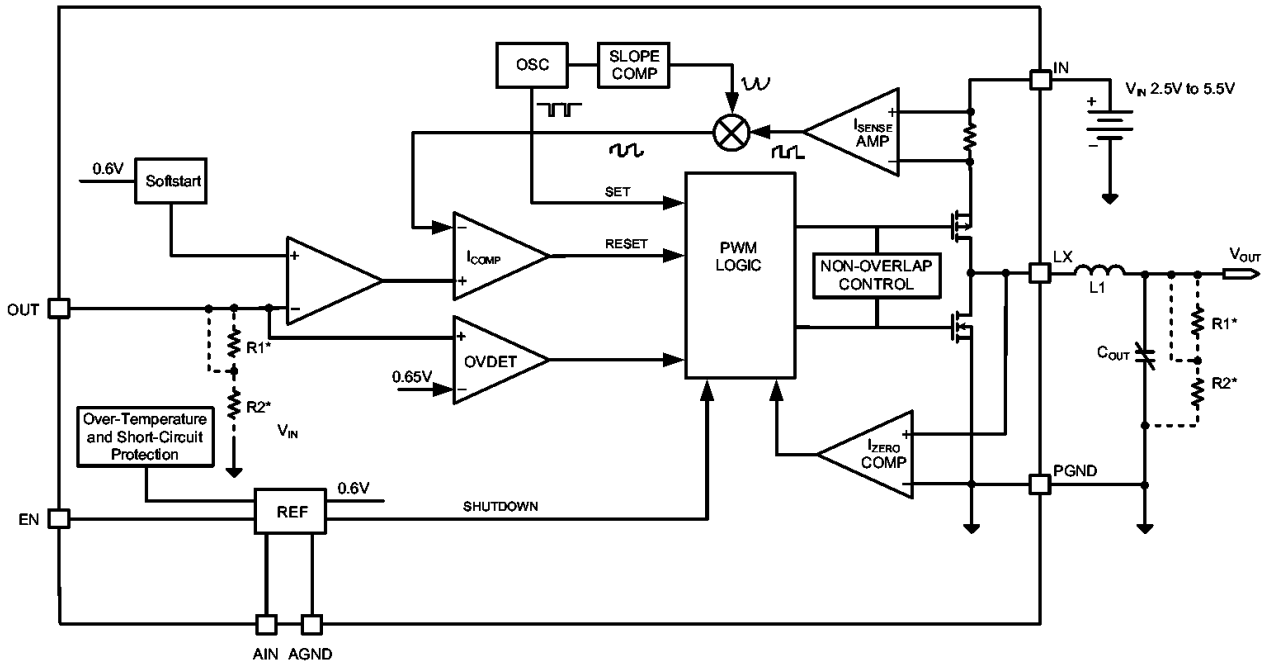








■ BLOCK DIAGRAM



*The resistor divider R1 + R2 is internally set for the fixed output versions, and is externally set for the adjustable output versions.

■ OPERATION

Functional Description

The CE8515 is a high output current monolithic switch-mode step-down DC-DC converter. The device operates at a fixed 1.2MHz switching frequency, and uses a slope compensated current mode architecture. This step-down DC-DC converter can supply up to 1500mA output current at V_{IN} = 3.6V and has an input voltage range from2.5V to 5.5V. It minimizes external component size and optimizes efficiency at the heavy load range. The slope compensation allows the device to remain stable over a wider range of inductor values so that smaller values (1μH to 4.7μH) with lower DCR can be used to achieve higher efficiency. Apart from the small bypass input capacitor, only a small L-C filter is required at the output. The fixed output version requires only three external power components (C_{IN}, C_{OUT}, and L). The adjustable version can be programmed with external feedback to any voltage, ranging from 0.6V to near the input voltage. It uses internal MOSFETs to achieve high efficiency and can generate very low output voltages by using an internal reference of 0.6V. At dropout, the converter duty cycle increases to100% and the output voltage tracks the input voltage minus the low $R_{DS(ON)}$ drop of the P-channel high-side MOSFET and the inductor DCR. The internal error amplifier and compensation provides excellent transient response, load and line regulation. Internal soft start eliminates any output voltage overshoot when the enable or the input voltage is applied.

Current Mode PWM Control

Slope compensated current mode PWM control provides stable switching and cycle-by-cycle current limit for excellent load and line response with protection of the internal main switch (P-channel MOSFET) and synchronous rectifier (N-channel MOSFET). During normal operation, the internal P-channel MOSFET is turned on for a specified time to ramp the inductor current at each rising edge of the internal oscillator, and switched off when the peak inductor current is above the error voltage. The current comparator, ICOMP, limits the peak inductor current. When the main switch is off, the synchronous rectifier turns on immediately and stays on until either the inductor current starts to reverse, as indicated by the current reversal comparator, IZERO, or the beginning of the next clock cycle.

Current Limit and
Over-Temperature Protection

For overload conditions, the peak input current is limited to 2.5A. To minimize power dissipation and stresses under current limit and short-circuit conditions, switching is terminated after entering current limit for a series of pulses. The termination lasts for seven consecutive clock cycles after a current limit has been sensed during a series of four consecutive clock cycles. Thermal protection completely disables switching when internal dissipation becomes excessive. The junction over-temperature threshold is 170°C with 10°C of hysteresis. Once an over-temperature or over-current fault conditions is removed, the output voltage automatically recovers.

Control Loop

The CE8515 is a peak current mode step-down converter. The current through the P-channel MOSFET (high side) is sensed for current loop control, as well as short circuit and overload protection. A slope compensation signal is added to the sensed current to maintain stability for duty cycles greater than 50%. The peak current mode loop appears as a voltage-programmed current source in parallel with the output capacitor. The output of the voltage error amplifier programs the current mode loop for the necessary peak switch current to force a constant output voltage for all load and line conditions. Internal loop compensation terminates the transconductance voltage error amplifier output. For fixed voltage versions, the error amplifier reference voltage is internally set to program the converter output voltage. For the adjustable output, the error amplifier reference is fixed at 0.6V.

Dropout Operation

When the battery input voltage decreases near the value of the output voltage, the CE8515 allows the main switch to remain on for more than one switching cycle and increases the duty cycle until it reaches 100%. The duty cycle D of a step-down converter is defined as:

$$D=T_{ON}\cdot F_{OSC}\cdot 100\%\approx \frac{V_{OUT}}{V_{IN}}\cdot 100\%$$

Where T_{ON} is the main switch on time and F_{OSC} is the oscillator frequency. The output voltage then is the input voltage minus the voltage drop across the main switch and the inductor. At low input supply voltage, the RDS(ON) of the P-channel MOSFET increases, and the efficiency of the converter decreases. Caution must be exercised to ensure the heat dissipated does not exceed the maximum junction temperature of the IC.

Soft Start / Enable

Soft start limits the current surge seen at the input and eliminates output voltage overshoot. The enable pin is active high. When pulled low, the enable input (EN) forces the CE8515 into a low-power, non-switching state. The total input current during shutdown is less than 1μA.

Maximum Load Current

The CE8515 will operate with an input supply voltage as low as 2.5V, however, the maximum load current decreases at lower input voltages due to a large IR drop on the main switch and synchronous rectifier. The slope compensation signal reduces the peak inductor current as a function of the duty cycle to prevent sub-harmonic oscillations at duty cycles greater than 50%. Conversely the current limit increases as the duty cycle decreases.

■ APPLICATION INFORMATION

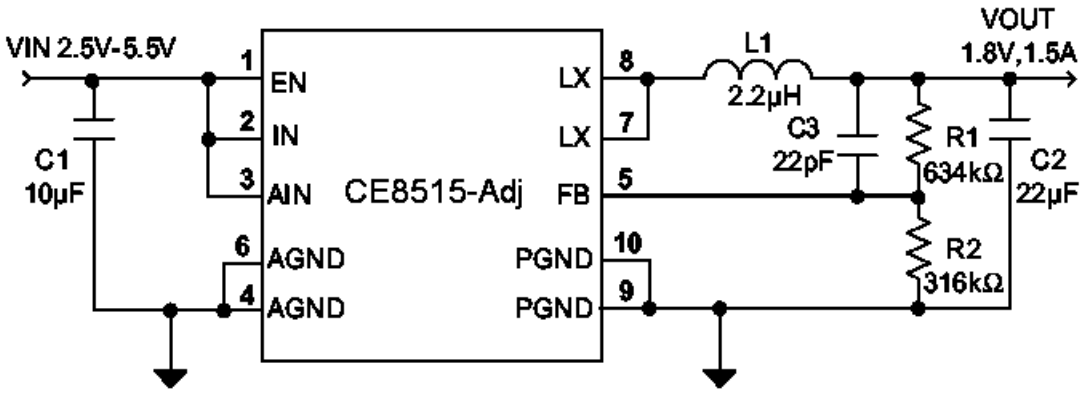


Figure2: Basic Application Circuit for the Adjustable Output Version.

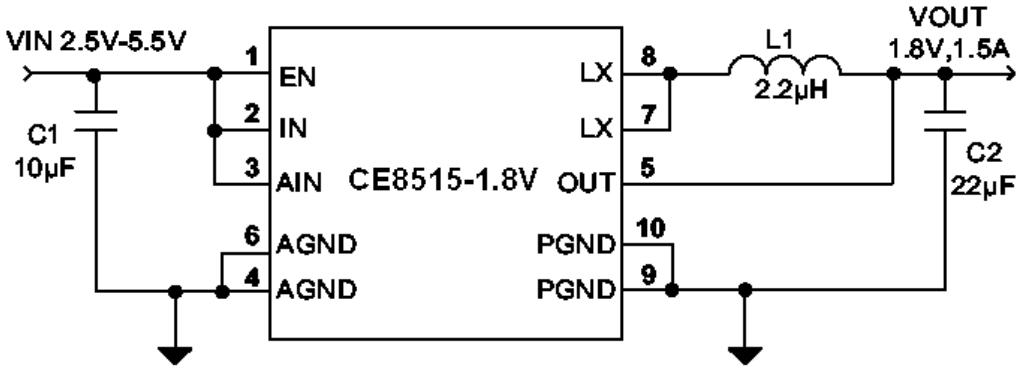


Figure3: Basic Application Circuit for the Fixed Output Versions.

Setting the Output Voltage

Figure 2 shows the basic application circuit with the CE8515 adjustable output version while Figure 3 shows the application circuit with the CE8515 fixed output version. For applications requiring an adjustable output voltage, the CE8515-0.6 adjustable version can be externally programmed. Resistors R1 and R2 in Figure 1 program the output to regulate at a voltage higher than 0.6V. To limit the bias current required for the external feedback resistor string while maintaining good noise immunity, the minimum suggested value for R2 is 59kΩ. Although a larger value will further reduce quiescent current, it will also increase the impedance of the feedback node, making it more sensitive to external noise and interference. Table 1 summarizes the resistor values for various output voltages with R2 set to either 59kΩ for good noise immunity or 316kΩ for reduced no load input current.

The adjustable version of the CE8515, combined with an external feed forward capacitor (C3 in Figure 2), delivers enhanced transient response for extreme pulsed load applications. The addition of the feed forward capacitor typically requires a larger output capacitor C2 for stability.

The external resistor sets the output voltage according to the following equation:

$$V_{OUT}=0.6V\cdot\left(1+\frac{R1}{R2}\right)$$

$$R1=\left(\frac{V_{OUT}}{0.6V}-1\right)\cdot R2$$

Table 1 shows the resistor selection for different output voltage settings.

V_{OUT}(V)	R2=59kΩ R1 (kΩ)	R2=316kΩ R1 (kΩ)
0.8	19.6	105
0.9	29.4	158
1.0	39.2	210
1.1	49.9	261
1.2	59.0	316
1.3	68.1	365
1.4	78.7	422
1.5	88.7	475
1.8	118	634
2.0	137	732
2.5	187	1000
3.3	267	1430

Table1: Resistor Selections for Different Output Voltage Settings (Standard 1% Resistors Substituted for Calculated Values).

Inductor Selection

For most designs, the CE8515 operates with inductor values of 1μH to 4.7μH. Low inductance values are physically smaller but require faster switching, which results in some efficiency loss. The inductor value can be derived from the following equation:

$$L=\frac{V_{OUT}\cdot(V_{IN}-V_{OUT})}{V_{IN}\cdot\Delta I_L\cdot f_{OSC}}$$

Where ΔI_L is inductor ripple current. Large value inductors lower ripple current and small value inductors result in high ripple currents. Choose inductor ripple current approximately 30% of the maximum load current

1500mA, or

$$\Delta I_L=450mA$$

For output voltages above 2.0V, when light-load efficiency is important, the minimum recommended inductor is 2.2μH.

Manufacturer's specifications list both the inductor DC current rating, which is a thermal limitation, and the peak current rating, which is determined by the saturation characteristics. The inductor should not show any appreciable saturation under normal load conditions. Some inductors may meet the peak and average current ratings yet result in excessive losses due to a high DCR.

Always consider the losses associated with the DCR and its effect on the total converter efficiency when selecting an inductor. For optimum voltage-positioning load transients, choose an inductor with DC series resistance in the 20mΩ to 100mΩ range. For higher efficiency at heavy loads (above 200mA), or minimal load regulation (but some transient overshoot), the resistance should be kept below 100mΩ. The DC current rating of the inductor should be at least equal to the maximum load current plus half the ripple current to prevent core saturation (1500mA + 225mA). Table 2 lists some typical surface mount inductors that meet target applications for the CE8515.

For example, the 2.2μH SD3118-2R2-R inductor selected from Coiltronics has a 74mΩ DCR and a 2.00ADC current rating. At full load, the inductor DC loss is 106mW which gives a 5% loss in efficiency for a 1200mA, 1.8V output.

Slope Compensation

The CE8515 step-down converter uses peak current mode control with slope compensation for stability when duty cycles are greater than 50%. The slope compensation is set to maintain stability with lower value inductors which provide better overall efficiency. The output inductor value must be selected so the inductor current down slope meets the internal slope compensation requirements. As an example, the value of the slope compensation is set to 1A/μs which is large enough to guarantee stability when using a 2.2μH inductor for all output voltage levels from 0.6V to 3.3V.

The worst case external current slope (m) using the2.2μH inductor is when V_{OUT} = 3.3V and is:

$$m=\frac{V_{OUT}}{L}=\frac{3.3}{2.2}=1.5A/\mu s$$

To keep the power supply stable when the duty cycle is above 50%, the internal slope compensation (mA) should be:

$$m_a \geq \frac{1}{2}\cdot m=0.75A/\mu s$$

Therefore, to guarantee current loop stability, the slope of the compensation ramp must be greater than one-half of the down slope of the current waveform. So the internal slope compensated value of 1A/μs will guarantee stability using a 2.2μH inductor value for all output voltages from 0.6V to 3.3V.

Input Capacitor Selection

The input capacitor reduces the surge current drawn from the input and switching noise from the device. The input capacitor impedance at the switching frequency should be less than the input source impedance to prevent high frequency switching current passing to the input. The calculated value varies with input voltage and is a maximum when V_{IN} is double the output voltage.

$$C_{IN}=\frac{\frac{V_O}{V_{IN}}\cdot\left(1-\frac{V_O}{V_{IN}}\right)}{\left(\frac{V_{PP}}{I_O}-ESR\right)\cdot f_S}$$

$$C_{IN(MIN)}=\frac{1}{\left(\frac{V_{PP}}{I_O}-ESR\right)\cdot 4\cdot f_S}$$

A low ESR input capacitor sized for maximum RMS current must be used. Ceramic capacitors with X5R or X7R dielectrics are highly recommended because of their low ESR and small temperature coefficients. A 10μF ceramic capacitor for most applications is sufficient. A large value may be used for improved input voltage filtering.

The maximum input capacitor RMS current is:

$$I_{RMS}=I_O\cdot\sqrt{\frac{V_O}{V_{IN}}\cdot\left(1-\frac{V_O}{V_{IN}}\right)}$$

The input capacitor RMS ripple current varies with the input and output voltage and will always be less than or equal to half of the total DC load current.

$$I_{RMS(MAX)}=\frac{1}{2}\cdot I_O$$

To minimize stray inductance, the capacitor should be placed as closely as possible to the IC. This keeps the high frequency content of the input current localized, minimizing EMI and input voltage ripple.

A laboratory test set-up typically consists of two long wires running from the bench power supply to the evaluation board input voltage pins. The inductance of these wires, along with the low-ESR ceramic input capacitor, can create a high Q network that may affect converter performance. This problem often becomes apparent in the form of excessive ringing in the output voltage during load transients. Errors in the loop phase and gain measurements can also result.

Since the inductance of a short PCB trace feeding the input voltage is significantly lower than the power leads from the bench power supply, most applications do not exhibit this problem.

In applications where the input power source lead inductance cannot be reduced to a level that does not affect the converter performance, a high ESR tantalum or aluminum electrolytic should be placed in parallel with the low ESR, ESL bypass ceramic. This dampens the high Q network and stabilizes the system.

Output Capacitor Selection

The function of output capacitance is to store energy to attempt to maintain a constant voltage. The energy is stored in the capacitor's electric field due to the voltage applied. The value of output capacitance is generally selected to limit output voltage ripple to the level required by the specification. Since the ripple current in the output inductor is usually determined by L, VOUT and VIN, the series impedance of the capacitor primarily determines the output voltage ripple. The three elements of the capacitor that contribute to its impedance (and output voltage ripple) are equivalent series resistance (ESR), equivalent series inductance (ESL), and capacitance (C).

The output voltage droop due to a load transient is dominated by the capacitance of the ceramic output capacitor. During a step increase in load current, the ceramic output capacitor alone supplies the load current until the loop responds. Within two switching cycles, the loop responds and the inductor current increases to match the load current demand. The relationship of the output voltage droop during the two switching cycles to the output capacitance can be estimated by:

$$C_{OUT}=\frac{2\cdot\Delta I_{LOAD}}{V_{DROOP}\cdot f_S}$$

In many practical designs, to get the required ESR, a capacitor with much more capacitance than is needed must be selected.

For both continuous or discontinuous inductor current mode operation, the ESR of the COUT needed to limit the ripple to $\Delta V_{O,}$ V peak-to-peak is:

$$ESR\leq\frac{\Delta V_O}{\Delta I_L}$$

Ripple current flowing through a capacitor's ESR causes power dissipation in the capacitor. This power dissipation causes a temperature increase internal to the capacitor. Excessive temperature can seriously shorten the expected life of a capacitor. Capacitors have ripple current ratings that are dependent on ambient temperature and should not be exceeded. The output capacitor ripple current is the inductor current, IL, minus the output current, IO. The RMS value of the ripple current flowing in the output capacitance (continuous inductor current mode operation) is given by:

$$I_{RMS}=\Delta I_L\cdot\frac{\sqrt{3}}{6}=\Delta I_L\cdot 0.289$$

ESL can be a problem by causing ringing in the low megahertz region but can be controlled by choosing low ESL capacitors, limiting lead length (PCB and capacitor), and replacing one large device with several smaller ones connected in parallel.

In conclusion, in order to meet the requirement of output voltage ripple small and regulation loop stability, ceramic capacitors with X5R or X7R dielectrics are recommended due to their low ESR and high ripple current ratings. The output ripple V_{OUT} is determined by:

$$\Delta V_{OUT} \leq \frac{V_{OUT} \cdot (V_{IN} - V_{OUT})}{V_{IN} \cdot f_{OSC} \cdot L} \cdot \left(ESR + \frac{1}{8 \cdot f_{OSC} \cdot C_{OUT}} \right)$$

A 22μF ceramic capacitor can satisfy most applications.

Thermal Calculations

There are three types of losses associated with the CE8515 step-down converter: switching losses, conduction losses, and quiescent current losses. Conduction losses are associated with the $R_{DS(ON)}$ characteristics of the power output switching devices. Switching losses are dominated by the gate charge of the power output switching devices. At full load, assuming continuous conduction mode (CCM), a simplified form of the losses is given by:

$$P_{TOTAL} = \frac{I_O^2 \cdot (R_{DSON(HS)} \cdot V_O + R_{DSON(LS)} \cdot [V_{IN} - V_O])}{V_{IN}} + (t_{SW} \cdot F \cdot I_O + I_Q) \cdot V_{IN}$$

I_Q is the step-down converter quiescent current. The term t_{SW} is used to estimate the full load step-down converter switching losses.

For the condition where the step-down converter is in dropout at 100% duty cycle, the total device dissipation reduces to:

$$P_{TOTAL} = I_O^2 \cdot R_{DSON(HS)} + I_Q \cdot V_{IN}$$

Since $R_{DS(ON)}$, quiescent current, and switching losses all vary with input voltage, the total losses should be investigated over the complete input voltage range. Given the total losses, the maximum junction temperature can be derived from the θ_{JA} for the DFN-10 package which is 45°C/W.

$$T_{J(MAX)} = P_{TOTAL} \cdot \theta_{JA} + T_{AMB}$$

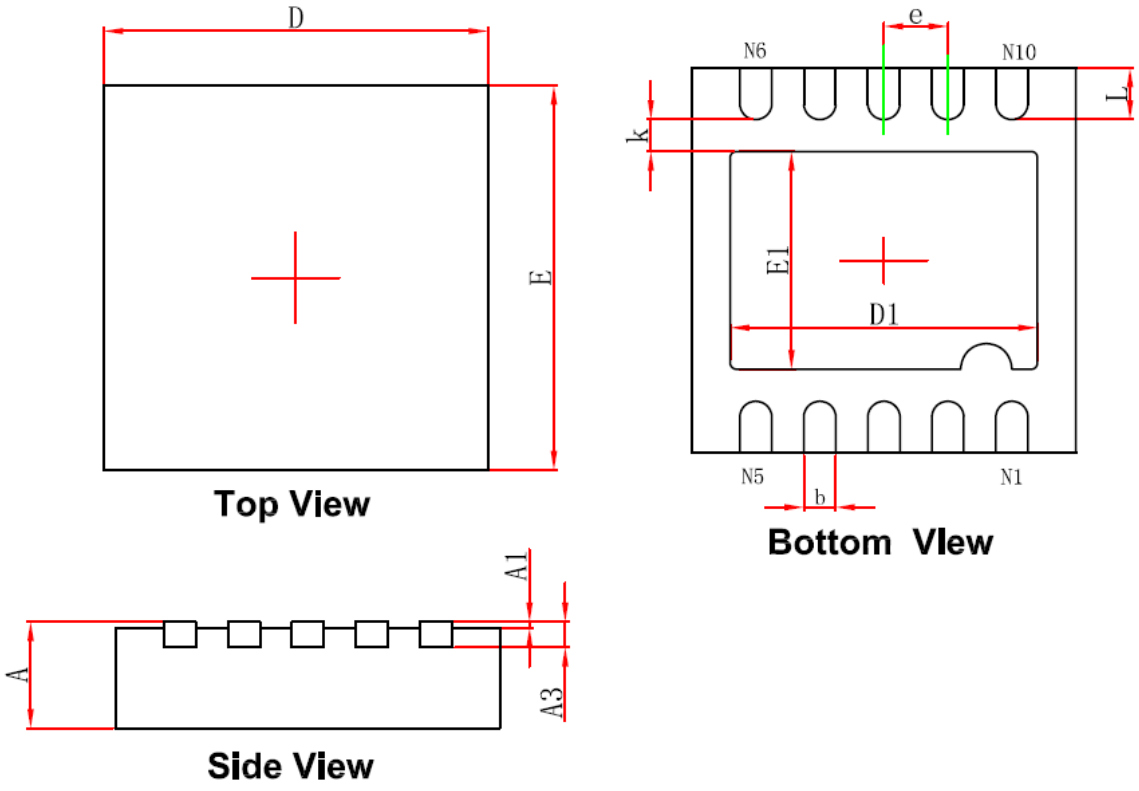
Layout Guidance

When laying out the PC board, the following layout guideline should be followed to ensure proper operation of the CE8515:

1. The exposed pad (EP) must be reliably soldered to the GND plane. A PGND pad below EP is strongly recommended.
2. The power traces, including the GND trace, the LX trace and the IN trace should be kept short, direct and wide to allow large current flow. The L1 connection to the LX pins should be as short as possible. Use several VIA pads when routing between layers.
3. The input capacitor (C1) should connect as closely as possible to IN (Pin 2) and AGND (Pins 4 and 6) to get good power filtering.
4. Keep the switching node, LX (Pins 7 and 8), away from the sensitive FB/OUT node.
5. The feedback trace or OUT pin (Pin 5) should be separate from any power trace and connect as closely as possible to the load point. Sensing along a high-current load trace will degrade DC load regulation. If external feedback resistors are used, they should be placed as closely as possible to the FB pin (Pin 5) to minimize the length of the high impedance feedback trace.
6. The output capacitor C2 and L1 should be connected as closely as possible. The connection of L1 to the LX pin should be as short as possible and there should not be any signal lines under the inductor.
7. The resistance of the trace from the load return to PGND should be kept to a minimum. This will help to minimize any error in DC regulation due to differences in the potential of the internal signal ground and the power ground.

■ PACKAGING INFORMATION

DFN3×3-10 Package Outline Dimensions



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min.	Max.	Min.	Max.
A	0.700/0.800	0.800/0.900	0.028/0.031	0.031/0.035
A1	0.000	0.050	0.000	0.002
A3	0.203REF.		0.008REF.	
D	2.900	3.100	0.114	0.122
E	2.900	3.100	0.114	0.122
D1	2.300	2.500	0.091	0.098
E1	1.600	1.800	0.063	0.071
k	0.200MIN.		0.008MIN.	
b	0.180	0.300	0.007	0.012
e	0.500TYP.		0.020TYP.	
L	0.300	0.500	0.012	0.020