National Semiconductor

PRELIMINARY

January 2002

LM2794/LM2795 Current Regulated Switched Capacitor LED Supply with Analog Brightness Control

General Description

The LM2794/95 is a fractional CMOS charge-pump and regulator that provides four regulated current sources. It accepts an input voltage range from 2.7V to 5.5V and maintains a constant current determined by an external sense resistor.

The LM2794/5 delivers up to 80mA of load current to accommodate four White LEDs. The switching frequency is 325kHz. (min.) to keep the conducted noise spectrum away from sensitive frequencies within portable RF devices. Maximum operating current is 8.2mA (unloaded) and the maximum shutdown current is only 5µA. If not all output pins are used, leave pin(s) unconnected.

Brightness can be controlled by both linear and PWM techniques. A voltage between 0V and 3.0V may be applied to the BRGT pin to vary the current over more than a 5 to 1 ratio. Output current will linearly track the voltage applied to the BRGT pin. Alternatively, a PWM signal can be applied to the SD pin to vary the perceived brightness of the LED. The SD pin reduces the operating current to 5µA (max.) The LM2794 uses an active-low shutdown level, and the LM2795 uses an active-high shutdown level.

The LM2794/95 is available in a micro SMD-14 CSP package.

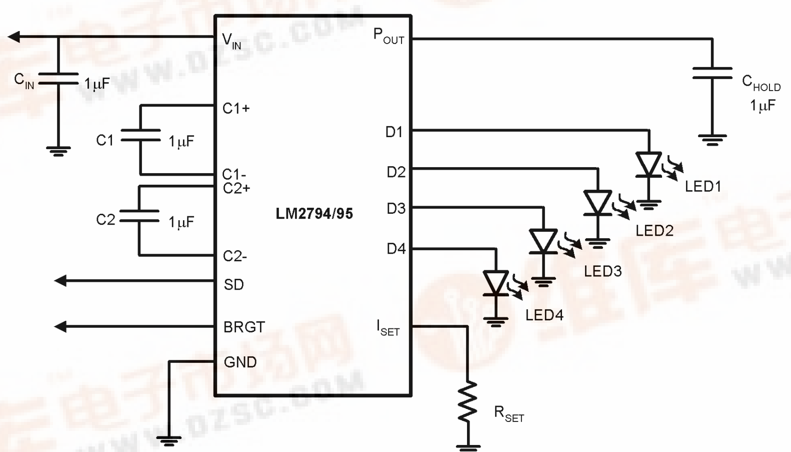
Features

- Regulated I_{OUT} with ±0.5% matching between any two outputs
- High efficiency 3/2 boost function
- Drives one, two, three or four white LEDs
- 2.7V to 5.5V Input Voltage
- Up to 80mA output current
- Soft start limits inrush current
- Analog brightness control
- Active-low or high shutdown input ('94/95)
- Very small solution size and no inductor
- 5µA (max.) shutdown current
- 325kHz switching frequency (min.)
- Linear regulation generates predictable noise spectrum
- micro SMD-14 package: 2.08mm X 2.403mm X 0.845mm

Applications

- White LED Display Backlights
- White LED Keypad Backlights
- 1-Cell Li-Ion battery-operated equipment including PDAs, hand-held PCs, cellular phones
- Flat Panel Displays

Basic Application Circuit



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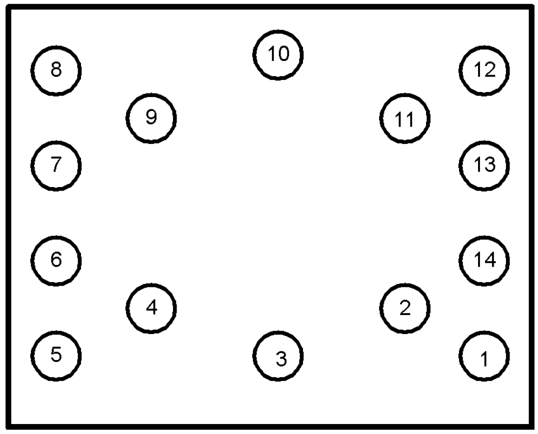
Connection Diagram



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Bottom View

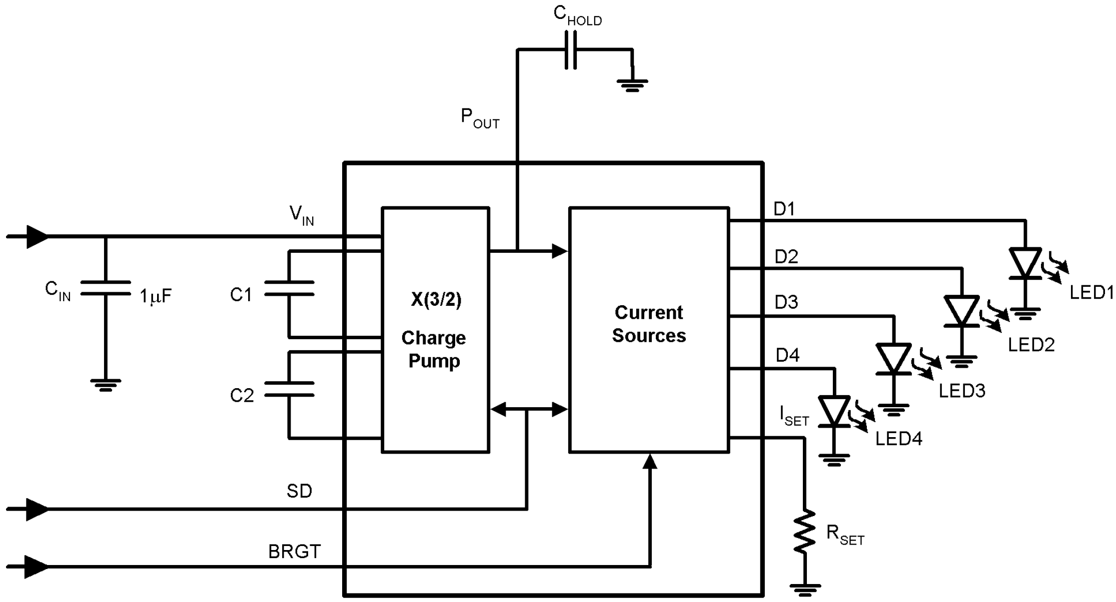
Ordering Information

Order Number	Shutdown Polarity	Package Number	Package Marking	Supplied As
LM2794BL	Active Low	BLP14EHB	I LOG	250 Units, Tape and Reel
LM2794BLX	Active Low	BLP14EHB	I LOG	3000 Units, Tape and Reel
LM2795BL	Active High	BLP14EHB	I LOJ	250 Units, Tape and Reel
LM2795BLX	Active High	BLP14EHB	I LOJ	3000 Units, Tape and Reel

Pin Description

Pin	Name	Function
1	C1+	Positive terminal of C1
2	C1−	Negative terminal of C1
3	V_{IN}	Power supply voltage input
4	GND	Power supply ground input
5	C2−	Negative terminal of C2
6, 7, 8, 9	D1−4	Current source outputs. Connect directly to LED
10	I_{SET}	Current Sense Input. Connect 1% resistor to ground to set constant current through LED
11	BRGT	Variable voltage input controls output current
12	SD	Shutdown input. On LM2795, a high level inhibits device operation. Internal pull-up current source allows open drain drive. On LM2794, a low level inhibits device operation
13	C2+	Positive terminal of C2
14	P_{OUT}	Charge pump output

Block Diagram



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Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

V_{IN}	−0.5 to 6.2V max
SD	−0.5 to (V_{IN}+0.3V) w/ 6.2V max
BRGT	−0.5 to (V_{IN}+0.3V) w/ 6.2V max
Power Dissipation (T_A = 25˚C (Note 2)	400 mW
T_{JMAX} (Note 2)	135˚C
θ_{JA} (Notes 2, 3)	125˚C/W
Storge Temperature	−65˚C to +150˚C
Lead Temp. (Soldering, 5 sec.)	260˚C
ESD Rating (Note 4)	
Human Body Model	2KV
Machine Model	200V

Operating Conditions

Input Voltage (V_{IN})	2.7V to 5.5V
Ambient Temperature (T_A)	−30˚C to +85˚C
Junction Temperature (T_J)	−30˚C to +125˚C

Electrical Characteristics

Limits in standard typeface are for T_J = 25˚C and limits in **boldface type** apply over the full **Operating Temperature Range**. Unless otherwise specified, C1 = C2 = C_{IN} = C_{HOLD} = 1 µF, V_{IN} = 3.6V, BRGT pin = 0V; R_{SET} =124Ω ; LM2794:V_{SD} = V_{IN} (LM2795: V_{SD} = 0V).

Symbol	Parameter	Conditions	Min	Typ	Max	Units
I_{DX}	Available Current at Output Dx	3.0V ≤ V_{IN} ≤ 5.5V V_{DX} ≤ 3.8V BRGT = 50mV	**15**	16.8		mA
		2.7V ≤ V_{IN} ≤ 3.0V V_{DX} ≤ 3.6V BRGT = 0V	10			mA
		V_{DX} ≤ 3.8V BRGT = 200mV	20			mA
V_{DX}	Available Voltage at Output Dx	3.0V ≤ V_{IN} ≤ 5.5V I_{DX} ≤ 15mA BRGT = 50mV	**3.8**			V
I_{DX}	Line Regulation of Dx Output Current	3.0V ≤ V_{IN} ≤ 5.5V V_{DX} = 3.6V	**14.18**	15.25	**16.78**	mA
		3.0V ≤ V_{IN} ≤ 4.4V V_{DX} = 3.6V	**14.18**	15.25	**16.32**	mA
I_{DX}	Load Regulation of Dx Output Current	V_{IN} = 3.6V 3.0V ≤ V_{DX} ≤ 3.8V	**14.18**	15.25	**16.32**	mA
$I_{D-MATCH}$	Current Matching Between Any Two Outputs	V_{IN} = 3.6V, V_{DX} = 3.6V		0.5		%
I_Q	Quiescent Supply Current	3.0V ≤ V_{IN} ≤ 4.2V, Active, No Load Current R_{SET} = OPEN		5.5	**8.2**	mA
I_{SD}	Shutdown Supply Current	3.0V ≤ V_{IN} ≤ 5.5V, Shutdown		2.3	**5**	µA
$I_{PULL-SD}$	Shutdown Pull-Up Current (LM2795)	V_{IN} = 3.6V		1.5		µA
V_{CP}	Input Charge-Pump Mode To Pass Mode Threshold			4.7		V
V_{CPH}	Input Charge-Pump Mode To Pass Mode Hysteresis	(Note 5)		250		mV
V_{IH}	SD Input Logic High (LM2794)	3.0V ≤ V_{IN} ≤ 5.5V	1.0			V
	SD Input Logic High (LM2795)		0.8V_{IN}			
V_{IL}	SD Input Logic Low (LM2794)	3.0V ≤ V_{IN} ≤ 5.5V			0.2	V
	SD Input Logic Low (LM2795)				0.2V_{IN}	
$I_{LEAK-SD}$	SD Input Leakage Current	0V ≤ V_{SD} ≤ V_{IN}		100		nA
R_{BRGT}	BRGT Input Resistance			240		kΩ

Electrical Characteristics (Continued)

Limits in standard typeface are for T_J = 25˚C and limits in **boldface type** apply over the full **Operating Temperature Range**. Unless otherwise specified, C1 = C2 = C_{IN} = C_{HOLD} = 1 µF, V_{IN} = 3.6V, BRGT pin = 0V; R_{SET} =124Ω ; LM2794:V_{SD} = V_{IN} (LM2795: V_{SD} = 0V).

Symbol	Parameter	Conditions	Min	Typ	Max	Units
I_{SET}	I_{SET} Pin Output Current			I_{DX}/10		mA
f_{SW}	Switching Frequency (Note 6)	3.0V ≤ V_{IN} ≤ 4.4V	**325**	515	**675**	kHz

Note 1: Absolute maximum ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its rated operating conditions.

Note 2: D1, D2, D3 and D4 may be shorted to GND without damage. P_{OUT} may be shorted to GND for 1sec without damage.

Note 3: The value of θ_{JA} is based on a two layer evaluation board with a dimension of 2in. x1.5in.

Note 4: In the test circuit, all capacitors are 1.0µF, 0.3Ω maximum ESR capacitors. Capacitors with higher ESR will increase output resistance, reduce output voltage and efficiency.

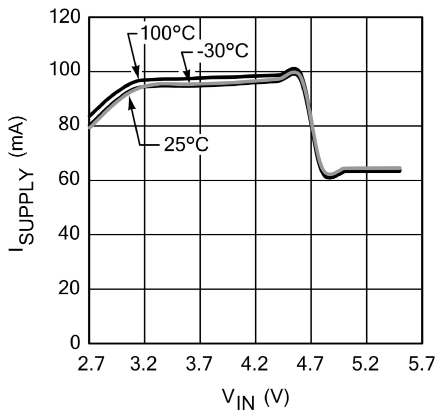
Note 5: Voltage at which the device switches from charge-pump mode to pass mode or pass mode to charge-pump mode. For example, during pass mode the device output (Pout) follows the input voltage.

Note 6: The output switches operate at one eigth of the oscillator frequency, f_{OSC} = 1/8f_{SW}.

Typical Performance Characteristics

Unless otherwise specified, C1 = C2 = C_{IN} = C_{HOLD} = 1µF, V_{IN} = 3.6V, BRGT pin = 0V, R_{SET} = 124Ω.

Supply Current with Load
ID 1-4 = 15mA



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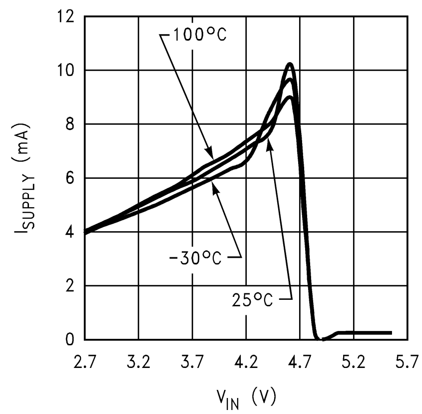
Supply Current with No Load



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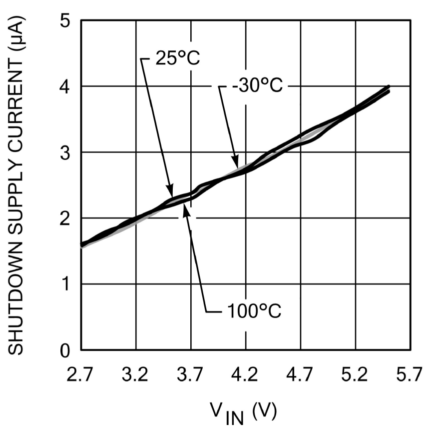
Shutdown Supply Current



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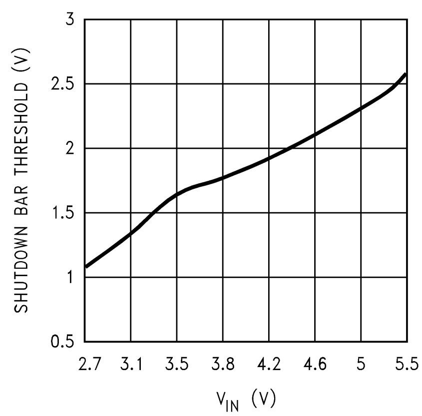
Shutdown Threshold vs V_{IN}



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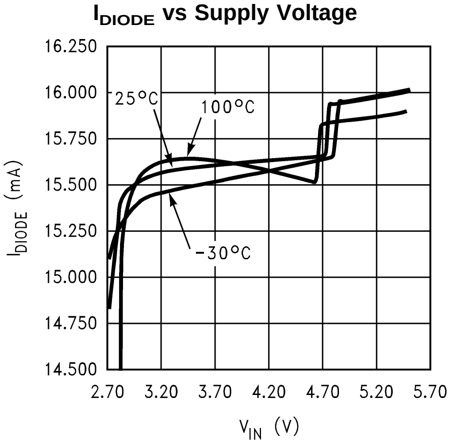
I_{DIODE} vs Supply Voltage



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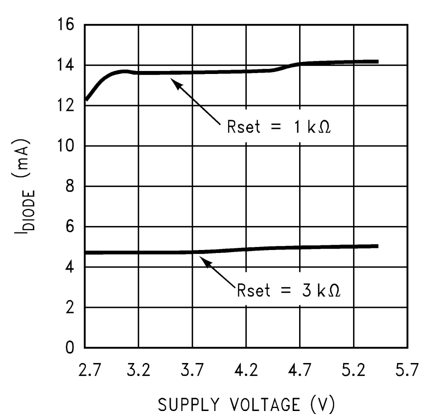
I_{DIODE} vs V_{IN} @ R_{SET} = 1KΩ, 3KΩ
BRGT =3V



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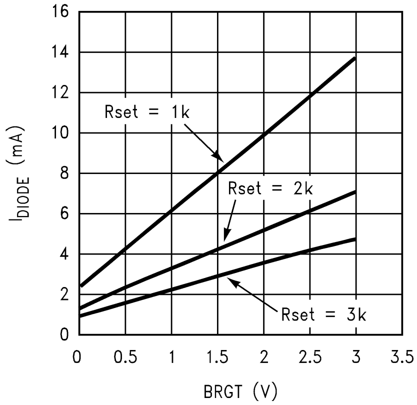
Typical Performance Characteristics
Unless otherwise specified, C1 = C2 = C_{IN} = C_{HOLD} = 1µF, V_{IN} = 3.6V, BRGT pin = 0V, R_{SET} = 124Ω. (Continued)

I_{DIODE} vs BRGT



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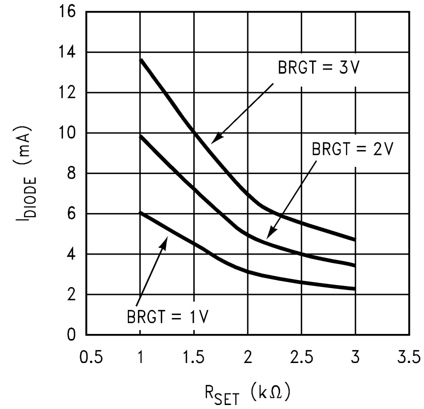
I_{DIODE} vs R_{SET}



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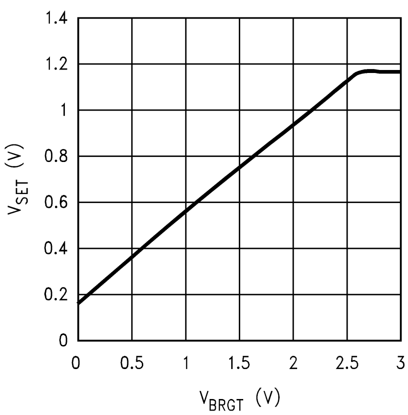
V_{SET} vs V_{BRGT}
R_{SET} = 1KΩ



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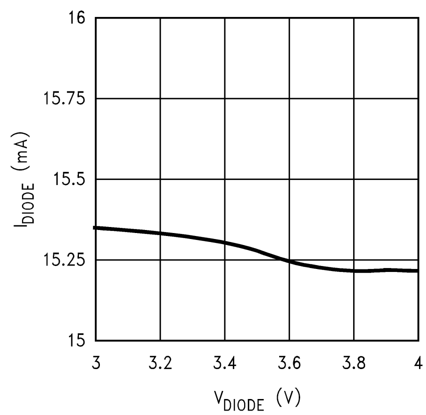
I_{DIODE} vs V_{DIODE}



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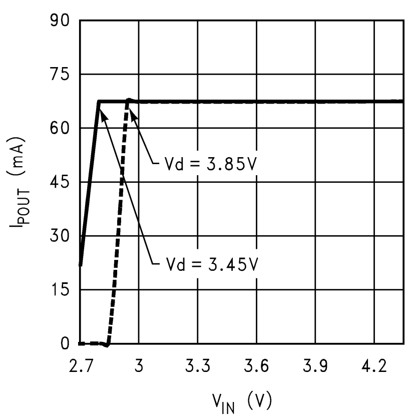
Available Additional Current @ P_{OUT}
ID 1− 4 = 15mA, R_{SET} = 124 ohms



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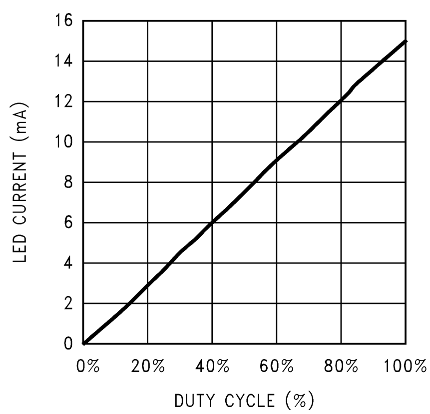
Duty Cycle vs. Led Current (LM2794)
ID 1- 4 = 15mA

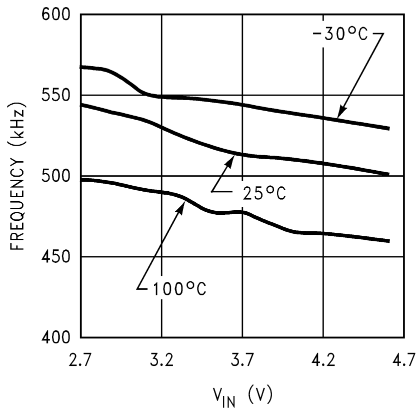


20028532

Typical Performance Characteristics

Unless otherwise specified, $C1 = C2 = C_{IN} = C_{HOLD} = 1\mu F$, $V_{IN} = 3.6V$, BRGT pin = 0V, $R_{SET} = 124\Omega$. (Continued)

Switching Frequency



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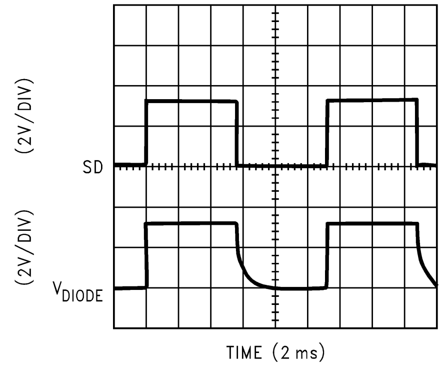
Start-Up Response @ 3.6V_{IN} (LM2794)



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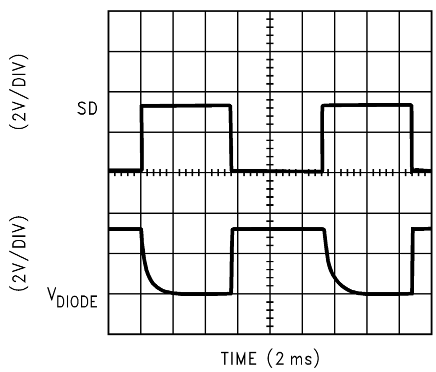
Start-Up Response @ 3.6V_{IN} (LM2795)



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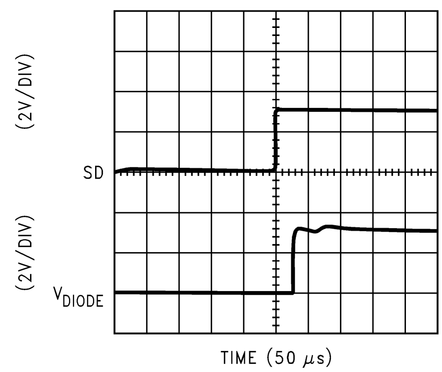
Start-Up Response @ 2.7V_{IN} (LM2794)



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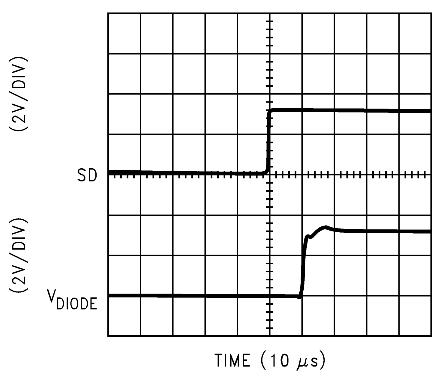
Start-Up Response @ 4.2V_{IN} (LM2794)



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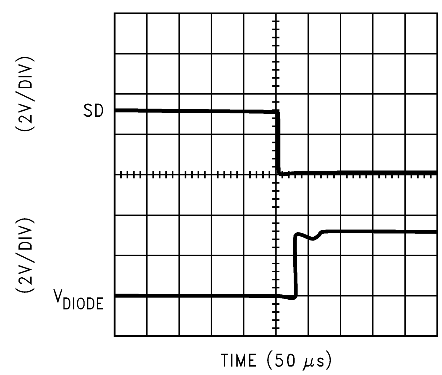
Start-Up Response @ 2.7V_{IN} (LM2795)



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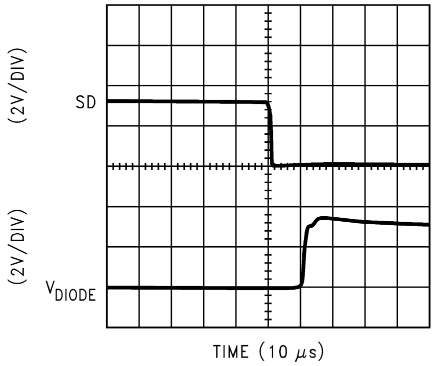
Typical Performance Characteristics

Unless otherwise specified, C1 = C2 = C_{IN} = C_{HOLD} = 1µF, V_{IN} = 3.6V, BRGT pin = 0V, R_{SET} = 124Ω. (Continued)

Start-Up Response @ 4.2V_{IN} (LM2795)



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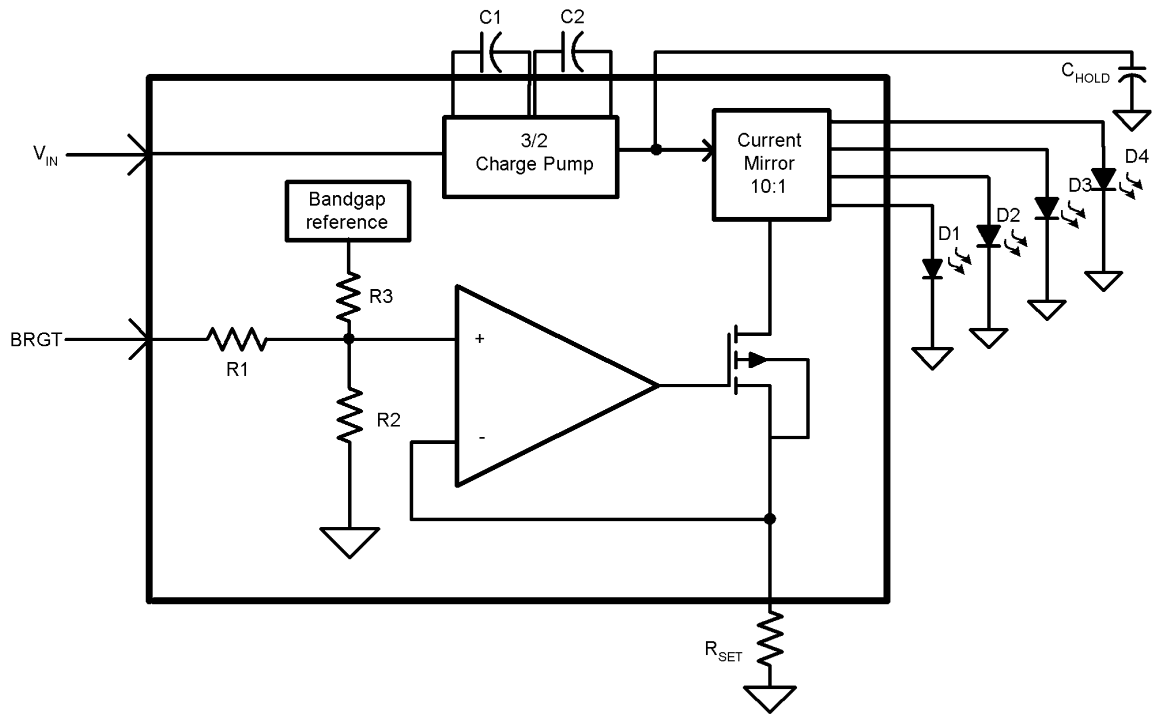
Circuit Description

The LM2794/5 employs a fractional charge-pump technique to step up the output voltage to 1.5 times the input voltage. The charge-pump provides the voltage that is needed by the four matched internal current sources to drive high forward voltage drop LEDs from Li-Ion battery sources. The part has on-chip current regulators which are composed of current mirrors with a 10 to 1 ratio. The mirrors control the LED current without using current limiting resistors in the LED current path. The device can drive up to a total of 80mA through the LEDs.

The LED brightness can be controlled by both analog and/or digital methods. The digital technique uses a PWM (Pulse Width Modulation) signal applied to the shutdown input. The analog technique applies an analog voltage to the brightness (BRGT) pin. Please refer to table 4 in the application information section for a quick reference table on BRGT voltage and R_{SET} selections. Futhermore, the LM2794/5 can be used for constant brightness by grounding the BRGT pin .

Functional Block Diagram



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Application Information

Soft Start

LM2794 includes a soft start function to reduce the inrush currents and high peak current during power up of the device. This is done to reduce stress on the LM2794/5 and external components. During soft start, the switch resistances limit the inrush current used to charge the flying and hold capacitors.

Shutdown Mode

A shutdown pin (SD or $\overline{SD}$) is available to disable the LM2794/5 and reduce the quiescent current to 5µA maximum.

During normal operation mode of the LM2794, applying an active high logic signal to the $\overline{SD}$ pin or tying the $\overline{SD}$ pin to V_{IN} will enable the device. Pulling $\overline{SD}$ low or connecting $\overline{SD}$ to ground will disable the device.

During normal operation mode of the LM2795, applying an active low logic signal to the SD pin or tying the SD pin to GND will enable the device. Pulling SD high or connecting SD to V_{IN} will disable the device.

Capacitor Selection

Low equivalent series resistance (ESR) capacitors such as X5R or X7R are recommended to be used for C_{IN}, C1, C2, and C_{HOLD} for best performance. Ceramic capacitors with less than or equal to 0.3 ohms ESR value are recommended for this application. *Table 1* below lists suggested capacitor suppliers for the typical application circuit.

TABLE 1. Low ESR Capacitor Manufactures

Manufacturer	Contact	website
TDK	(947) 803 6100	www.component.tdk.com
MuRata	(800) 831 9172	www.murata.com
Taiyo Yuden	(800) 348 2496	www.t-yuden.com

Application Information (Continued)

LED selection

The LM2794/5 are designed to drive LEDs with a forward voltage of about 3.0V to 3.8V. The typical and maximum V_F depends highly on the manufacturer and the technology. *Table 2* lists two suggested manufactures and example part numbers. Each supplier makes many LEDs that work well with the LM2794/5. The LEDs suggested below are in a surface mount package and TOPLED or SIDEVIEW configuration with a maximum forward current of 20mA. These diodes also come in SIDELED or SIDEVIEW configuration and various chromaticity groups. For applications that demand color and brightness matching, care must be taken to select LEDs from the same chromaticity group. Forward current matching is assured over the LED process variations due to the constant current output of the LM2794/5. For best fit selection for an application, consult the manufacturer for detailed information.

TABLE 2. White LED Selection:

Component	Manufacture	Contact
LWT673/LWT67C	Osram	www.osram-os.com
NSCW100/NSCW215	Nichia	www.nichia.com

I_{SET} Pin

An external resistor, R_{SET}, sets the mirror current that is required to provide a constant current through the LEDs. The current through R_{SET} and the LED is set by the internal current mirror circuitry with a ratio of 10:1 The currents through each LED are matched within 0.5%. R_{SET} should be chosen not to exceed the maximum current delivery capability of the device. *Table 3* shows a list of R_{SET} values when maximun BRGT = 3V is applied. For other BRGT voltages, R_{SET} can be calculated using this equation:

$$R_{SET} = ((0.188 + (0.385 \bullet BRGT)) / I_{SET}) \bullet 10$$

TABLE 3. R_{SET} Selections (when BRGT pin = 3V maximum)

I_{LED} per LED	*R_{SET} (+/-1%)
15mA	909Ω
10mA	1.4KΩ
5mA	2.67KΩ

* The Rset values are rounded off to the nearest 1% standard resistors

BRGT Pin

The BRGT pin can be used to smoothly vary the brightness of the White LEDs. In the LM2794/5, voltage on BRGT is connected to an internal resistor divider which gives a factor of 0.385 and summed with an offset voltage (188mV) from the bandgap (See Functional Block Diagram). This voltage is fed to the operational amplifier that controls the current through the mirror resistor R_{SET}. The nominal range on BRGT is 0V to 3V.

Care must be taken to prevent voltages on BRGT that cause LED current to exceed a total of 80 mA. Although this will not cause damage to the IC, it will not meet the guaranteed specifications listed in the Electrical Characteristics. *Table 4* shows the current through each LED for the LM2794/5 with various BRGT and R_{SET} values using I_{LED} equation below.

TABLE 4. LED Current When Using BRGT Input (Values Highlighted in Boldface exceeded maximum current range of the device)

R_{SET} (Ω)	124Ω	500Ω	900Ω	1750Ω
V_{BRGT} (V)	I_{LED} (mA)	I_{LED} (mA)	I_{LED} (mA)	I_{LED} (mA)
0.0	15.16	3.76	2.09	1.07
0.5	**30.69**	7.61	4.23	2.17
1	**46.21**	11.46	6.37	3.27
1.5	**61.73**	15.31	8.51	4.37
2	**77.26**	19.16	10.64	5.47
2.5	**92.78**	**23.01**	12.78	6.57
3	**108.31**	**26.86**	14.92	7.67

Calculation of LED Current When Using BRGT :

$V_{IN} = 3.6V$

$R_{SET} = 1000\Omega$, BRGT = 3V

$I_{LED} = ((V_{OFFSET} + (0.385 \bullet BRGT))/1000) \bullet 10$

$I_{LED} = ((0.188 + (0.385 \bullet 3)) / 1000) \bullet 10 = 13.4mA$

Brightness Control using PWM

Brightness control can be implemented by pulsing a signal at the SD pin. The recommended frequency is between 100Hz to 1kHz. If the PWM frequency is much less than 100Hz, flicker may be seen in the LEDs. Likewise, if frequency is much higher, brightness in the LEDs will not be linear. When a PWM signal is used to drive the SD pin of the LM2794/5, connect BRGT pin to GND. The R_{SET} value is then selected using the above I_{SET} equation when BRGT = 0V. The brightness is controlled by increasing and decreasing the duty cycle of the PWM signal. Zero duty cycle will turn off the LED and a 50% duty cycle waveform produces an average current of 7.5mA if R_{SET} is set to produce a maximum LED current of 15mA. So the LED current varies linearly with the duty cycle.

Pout

The charge-pump output voltage (Pout) on the LM2794/5 can be used to deliver additional current to other circuitry if desired. The available current from Pout depends on the total LED current consumed and the diode forward voltage. The graph on page 7 (typical performance) shows the additional available output current from Pout when all four diodes are consuming a total current of 60mA. The graph shows that the available additional current from Pout will vary with diode forward voltage. Moreover, if the total diode current is reduced below 60mA, then more current will be available from Pout. It is imperative not to exceed the maximum power dissipation of the device when Pout is used to power addi-

Application Information (Continued)

tional circuitry in an application. Note that the Pout voltage is not regulated, and will thus be equal to 1.5 times the input voltage. It is possible to regulate the output voltage of the LM2794/5 by using a Linear Dropout Regulator (LDO) such as the LP3985-series LDOs.

Thermal Protection

The LM2794/5 has internal thermal protection circuitry to disable the charge pump if the junction temperature exceeds 150˚C. This feature will protect the device from damage due to excessive power dissipation. The device will recover and operate normally when the junction temperature falls below the maximum operating junction temperature of 125˚C. It is important to have good thermal conduction with a proper layout to reduce thermal resistance.

Power Efficiency

The efficiency of the LM2794/5 is calculated by dividing the output power by the input power. This is shown in the following equation:

$$\text{Efficiency} = (V_{D1} \bullet I_{D1} + V_{D2} \bullet I_{D2} + V_{D2} \bullet I_{D3} + V_{D4} \bullet I_{D4}) / (V_{IN} \bullet I_{SUPPLY})$$

Where V_{DX} is the corresponding diode voltage and I_{DX} is the corresponding diode currrent.

An approximation of the efficiency for the LM2794/95 is given as:

$$\text{Efficiency} = (V_{D(AVG)} \bullet 4I_{D(AVG)}) / 3/2V_{IN} \bullet 4I_{D(AVG)} = V_{D(AVG)} / (3/2\ V_{IN})$$

where $V_{D(AVG)}$ is the average diode and $I_{D(AVG)}$

It is clear that the efficiency will depend on the supply voltage in the above equation. As such, the lower the supply voltage, the higher the efficiency.

Power Dissipation

The maximum allowable power dissipation that this package is capable of handling can be determined as follows:

$$P_{DMax} = (T_{JMax} - T_A) / \theta_{JA}$$

where T_{JMax} is the maximum junction temperature, T_A is the ambient temperature, and θ_{JA} is the junction-to-ambient thermal resistance of the specified package.

The actual power dissipation of the device can be calculated using this equation:

$$P_{Dissipation} = (3/2\ V_{IN} - V_{DIODE}) \bullet I_{LOAD}$$

As an example, if V_{IN} in the target application is 4.2V, V_{DIODE} = 3.0V and worse case current consumption is 60mA (15mA for each diode).

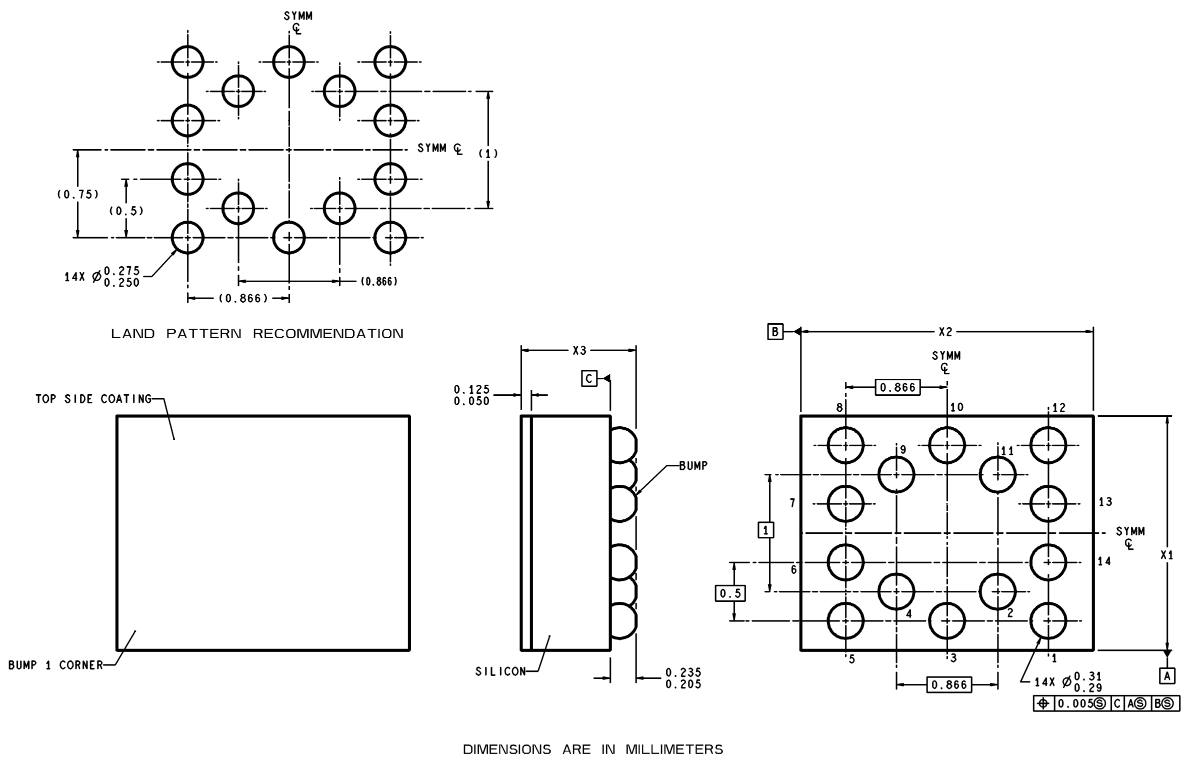
$$P_{Dissipation} = ((1.5 \bullet 4.2) - 3.0) \bullet 0.06 = 198\text{mW}$$

Power dissipation must be less than that allowed by the package. Please refer to the Absolute Maximum Rating of the LM2794/5.

Micro SMD Mounting

The LM2794/5 is a 14-bump micro SMD with a bump size of 300 micron. The micro SMD package requires specific mounting techniques which are detailed in National Semiconductor Application Note (AN -1112). NSMD (non-solder mask defined) layout pattern is recommended over the SMD (solder mask defined) since the NSMD requires larger solder mask openings over the pad size as opposed to the SMD. This reduces stress on the PCB and prevents possible cracking at the solder joint. For best results during assembly, alignment ordinals on the PC board should be used to faciliate placement of the micro SMD device. Micro SMD is a wafer level chip size package which means the dimensions of the package is equal to the die size. As such, the micro SMD package are lacks the plastic encapsulation characteristic of the larger devices and ; it is sensitive to direct exposure to sun light and light sources such as infrared light and halogen light. These wavelenghts may cause unpreditabled operation.

Physical Dimensions inches (millimeters) unless otherwise noted



BLA14XXX (Rev A)

For Ordering, Refer to Ordering Information Table
NS Package Number BLP14
The dimensions for X1, X2, X3 are given as:
X1 = 2.08mm ± 0.03mm
X2 = 2.403mm ± 0.03mm
X3 = 0.845mm ± 0.01mm

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