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Automotive Backlight LED Drivers

ABSTRACT

The LP886x-Q1 family of LED drivers from TI can be configured as boost or SEPIC topology in various automotive backlight applications in infotainment, cluster and Central Information Displays (CID). Throughout this document, LP886x-Q1 refers to the following devices: LP8863-Q1, LP8864S-Q1, LP8864-Q1, LP8866S-Q1, and LP8866-Q1. LP886x-Q1 has adaptive output voltage control based on headroom voltage of LED current sink. They also have incorporated an 11-bit current DAC to achieve wide range of output voltage by dynamically adjusting current sinking from feedback pin. Feedback resistor values are crucial to set suitable boost output voltage range for driving LED string with forward voltage variations. This application note provides the design considerations for selecting proper feedback resistor values for LP886x-Q1.

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1 Introduction

Unlike the conventional constant voltage boost controller that uses feedback resistor network to set one regulated voltage, the feedback network of LP886x-Q1 is used to determine the minimum and maximum voltages at boost output. In the actual application, the boost output voltage is adjusted dynamically by an internal 11-bit current DAC to the minimum necessary level needed by the output channels to achieve optimum efficiency. Boost UVP and OVP levels are also defined by the feedback network and appropriate feedback resistor values need to be chosen to prevent false triggering of UVP and OVP faults.

2 Boost Output Voltage Range Design Consideration

Feedback resistors are selected to ensure that the minimum boost voltage with $I_{SEL} = 0 \mu\text{A}$ is below the minimum LED string voltage, as shown in [Equation 1](#). The maximum boost voltage with $I_{SEL} = 38.7 \mu\text{A}$ need to be at least 2 V greater than the maximum LED string voltage + the maximum headroom at LED sink pins as shown in [Equation 2](#).

$$V_{\text{MINBOOST}} < V_{\text{STRING,MIN}} \quad (1)$$

$$V_{\text{MAXBOOST}} > (V_{\text{STRING}} + V_{\text{HEADROOM}})_{\text{MAX}} + 2 \text{ V} \quad (2)$$

Where:

- – V_{MINBOOST} is the minimum boost voltage when $I_{SEL} = 0 \mu\text{A}$ (minimum)
- V_{MAXBOOST} is the maximum boost voltage when $I_{SEL} = 38.7 \mu\text{A}$ (maximum)
- V_{STRING} is the voltage across LED string
- V_{HEADROOM} is the headroom voltage of LED current sink and can be substituted with 1 V in [Equation 2](#)
- 2 V in [Equation 2](#) is an empirical design margin considering the variations of internal reference and the tolerance of feedback resistors.

3 Boost UVP Design Consideration

When $V_{\text{BOOST_UVP}}$ is reached, in other words, when V_{FB} is below V_{UVP} of 0.886 V, it is a sign that the boost is no longer in regulation. During normal operation, V_{FB} is regulated at V_{BG} of 1.21 V. If undervoltage condition lasts longer than 110 ms, LP8863-Q1 (using LP8863-Q1 as an example and it is similar for LP886x-Q1) will report boost overcurrent, by generating fault interrupt and asserting BSTOCP_STATUS bit in $\text{INTERRUPT_STATUS_1}$ register, as shown in [Table 3-1](#). The device will go to standby for 200 ms before restart attempt. If $V_{\text{BOOST_UVP_MAX}}$ (when I_{SEL} is at maximum value) level is lower than $(V_{\text{STRING}} + V_{\text{HEADROOM_MAX}})$, open LED fault may be reported unintentionally instead of overcurrent fault during an overcurrent event. Therefore, we recommend to design the maximum boost UVP threshold $V_{\text{BOOST_UVP_MAX}}$ when the current DAC I_{SEL} is at maximum value, higher than $V_{\text{STRING_MAX}} + V_{\text{HEADROOM_MAX}}$, as shown in [Equation 3](#). The aim is to prevent false triggering of LED open fault during an overcurrent event when boost under voltage is detected.

$$V_{\text{BOOST_UVP_MAX}} > (V_{\text{STRING}} + V_{\text{HEADROOM}})_{\text{MAX}} \quad (3)$$

Table 3-1. Boost OCP, OVP and Open LED Fault Table

FAULT NAME	CONDITION	ACTION
Boost overcurrent	FB pin voltages falls below V_{UVP} level for > 110 ms.	Device goes to standby and then attempts to restart 200 ms after fault occurs.
Open LED string	Headroom voltage on one or more channels is below minimum level and boost has adapted to maximum level.	Faulted LED string is disabled and removed from adaptive boost control loop. String is re-enabled next power cycle.
Boost OVP low	FB pin voltage rises above $V_{\text{FB_OVPL}}$ level.	Boost stops switching until boost voltage level falls. The device remains in normal mode with LED drivers operational.
Boost OVP high	FB pin voltage rises above $V_{\text{FB_OVPH}}$ level or DISCHARGE pin voltage rises above $V_{\text{BST_OVPH}}$.	Device goes to Fault Recovery and waits until output voltage falls below threshold before restarting.

4 Boost OVP Design Consideration

When the voltage of DISCHARGE pin is higher than $V_{\text{BOOST_OVPH}}$ (typically 50 V, minimum 48.5 V for LP8866-Q1), boost OVP high fault will be reported and device will go to fault recovery until boost voltage falls below threshold before restarting, as shown in [Table 3-1](#). Be careful when designing boost OVP low threshold of initial voltage considering the overshoot during start-up. The boost OVP low threshold of initial voltage should be designed to be triggered first before DISCHARGE pin reaching $V_{\text{BOOST_OVPH}}$. Otherwise, boost OVP high fault will be reported if DISCHARGE pin reaches 48.5 V during start-up. Then the device will go to fault recovery mode and restart again and again. Therefore, we recommend to design $V_{\text{BOOST_OVP_LOW_INITIAL}} < 48$ V, as shown in [Equation 4](#).

$$V_{\text{BOOST_OVP_LOW_INITIAL}} < 48 \text{ V} \quad (4)$$

Where:

- $V_{\text{BOOST_OVP_LOW_INITIAL}}$ is the boost OVP Low threshold for initial voltage during start up
- 48 V is 0.5 V (additional margin) below the minimum $V_{\text{BOOST_OVPH}}$.

5 Calculation of Feedback Resistor Values

The resistive divider (R_{FB1} , R_{FB2} , R_{FB3}) defines both the minimum and maximum adaptive boost voltage levels, as well as UVP and OVP levels. For feedback network using two-resistor method as shown in [Figure 5-1](#), $V_{MINBOOST}$, $V_{MAXBOOST}$, $V_{BOOST_UVP_MAX}$, $V_{BOOST_OVP_LOW}$ and V_{STRING} can be expressed in [Equation 5](#), [Equation 6](#), [Equation 7](#), [Equation 8](#), and [Equation 9](#):

$$V_{MINBOOST} = \left(\frac{V_{BG}}{R_{FB2}} \right) \times R_{FB1} + V_{BG} \quad (5)$$

$$V_{MAXBOOST} = \left(\frac{V_{BG}}{R_{FB2}} + I_{SEL_MAX} \right) \times R_{FB1} + V_{BG} \quad (6)$$

$$V_{BOOST_UVP_MAX} = \left(\frac{V_{UVP}}{R_{FB2}} + I_{SEL_MAX} \right) \times R_{FB1} + V_{UVP} \quad (7)$$

$$V_{BOOST_OVP_LOW_INITIAL} = \left(\frac{V_{OVPL}}{R_{FB2}} + 0.886 \times I_{SEL_MAX} \right) \times R_{FB1} + V_{OVPL} \quad (8)$$

$$V_{STRING} = n \times V_{LED} \quad (9)$$

where:

- V_{BG} is the band-gap voltage = 1.21 V
- R_{FB1} is the upper feedback resistor
- R_{FB2} is the lower feedback resistor
- I_{SEL_MAX} is the maximum internal 11-bit DAC current $I_{SEL} = 38.7 \mu A$
- V_{UVP} is the undervoltage threshold at feedback pin = 0.886 V
- V_{OVPL} is the overvoltage low level at feedback pin = 1.423 V
- 0.886 is the ratio of initial I_{SEL} DAC current with respect to I_{SEL_MAX} to set initial boot voltage during start-up
- V_{LED} is the voltage cross an LED
- n is the number of LEDs in a string

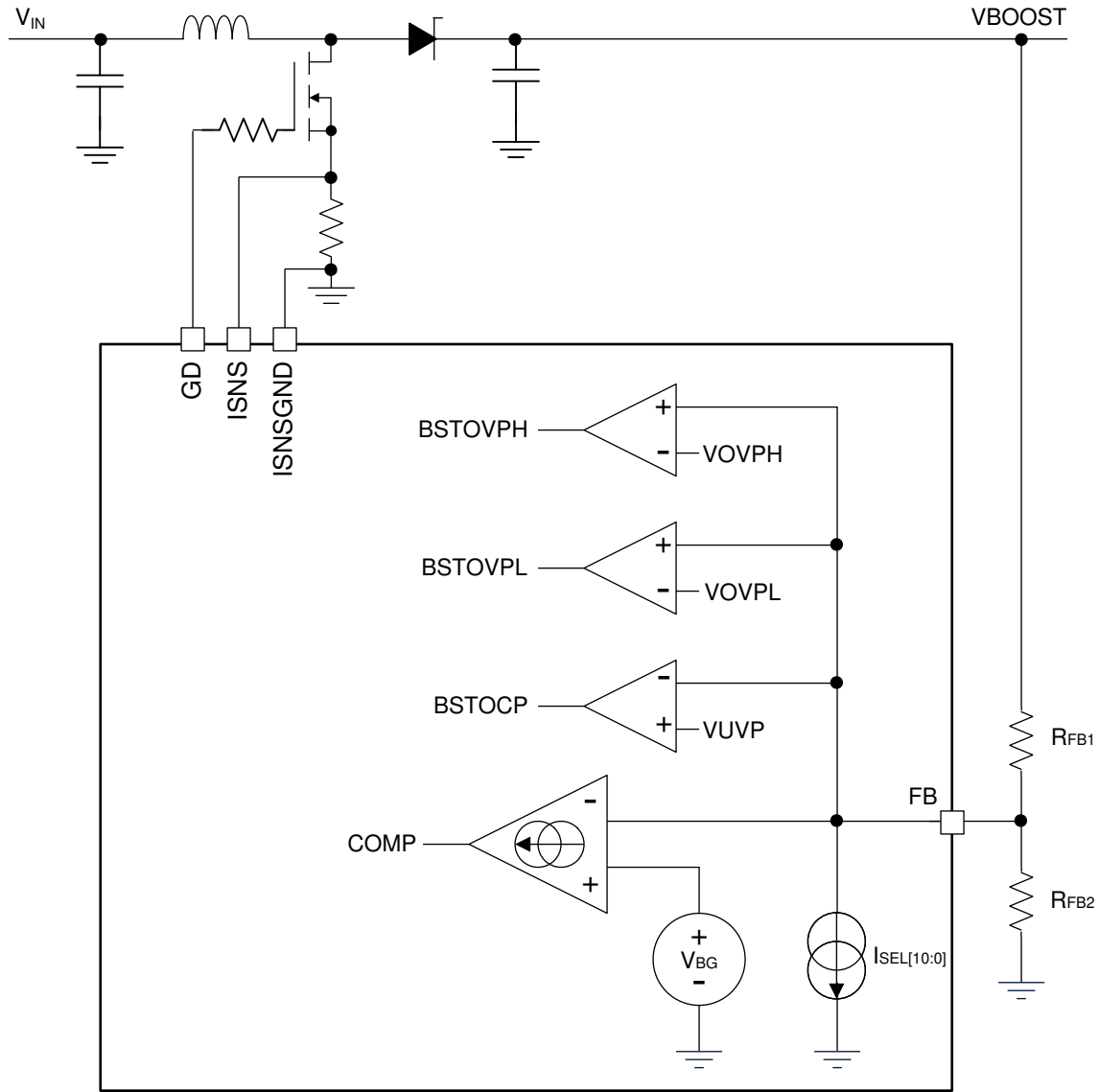


Figure 5-1. Two-Resistor Feedback Network

For feedback network using three-resistor method as shown in [Figure 5-2](#), $V_{MINBOOST}$, $V_{MAXBOOST}$, $V_{BOOST_UVP,MAX}$ and $V_{BOOST_OVP_LOW}$ can be expressed in [Equation 10](#), [Equation 11](#), [Equation 12](#), and [Equation 13](#):

$$V_{MINBOOST} = \left(\frac{V_{BG}}{R_{FB2}} \right) \times R_{FB1} + V_{BG} \quad (10)$$

$$V_{MAXBOOST} = \left(\frac{V_{BG}}{R_{FB2}} + I_{SEL_MAX} \right) \times R_{FB1} + V_{BG} + I_{SEL_MAX} \times R_{FB3} \times \left(1 + \frac{R_{FB1}}{R_{FB2}} \right) \quad (11)$$

$$V_{BOOST_UVP,MAX} = \left(\frac{V_{BG}}{R_{FB2}} + I_{SEL_MAX} \right) \times R_{FB1} + V_{UVP} + I_{SEL_MAX} \times R_{FB3} \times \left(1 + \frac{R_{FB1}}{R_{FB2}} \right) \quad (12)$$

$$V_{\text{BOOST_OVP_LOW_INITIAL}} = \left(\frac{V_{\text{OVPL}}}{R_{\text{FB2}}} + 0.886 \times I_{\text{SEL_MAX}} \right) \times R_{\text{FB1}} + V_{\text{OVPL}} + 0.886 \times I_{\text{SEL_MAX}} \times R_{\text{FB3}} \times \left(1 + \frac{R_{\text{FB1}}}{R_{\text{FB2}}} \right) \quad (13)$$

where:

- R_{FB3} is the third feedback resistor can be used in applications where less than 200-k Ω resistors are required.

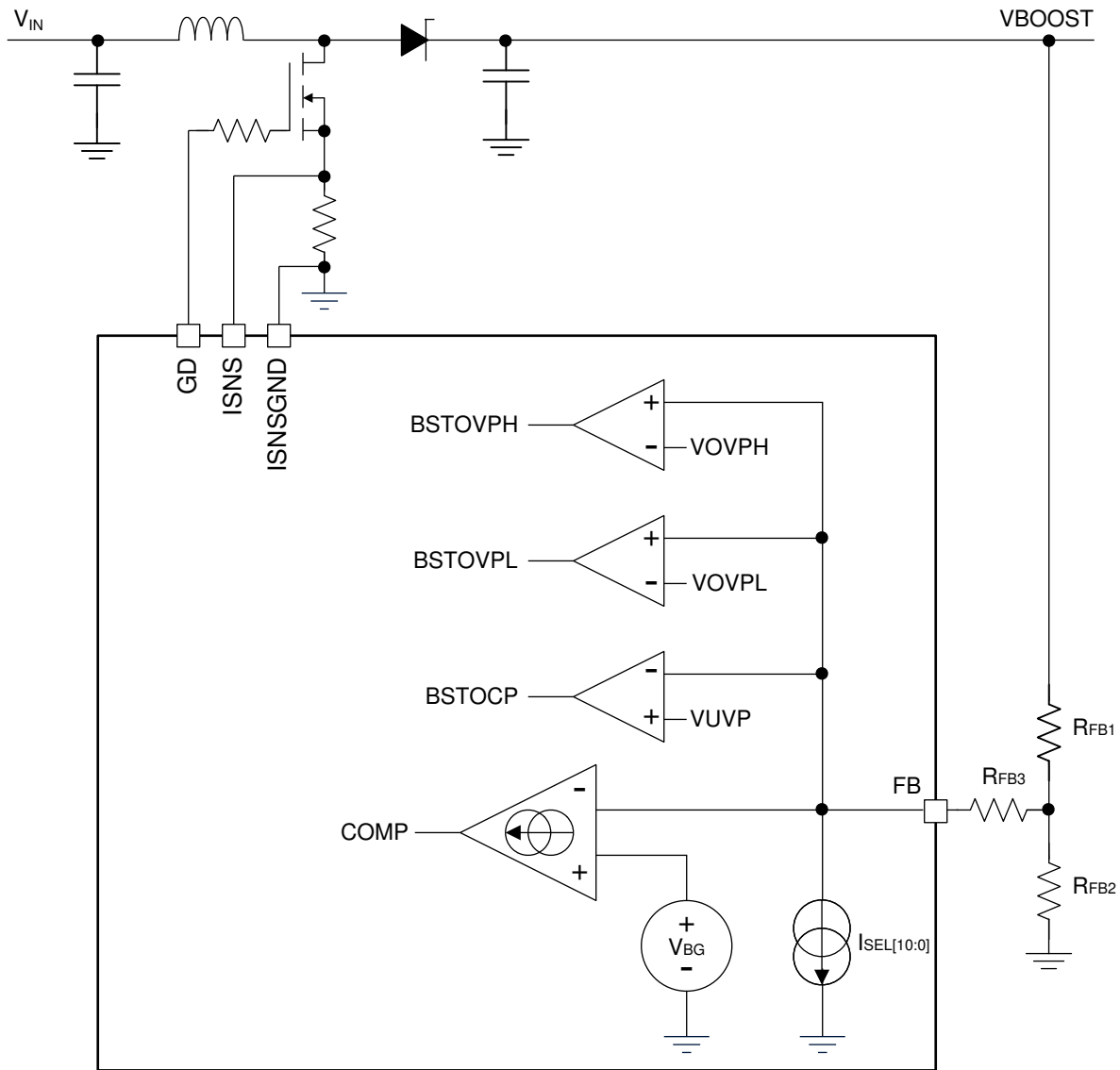


Figure 5-2. Three-Resistor Feedback Network

6 Feedback Resistor Calculation Example

Using the 2-resistor network as an example, the feedback resistors calculation can be found from the product folder. The same calculator can also be used for 3-resistor network calculation by simply setting $R_{FB3} = 0 \Omega$.

In this example, there are 8 LEDs in a string, with forward voltage drop varies from 3.1 V to 3.4 V. The worst-case $V_{STRING,MIN}$ and $(V_{STRING} + V_{HEADROOM,MAX}) + \text{Design Margin}$ can be calculated as 24.8 V and 30.2 V, respectively, in [Table 6-1](#).

Table 6-1. LED String Calculation

DESIGN PARAMETER	VALUE	UNIT
Number of LEDs in one string	8	S
Min LED Forward Voltage $V_{F,MIN}$	3.1	V
Max LED Forward Voltage $V_{F,MAX}$	3.4	V
Min Headroom $V_{HEADROOM,MIN}$	0.4	V
Max Headroom $V_{HEADROOM,MAX}$	1.0	V
Design Margin for reference and feedback resistor variations	2.0	V
$V_{STRING,MIN}$	24.8	V
$V_{STRING,MAX}$	28.2	V
$(V_{STRING,MAX} + V_{HEADROOM,MAX}) + \text{Design Margin}$	30.2	V

Assuming 1% feedback resistors are used, select feedback resistor values to meet the worst-case conditions listed in [Equation 1](#), [Equation 2](#), [Equation 3](#), and [Equation 4](#). In this example, with $R_{FB1} = 620 \text{ k}\Omega$ and $R_{FB2} = 56 \text{ k}\Omega$, the calculated $V_{MINBOOST} = 14.61 \text{ V}$ ($< 24.8 \text{ V}$) and $V_{MAXBOOST} = 38.60 \text{ V}$ ($> 30.2 \text{ V}$) are able to cover the voltage range of LED string, as shown in [Table 6-2](#).

Table 6-2. VBoost Calculation

DESIGN PARAMETER	VALUE	UNIT
R_{FB1} (1%)	620	$\text{k}\Omega$
R_{FB2} (1%)	56	$\text{k}\Omega$
R_{FB3} (1%)	0	$\text{k}\Omega$
I_{SEL_MAX}	38.7	μA
V_{bg}	1.21	V
$V_{MINBOOST}$ (V)	14.61	V
$V_{MAXBOOST}$ (V)	38.60	V

With V_{UVP} of 0.886 V, the calculated $V_{BOOST_UVP,MAX} = 34.69 \text{ V}$ as shown in [Table 6-3](#), which is above 28.2 V so that LED open fault will not get false triggered during boost UVP event.

Table 6-3. VBoost_UVP,MAX Calculation

DESIGN PARAMETER	VALUE	UNIT
V_{UVP}	0.886	V
$V_{BOOST_UVP,MAX}$	34.69	V

With V_{OVPL} of 1.423 V, the calculated $V_{BOOST_OVP_LOW} = 38.44 \text{ V}$ as shown in [Table 6-4](#), which is below 48 V so that boost OVP low fault will always be reported before boost OVP High Fault.

Table 6-4. VBoost_OVP_LOW Calculation

DESIGN PARAMETER	VALUE	UNIT
V_{OVPL}	1.423	V
$V_{BOOST_OVP_LOW}$	38.44	V

7 References

- Texas Instruments, [LP8863-Q1 Automotive Display LED-Backlight Driver With Six 150-mA Channels Data Sheet](#)
- Texas Instruments, [LP8864-Q1 Automotive Display LED-backlight Driver with Four 200-mA Channels Data Sheet](#)
- Texas Instruments, [LP8864S-Q1 Automotive Display LED-backlight Driver with Four 150-mA Channels Data Sheet](#)
- Texas Instruments, [LP8866-Q1 Automotive Display LED-backlight Driver with Six 200-mA Channels Data Sheet](#)
- Texas Instruments, [LP8866S-Q1 Automotive Display LED-backlight Driver with Six 150-mA Channels Data Sheet](#)
- Texas Instruments, [LP8863-Q1 External Component Selection Guide Application Report](#)

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