Application Note

Using Pre-Boost for More Robust Design of Automotive Display Modules With Global Dimming LED Drivers

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ABSTRACT

This application note introduces pre-boost designs for automotive display applications which can make the system more robust. Depending on the original equipment manufacturer (OEM) requirement of the vehicle, normal operation should be verified under low battery voltage condition such as 6V due to cranking and auto-start conditions using a typical 12V car battery. Take care to achieve normal operation under low voltage condition in real designs, considering system level challenges. Designers can make the system more robust by using pre-boost. LM5152-Q1 is a synchronous boost controller which can function as pre-boost controller if the battery voltage is low. This application note uses a design example using LP8866(S)-Q1 which is TI's automotive global dimming LED driver according to display market trends.

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1 Introduction

The large size of automotive displays is getting more popular in the market. Figure 1-1 shows the 30 inch display from GM which has integrated cluster and CID as an example. Some OEMs use pillar-to-pillar display which is an ultra-wide automotive display that spans the entire width of the dashboard of the vehicle. As the automotive panel size increases in size, more LEDs are used in the backlight. This means the power requirement increases and more LED drivers are required. The loss across long PCB pattern increases since the PCB size increases.

Figure 1-1. GM 30" Automotive Display

This trend can challenge tier-1s and panel makers to deal with low battery conditions according to the battery profile. The LED driver must light up normally even under 6V depending on the requirements of the OEM. The traditional block diagram of the display module is shown in Figure 1-2 as an example focusing on LED driver power design excluding peripherals. Table 1-1 lists the design requirements for one piece of the LED driver considering the LED specifications.

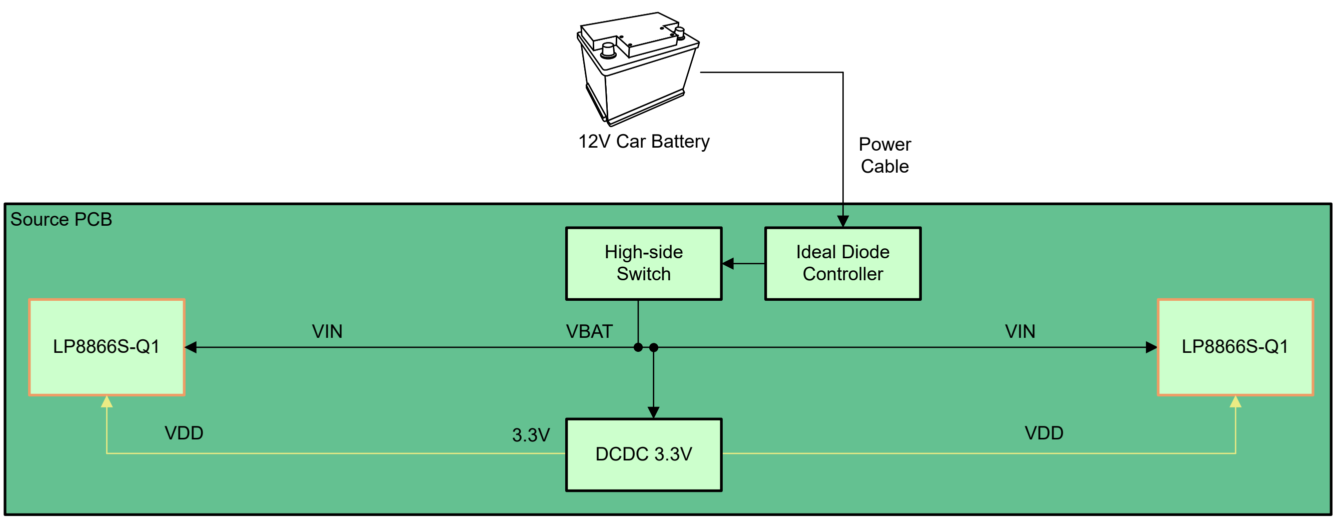

Figure 1-2. Traditional Block Diagram of a Display Module

Table 1-1. LED Specifications for Each LED Driver

Parameter	Value	Unit	Note
$V_{IN(MIN)}$	6	V	
$V_{IN(MAX)}$	26.5	V	
Maximum Forward Voltage, $V_{F(MAX)}$	3.6	V	LED Characteristic
Forward Current in one LED String Group, $I_{F(MAX)}$	80	mA	
Number of LEDs in one string	10	S	
Total number of LED sink channels used	6	Ch	
Maximum Required V_{out}, $VOUT_{(MAX)}$	37	V	Considering 1V margin due to headroom voltage
Max Output Power, P_{OUT_MAX}	17.76	W	
Max input current, I_{IN_MAX}	3.48	A	
Max input power, P_{IN_Max}	20.9	W	Need to consider system worst efficiency
System worst efficiency	85	%	

In this system example, input current increases significantly under a low voltage condition since the LED driver operates as a boost converter. The large input current causes a substantial voltage drop across the power cable, high-side switch, ideal diode due to losses. Eventually input voltage on PCB becomes smaller which requires even more current. This vicious cycle can make the system vulnerable to unexpected protection features such as UVLO even though LED driver can even support low input voltage condition. The pre-boost can help designers address this challenge in the system level.

2 Expected System Challenges Without Pre-Boost

2.1 Undervoltage Protection of High-Side Switch

As shown in Figure 1-2, there is a high-side switch to supply system power including LED drivers. Most high-side switch ICs have UVLO protection. This usually covers the voltage range considering cranking voltage such as 6V or 4.5V. However, the actual voltage level on the high-side switch can be lower than the acceptable voltage level since the long PCB pattern, power cable, ideal diode and others cause the voltage drop.

Because LED drivers work as boost converter, a lower input voltage results in a larger input current. This is worse in this system example which requires two LED drivers since the drivers draw much larger current as described in the Section 1. In such cases, the high-side switch can trigger unexpected UVLO protection which can cause power supply issues since the high-side switch usually shutdown under protection. Figure 2-1 and Figure 2-2 shows the waveforms under VIN transient condition from 12V to 6V considering cranking event. In the plots, VIN on LED driver is the red line, inductor current is the pink line and VDD on LED driver is the green line. When VIN drops to 6V, IL increases dramatically and causes the VIN on the LED driver to drop well below 6V.

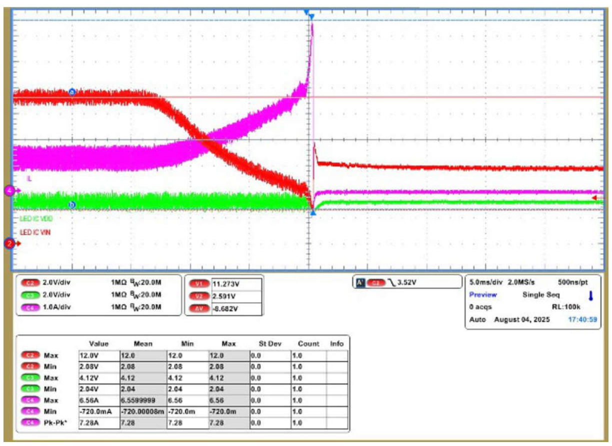

Figure 2-1. LED_VIN and LED_VDD and I_L During a VIN Transient 12V to 6V

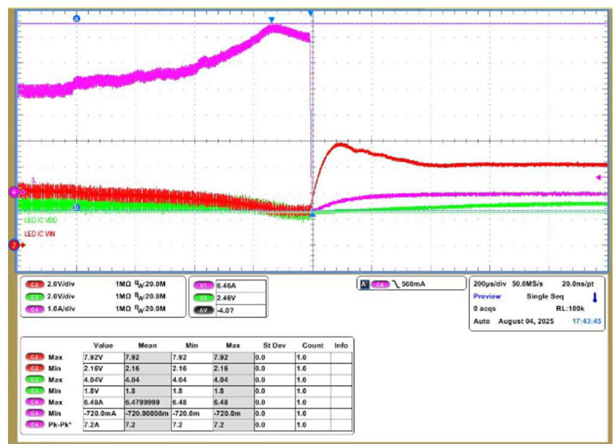

Figure 2-2. LED_VIN and LED_VDD and I_L During a VIN Transient 12V to 6V (Zoomed-in)

As expected, the voltage at high-side switch is already much lower than 6V due to losses. The high-side switch triggered UVLO, which causes shutdown. Therefore, the inductor current is reduced even though the LED driver is still switching with reduced input voltage as shown in Figure 2-2. If this happened in the real system, users experience a display shutdown during the cranking condition. To avoid this unexpected risk, designer must use the high-side switch which has much bigger margin on protections such as UVLO. However, this can increase cost and makes achieving precise protections difficult.

2.2 System Bias Power Interruption

If the high-side switch shuts down unexpectedly, all DC/DC converters that supply LED drivers, MCU, FPD-link and others also shut down. This can trigger VDD undervoltage protection in LED driver IC LP8866(S)-Q1 as DC/DC supplying VDD shuts down even though the LED driver supports low voltage condition. If the VDD falls below VDDUVLO falling level during device operation, IC stops switching and LED outputs are turned off, and the device enters STANDBY mode. The VDDUVLO_STATUS fault bit is set in the SUPPLY_FAULT_STATUS register, and the INT pin is triggered. The LP8866S-Q1 restarts automatically to ACTIVE mode when VDD rises above VDDUVLO rising threshold.

In Figure 2-1 and Figure 2-2, LED drivers shut down because of a VDD UVLO fault. This resets the IC causing a POR (Power on Reset). Therefore, if the system is not stable under cranking condition which leads to the VDD drop, the LED driver does not light up as the expected scenario. If the system is not written, run the I2C command again. This risk can also make software design more complicated.

2.3 Unexpected Lower Input Voltage on LED Driver

As described in Section 2, actual input voltage on LED driver will be much smaller if the input voltage is dropped due to the losses across long PCB pattern, power cable, ideal diode, high-side switch and so on. This is worse when two LED drivers are used as in this system example. This unexpected low input voltage on the LED driver can go below 3V due to system challenges and trigger VIN UVLO protection even though the LED driver can support up to 3V input voltage.

The undervoltage threshold is programmable through external resistor divider on the UVLO pin. If the UVLO pin voltage falls below the UVLO falling level (0.787V typical) during normal operation of the LP8866(S)-Q1 device, the IC stops switching and LED outputs are turned off and the device enters STANDBY mode. The VINUVLO_STATUS bit is also set in the SUPPLY_FAULT_STATUS register, and the INT pin is triggered. When the UVLO voltage rises above the rising threshold level, the LP8866(S)-Q1 exits STANDBY and begins the start up sequence.

Therefore, if the system is not stable under cranking condition which leads VIN drop below than 3V, LED driver cannot light up as the expected scenario. The UVLO protection setting must have much bigger margin to mitigate the risk, but the UVLO protection cannot achieve expected precise protection which is not efficient.

2.4 Unexpected Higher Input Current Condition in the System

As shown in Figure 2-1 and Figure 2-2, input current increases dramatically when input voltage drops. As a result, a much lower input voltage than expected draws much larger input current. This can also trigger unexpected overcurrent protection in the LED driver even though the LED driver can set enough OCP limit threshold.

VIN OCP current limit is to protect system from critical system hazard (for example, inductor short, switching MOSFET short). This triggers the device to shut-down all the LED channels and enter into fault recovery state. If the voltage across RISENSE resistor rises above 220mV during normal operation of the LP8866(S)-Q1 device, IC stops switching and LED outputs are turned off, and the device enters fault recovery mode and then attempt to restart 100ms after fault occurs. The VINOCP_STATUS fault bit are set in the SUPPLY_FAULT_STATUS register, and the INT pin is triggered

Therefore, if the system is not stable and the actual input voltage becomes much lower, designers must take care of unexpected overcurrent condition. This means inductor saturation current must be bigger and the OCP triggering point must be bigger which leads to less precise protection features due to system challenges.

3 Design Suggestion to Resolve the System Challenges by Using Pre-Boost

3.1 Block Diagram and Test Results

If the actual input voltage on the system is kept stable even under low battery condition, all the challenges in Section 2 can be resolved. The pre-boost is a preferred design, making sure that the minimum voltage of 8.5V on the system as shown in Figure 3-1.

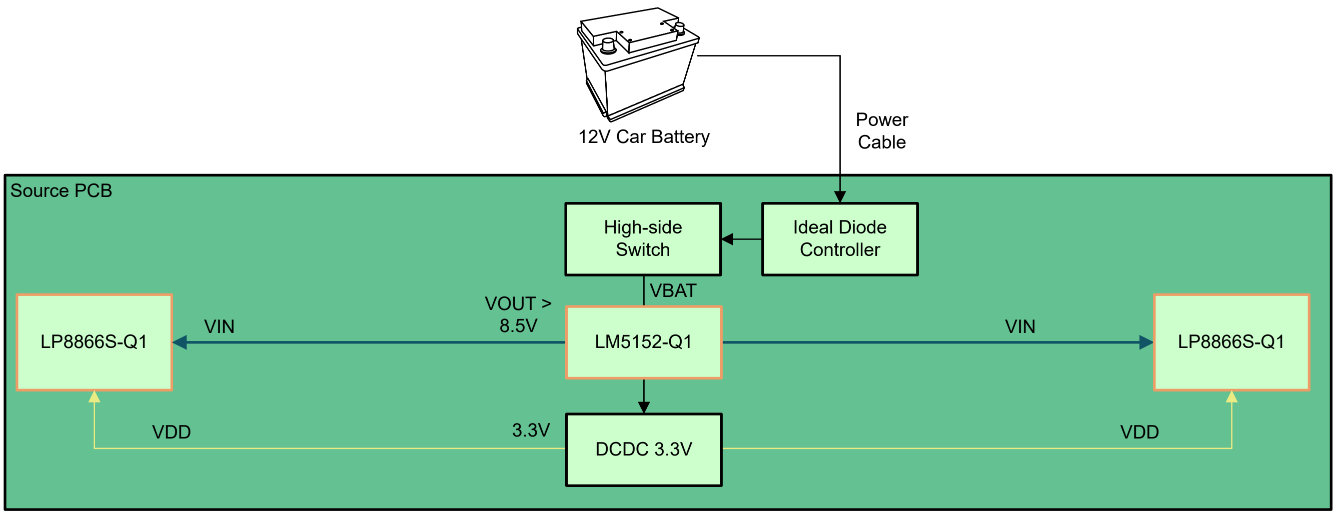

Figure 3-1. Recommended Block Diagram of a Display Module Using Pre-Boost

The LM5152-Q1 device is a wide input voltage range synchronous boost controller that employs peak current mode control. The device can work as a pre-boost controller which can boost up to a specific voltage if battery voltage is low when starting up as shown in Figure 3-2 . The device also supports an ultra-low IQ deep sleep mode with bypass operation, which eliminates the requirements for an external bypass switch when the supply voltage is greater than the boost output regulation target.

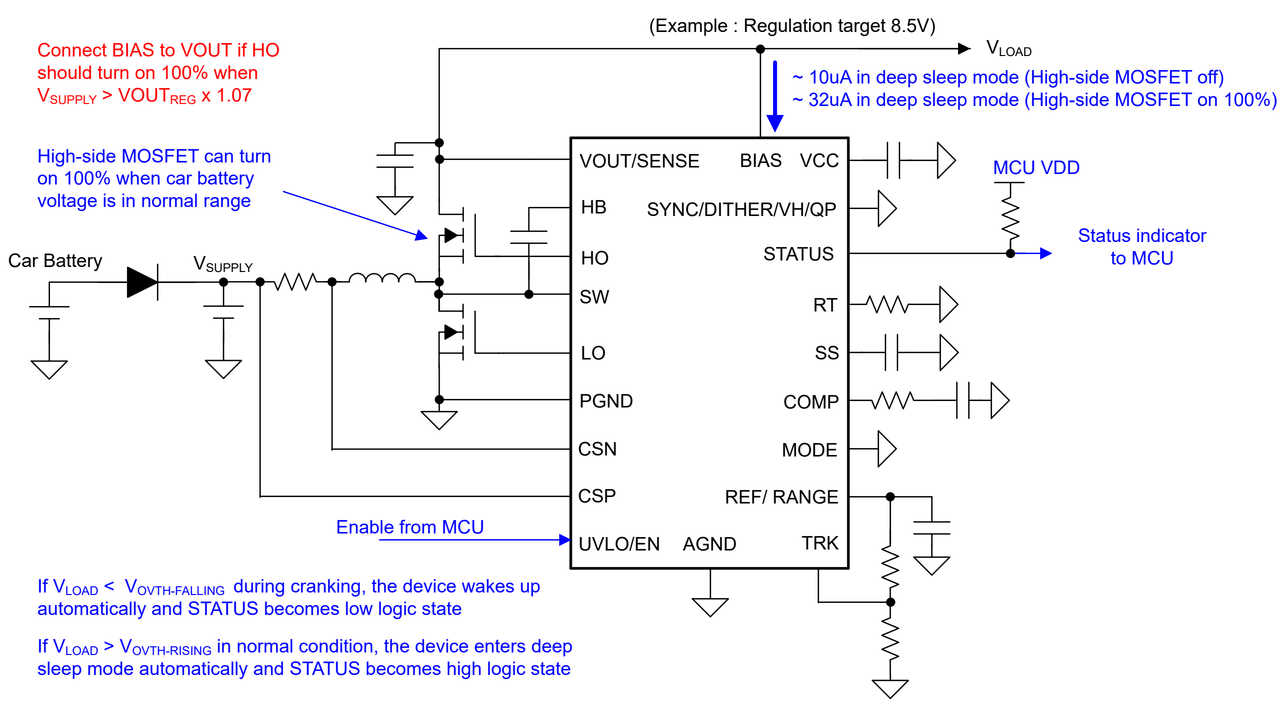

Figure 3-2. LM5152-Q1 in Automotive Pre-Boost Application

As shown in Figure 3-2, LM5152-Q1 EVM was used for testing in this system example as the design is preferred. Figure 3-3 shows the waveforms during a VIN transient from 12V to 6V. The red line is VIN, the green line is VOUT of the LM5152-Q1, which supplies system including LED drivers and pink line is input current from the battery. As VIN is reduced from 12V to 6V, the LM5152-Q1 maintains a minimum VOUT 8.5V as expected, keeping the system stable. Figure 3-4 shows the waveforms from the perspective of LP8866S-Q1 compared to Figure 2-1. VIN on the LED driver is shown as the red line, inductor current is the pink line and VDD on the LED driver is the green line. Even though VIN drops to 6V, the input voltage on LP8866S-Q1 is maintained at 8.5V as expected due to pre-boost. Therefore, the LED drivers can achieve stable operation even under cranking conditions on the battery.

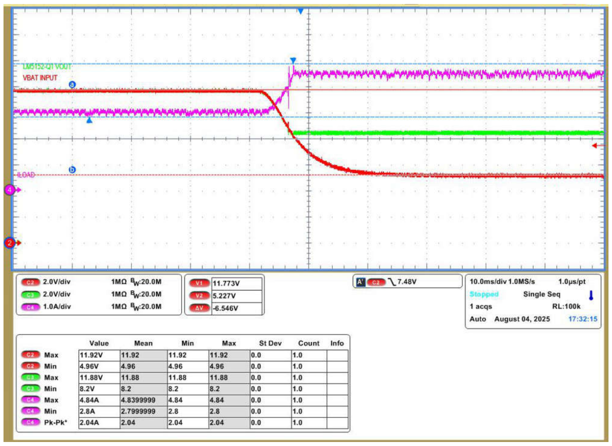

Figure 3-3. VBAT and VOUT of LM5152-Q1 and System Input Current During a VIN Transient 12V to 6V with Pre-Boost

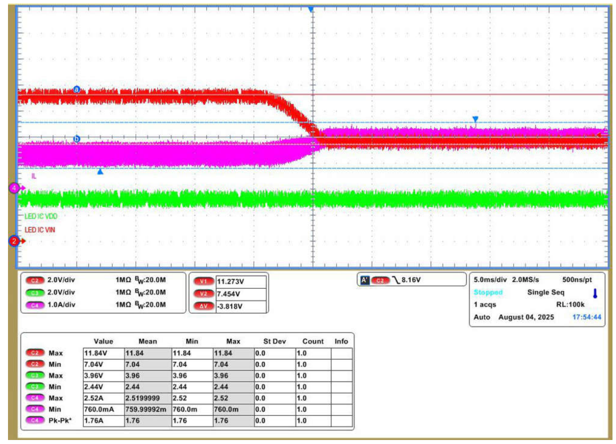

Figure 3-4. LED_VIN and LED_VDD and I_L Waveforms During a VIN Transient 12V to 6V with Pre-Boost

3.2 Key Design Considerations

The system example used LM5152-Q1 EVM to maintain the minimum output of 8.5V at 440kHz during the automotive cranking down to 2.5V boost input. The LM5152-Q1EVM is designed to achieve the power requirement as listed in Table 3-1 which can meet most requirements. The details are described in the *LM5152EVM-BST Evaluation Module*. Texas Instruments also provides many tools to assist designers such as Webench or the Excel design calculator for this device on ti.com.

Table 3-1. LM5152-Q1EVM Characteristics

Parameter	Test Condition	MIN	TYP	MAX	UNIT
Input voltage range	Operation	2.5	13.5	36	V
	Start-up voltage		7		
Input voltage				17	V
Output voltage			8.5		V
Output current 1	$2.5V \le V_{SUPPLY} \le 4.5V$			4	A
Output current 2	$4.5V \le V_{SUPPLY} \le 36V$			6	A
Switching frequency			440		kHz

One of key considerations is how to set minimum output voltage. The VOUT regulation target (VOUT-REG) is adjustable by programming the TRK pin voltage, which is the reference of the internal error amplifier. The accuracy of VOUT-REG is given when the TRK voltage is between 0.25V and 1V. The high impedance TRK pin allows users to program the pin voltage directly by a D/A converter or by connecting to a resistor voltage divider (RVREFT, RVREFB) between VREF and AGND.

This device provides a 1V voltage reference (VREF), which can be used to program the TRK pin voltage through a resistor voltage divider. When RVREFT and RVREFB are used to program the TRK pin voltage, VOUT-REG can be calculated as Equation 1.

$$VOUT_{REG} = 20 \times \frac{RV_{VREFB}}{R_{VREFB} + R_{VREFT}} \tag{1}$$

So R_{VREFT} = 56.2K and R_{VREFB} = 41.2K in the schematic as shown in Figure 3-5.

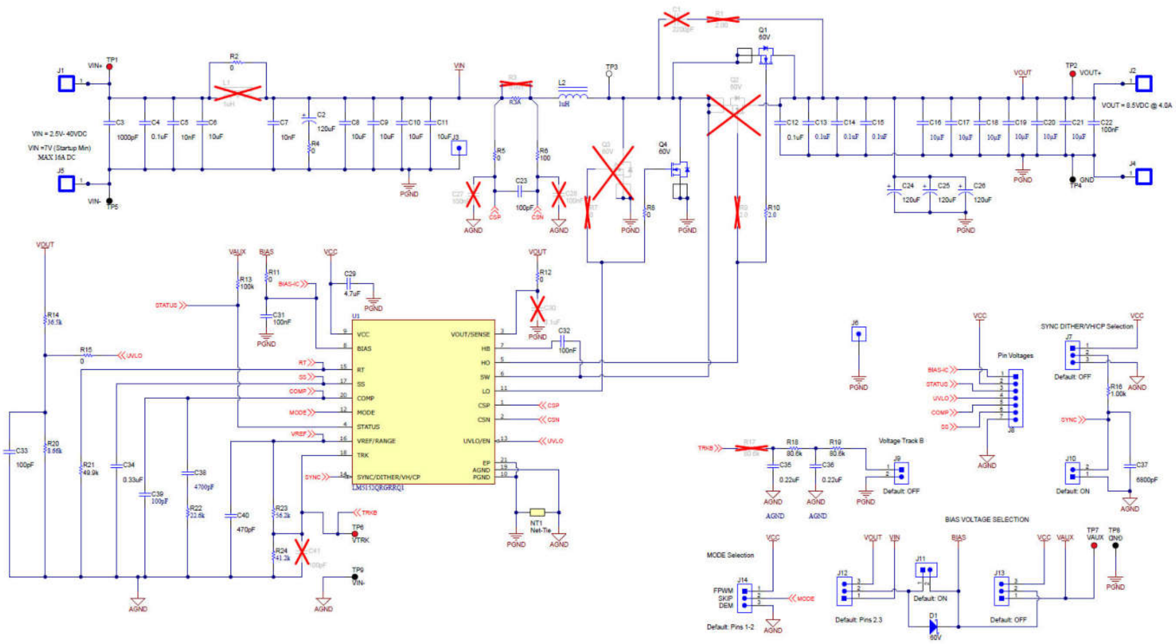

Figure 3-5. LM5152-Q1EVM Schematic

Another key issue is dithering feature. Most automotive applications require dithering feature such as spread-spectrum. LM5152-Q1 can achieve dithering feature by connecting STATUS pin to DITHER pin through diode as shown in Figure 3-6. The dithering is required when the LM5152-Q1 switches to boost output voltage. The STATUS pin is pulled down to ground during boost operation. The diode is reversed biased and the dithering ramp mechanism can work by charging and discharging the capacitor on the DITHER pin. However, this capacitor must be connected to the same SYNC/DITHER/VH/CP pin.

If VOUT pin voltage is bigger than over voltage (VOVTH), the LM5152-Q1 enters bypass mode. During bypass mode, high-side FET must be turned on 100% and the dithering is not required. As LM5152-Q1 does not have an internal charge pump, the DITHER/CP pin must be bigger than 2V to enable internal charge pump for bypass operation. Once the device enters bypass mode, STATUS pin is pulled-up and the pin enables the charge-pump. As a result, the diode and pull-up resistor must be used to implement both dithering feature and bypass mode.

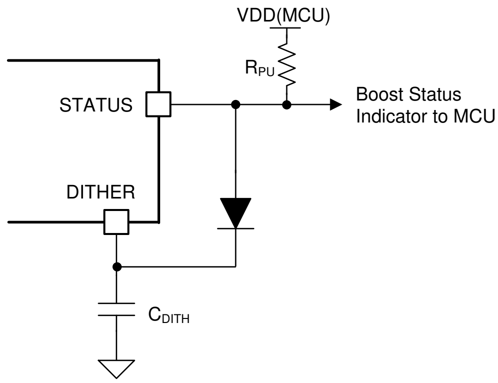

Figure 3-6. Enable Both Clock Dithering and Bypass Operation

4 Summary

This application note demonstrates how a pre-boost can stabilize automotive display applications even under low battery conditions especially during cranking events by using LM5152-Q1. As the automotive display panel size becomes larger in the market, the power requirements increase. This is more difficult for designers to achieve stable and robust systems in power management. However, the LM5152-Q1 provides a reliable pre-boost design which can also implement dithering feature for EMI performance. This design helps designers achieve more efficient and reliable automotive display systems even with simplified software design.

5 References

1. Texas Instruments, *LP8866S-Q1 Automotive Display LED-Backlight Driver with Six 150mA Channels*, data sheet.
2. Texas Instruments, *LM5152x-Q1 Automotive Low-IQ Synchronous Boost Controller for Start-Stop/Backup Battery Power Supply*, data sheet.
3. Texas Instruments, *LM5152EVM-BST Evaluation Module*, EVM user's guide.