Application Report
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How to Estimate the Output Voltage Ranges of the Charge Pumps in the TPS65150

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ABSTRACT

This application report tells you how to estimate the output voltage range of the charge pumps in the TPS65150. It assumes that the output current from each charge pump is 25 mA, or less.

This application report was written specifically for the TPS65150, but the principles in it are applicable to all devices that use the same charge-pump topology.

1 Introduction

The TPS65150 contains driver circuitry for a positive charge pump and a negative charge pump. The device regulates the output voltage of the charge pumps, if the output voltage is in the permitted range. The application circuit and the operating conditions set the permitted range of output voltages.

The mathematics used in the estimation is not complicated, but if you just want the answers, go straight to Figure 2 and Figure 5.

This application report assumes that the standard application circuits from the data sheet of the TPS65150 (SLVS576) are used.

2 Negative Charge Pump

Most TPS65150 application circuits use the one-stage negative charge-pump circuit shown in Figure 1. More than one stage can be used to generate more negative voltages, but few LCDs need such negative voltages and therefore they are not discussed here.

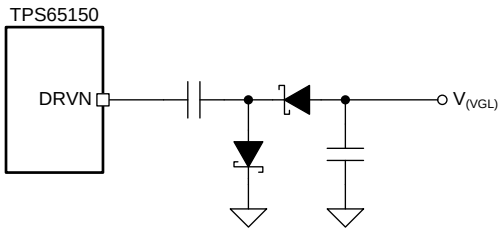

Figure 1. One-Stage Negative Charge-Pump Circuit

The minimum (that is, most negative) output voltage that this circuit can generate is given by:

$$V_{(VGL)}(\text{min}) \approx -\left(V_{(VS)} - 2\,V_F - V_{(DRVN)}\right) \quad (1)$$

where

- $V_{(VS)}$ is the output voltage of the boost converter
- V_F is the forward voltage of the diodes
- $V_{(DRVN)}$ is the voltage drop across the current sink in the negative charge-pump driver circuit

The values of V_F and $V_{(DRVN)}$ increase as the output current increases. The negative charge pump in the TPS65150 device operates with a 50% duty cycle, so the peak current in the diodes and the current sink is two times the output current. Thus, for output currents up to 25 mA, the peak current is 50 mA and

- V_F = 0.5 V (taken from the data sheet of the BAT54 (1) diode)
- $V_{(DRVN)}$ = 0.13 V (taken from the data sheet of the TPS65150 device)

Using these values, the minimum output voltage is given by:

$$V_{(VGL)}(\text{min}) \approx -\left(V_{(VS)} - 1.13\ \text{V}\right) \quad (2)$$

The data sheet of the TPS65150 specifies that the maximum (that is, least negative) output voltage the negative charge pump can generate is –2 V.

Figure 2 is a graphic representation of the range of output voltages that the negative charge pump in the TPS65150 device can generate.

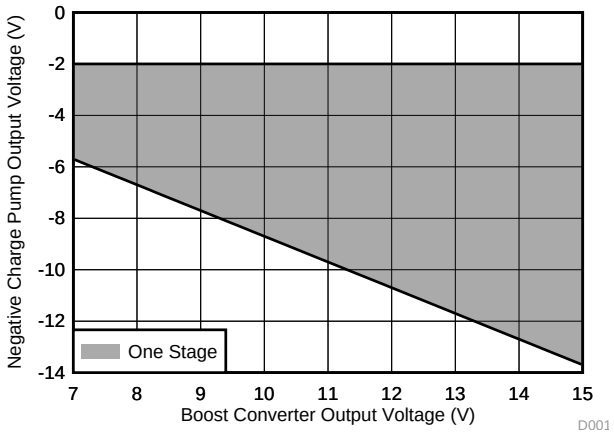

Figure 2. Negative Charge-Pump Output Voltage Range

Ensure that the output voltage of the negative charge pump in your application is in the gray area of Figure 2.

The bottom boundary of the gray area also tells you what output you will get if you try to generate an output voltage below the permitted range.

For example, if $V_{(VS)}$ = 11 V and you try to generate $V_{(VGL)}$ = –12 V, you will get about –9.7 V (found by following the $V_{(VS)}$ = 11 V grid line up until it hits the bottom boundary of the gray area).

(1) The BAT54 diode is commonly used in charge-pump circuits, but other diodes are available. If you use a different diode, make sure you use the correct value for V_F.

3 Positive Charge Pump

Many LCD applications can use the positive charge pump of the TPS65150 in a one-stage configuration. Applications that need a higher $V_{(VGH)}$ voltage than a one-stage charge pump can generate must use a two-stage configuration.

3.1 One-Stage Positive Charge Pump

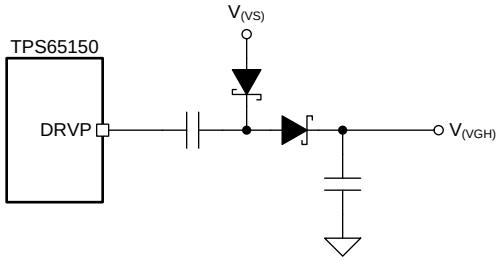

Figure 3. One-Stage Positive Charge-Pump Circuit

The maximum output voltage that a one-stage charge pump can generate is given by:

$$V_{(VGH)}(max) \approx 2\ V_{(VS)} - 2\ V_F - \left(V_{(SUP)} - V_{(DRVP)}\right) \quad (3)$$

where

- $V_{(VS)}$ is the output voltage of the boost converter
- V_F is the forward voltage of the diodes
- $V_{(SUP)} - V_{(DRVP)}$ is the voltage drop across the current source in the positive charge-pump driver circuit

The values of V_F and $V_{(SUP)} - V_{(DRVP)}$ increase as the output current increases. The positive charge pump operates with a 50% duty cycle, so the peak current in the diodes and the current source is two times the output current. Thus, for output currents up to 25 mA, the peak current is 50 mA, and

- V_F = 0.5 V (taken from the data sheet of the BAT54 diode)
- $V_{(SUP)} - V_{(DRVP)}$ = 0.42 V (taken from the data sheet of the TPS65150 device)

Using these values, the maximum output voltage is given by:

$$V_{(VGH)}(max) \approx 2\ V_{(VS)} - 1.42\ V \quad (4)$$

The minimum output voltage for a one-stage charge pump is given by:

$$V_{GH}(min) \approx V_{(VS)} - 2\ V_F \quad (5)$$

and if V_F = 0.5 V,

$$V_{GH}(min) \approx V_{(VS)} - 1\ V \quad (6)$$

3.2 Two-Stage Positive Charge Pump

If your application needs a higher voltage for $V_{(VGH)}$ than a one-stage charge pump can generate, you must use the two-stage circuit shown in Figure 4.

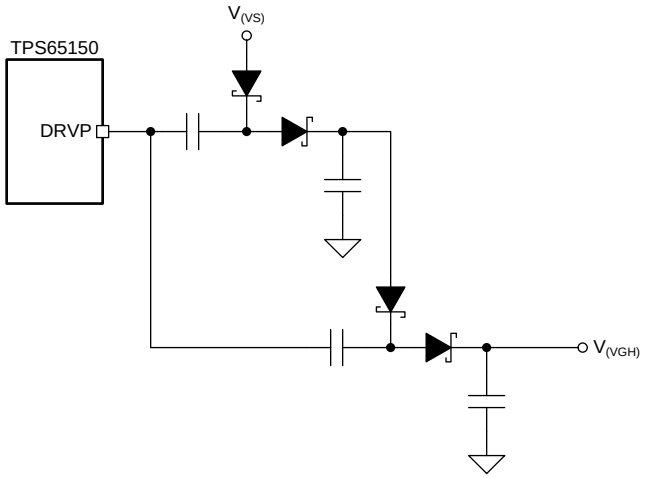

Figure 4. Two-Stage Positive Charge-Pump Circuit

NOTE: Be aware that the output current of a *Two-Stage Positive Charge Pump* is only half the current of a *One-Stage Charge Pump* if the second stage is as well driven by the DRVP pin. If the same output current is needed, the SW pin of the TPS65150 could drive the second stage. The calculation formulas for the estimated output voltage then slightly changes.

The maximum output voltage of the two-stage charge-pump circuit is given by:

$$V_{(VGH)}(max) \approx 3\ V_{(VS)} - 4\ V_F - 2\left(V_{(SUP)} - V_{(DRVP)}\right) \quad (7)$$

The values for V_F and $V_{(SUP)} - V_{(DRVP)}$ increase as the output current increases. In a two-stage charge pump with output currents up to 25 mA, the peak current in each diode is 50 mA, but the peak current from the DRVP pin is 100 mA (because it drives *two* charge-pump stages). Thus,

- V_F = 0.5 V (taken from the data sheet of the BAT54 diode)
- $V_{(SUP)} - V_{(DRVP)}$ = 0.9 V (taken from the data sheet of the TPS65150 device)

Using these values, the maximum output voltage is given by:

$$V_{(VGH)}(max) \approx 3\ V_{(VS)} - 3.8\ V \quad (8)$$

Note that the data sheet of the TPS65150 device specifies a maximum value for $V_{(VGH)}$ of 30 V. Even if Equation 8 says you can generate higher output voltages in your application, the maximum output voltage in practice is 30 V.

The minimum output voltage for a two-stage charge pump is given by:

$$V_{GH}(min) \approx 2\ V_{(VS)} - 4\ V_F, \quad (9)$$

and if V_F = 0.5 V

$$V_{GH}(min) \approx 2\ V_{(VS)} - 2\ V \quad (10)$$

Figure 5 shows a graphical representation of the output voltages that the TPS65150 device can generate in one- and two-stage configurations. The dark area between the gray and the red areas indicates an overlap of the two ranges.

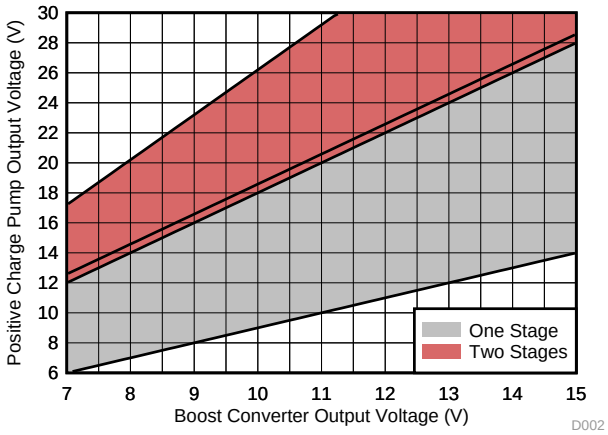

Figure 5. Positive Charge Pump Output Voltage Ranges

If you use a one-stage charge pump, make sure that the output voltage of the positive charge pump is in the gray area of Figure 5.

If you use a two-stage charge pump, you must make sure that the output voltage is in the red area of Figure 5.

The boundaries of each area also indicate what output you will get if you try to generate an output voltage outside the permitted range. For example:

- If $V_{(VS)}$ = 11 V and you try to generate $V_{(VGH)}$ = 24 V with a one-stage charge pump, you will get about 20.6 V (found by following the $V_{(VS)}$ = 11 V grid line up until it hits the top boundary of the gray area)
- If $V_{(VS)}$ = 11 V and you try to generate $V_{(VGH)}$ = 16 V with a two-stage charge pump you will get about 20 V (found by following the $V_{(VS)}$ = 11 V grid line up until it hits the bottom boundary of the gray area)

4 Summary

The charge pumps in the TPS65150 can regulate the output voltage if it is in the permitted range. Use Figure 2 and Figure 5 in this document to see the permitted output voltage range of your application. If your application operates close to the edge of the permitted range, make sure that your design has enough margin to operate correctly under all conditions.

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