Application Report

SLVA918–December 2017

# How to Estimate the Output Voltage Ranges of the Charge Pumps in the TPS6510x and TPS6514x Devices

Ilona Weiss


**ABSTRACT**

This application report details how to estimate the output voltage range of the charge pumps in the TPS65100, TPS65101, and TPS65105 (TPS6510x) series but also in the TPS65140, TPS65141, and TPS65145 (TPS6514x) series. It assumes the output current from each charge pump is 50 mA, or less.


## Trademarks



## 1 Introduction

The TPS6510x and TPS6514x devices contain driver circuitry for a positive and a negative charge pump. For the positive charge pump, these devices also include the diodes which usually need to be connected externally. The device regulates the output voltage of the charge pumps, if the output voltage is in the available range. The application circuit and the operating conditions set the available range of output voltages.

The mathematics used in the estimation is not complicated; however, see Figure 2 and Figure 5 for quick answers.

This application report is based on the standard application circuits from the data sheet of the TPS6510x (SLVS496) and TPS6514x (SLVS277) devices.

## 2 Negative Charge Pump

Most 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.

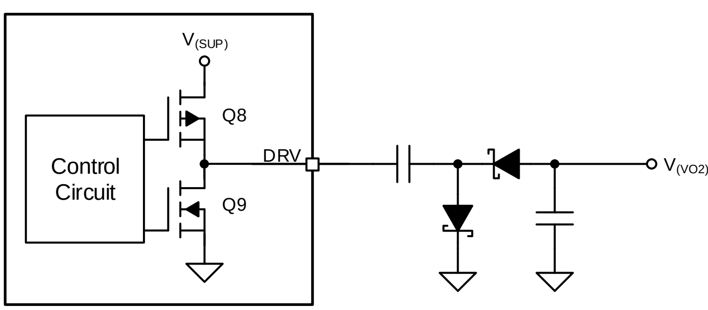




**Figure 1. One-Stage Negative Charge-Pump Circuit**

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

$$V_O2 = -(V_O1 - 2 \times V_F - I_O2 \times (2 \times r_{DS(on)Q8} + 2 \times r_{DS(on)Q9})) \quad (1)$$

where

- $V_O1$ is the output voltage of the boost converter (shown as $V_{(SUP)}$ in Figure 1)
- $V_F$ is the forward voltage of the diodes
- $I_O2$ is the output current of the negative charge-pump
- $r_{DS(ON)Q8}$ and $r_{DS(ON)Q9}$ are the on-resistances of the supply circuit

- $V_F$ = 0.5 V (taken from the data sheet of the BAT54 diode) [1] diode)
- $r_{DS(ON)Q8}$ = 4.3 Ω at $I_{DS}$ = 20 mA
- $r_{DS(ON)Q9}$= 2.9 Ω at $I_{DS}$ = 20 mA

The values of $V_F$ , $r_{DS(ON)Q8}$, and $r_{DS(ON)Q9}$ increase as the output current increases. The negative charge pump in these devices operate 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

The maximum (that is, least negative) output voltage of the negative charge pump is –2 V.

Figure 2 is a graphic representation of the range of output voltages the negative charge pump in the TPS6510x and TPS6514x devices can generate as a function of the supply voltage $V_O1$.

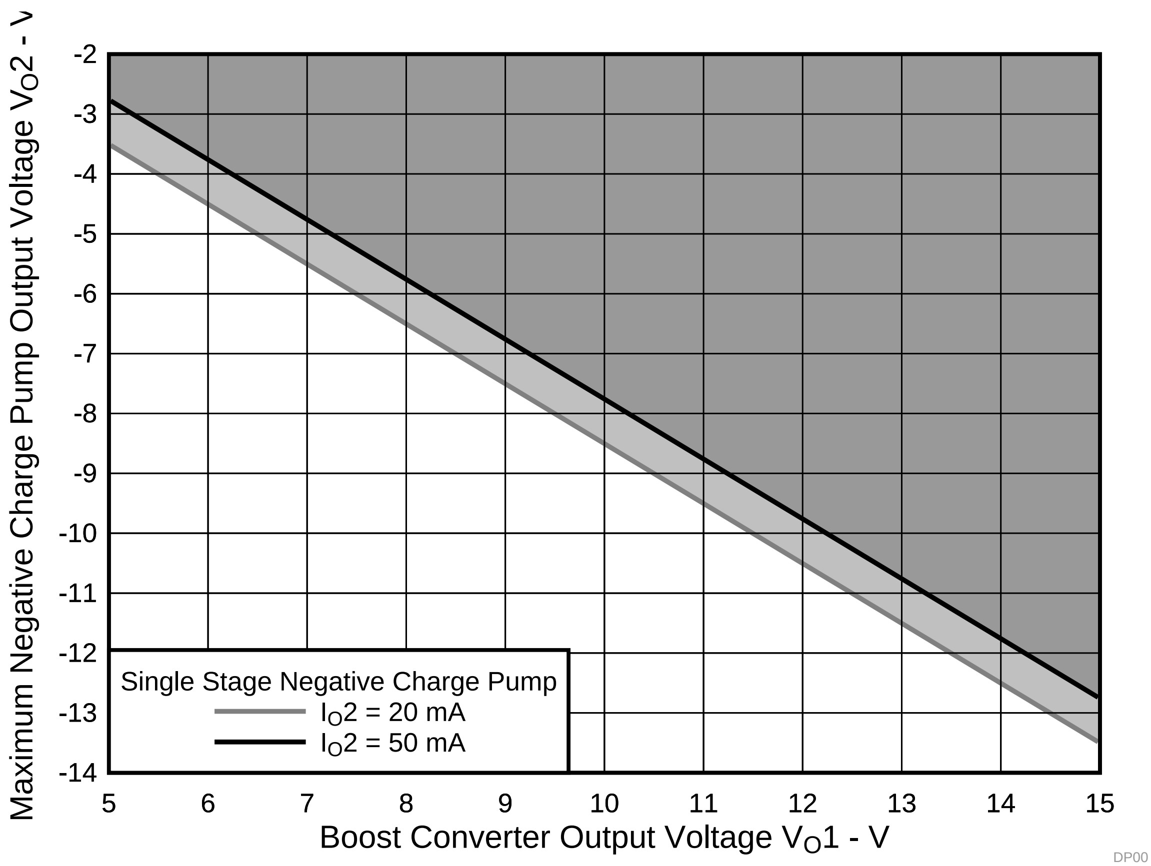


**Figure 2. Negative Charge-Pump Output Voltage Range**

Ensure that the output voltage of the negative charge pump in the application is in the gray area of Figure 2. The light gray filling shows the additional level the charge pump can provide if the load is only up to 20 mA.

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

The bottom boundary of the gray area also shows the output if you try to generate an output voltage below the available range.

For example, if $V_O1$ = 11 V and you try to generate $V_O2$ = –12 V, approximately –9.7 V is obtained (found by following the $V_O1$ = 11 V grid line up until it hits the bottom boundary of the gray area).

## 3 Positive Charge Pump

Many LCD applications can use the positive charge pump in a doubler configuration. Applications that need a higher $V_O3$ voltage (that is roughly 2 x $V_O1$) than a doubler can generate must use a tripler configuration.

### 3.1 Positive Charge Pump Doubler

To correctly use the doubler configuration of the positive charge pump connect the flying capacitor across the pins C1– and C1+. Leave pins C2+ open and connect pin C2–/Mode to ground, as shown in Figure 3

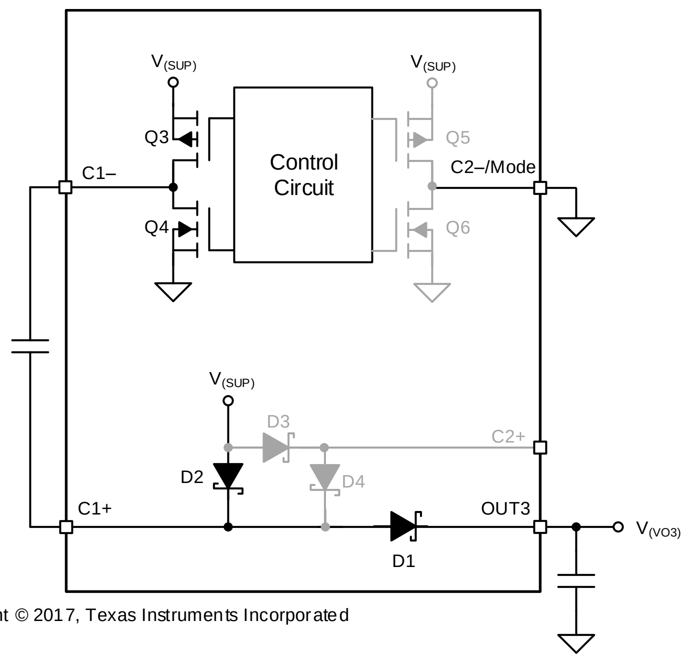




**Figure 3. Positive Charge-Pump Circuit in Doubler Mode**

The maximum output voltage the doubler can generate is given by:

$$V_O3_{(dbl)} = 2 \times V_O1 - 2 \times V_F - 2 \times I_O3 \times (2 \times r_{DS(on)Q5} + r_{DS(on)Q4} + r_{DS(on)Q3}) \quad (2)$$

where

- $V_O1$ is the output voltage of the boost converter (shown as $V_{(SUP)}$ in Figure 3)
- $V_F$ is the forward voltage of the diodes
- $I_o3$ is the output current of the charge pump
- $r_{DS(ON)Q3}$ = 9.9 Ω at $I_{DS}$ = 20 mA
- $r_{DS(ON)Q4}$ = 1.1 Ω at $I_{DS}$ = 20 mA
- $r_{DS(ON)Q5}$ = 4.6 Ω at $I_{DS}$ = 20 mA

The minimum output voltage for a doubler is given by:

$$V_O3_{(dbl)(min)} = V_O1 - 2 \times V_F \quad (3)$$

### 3.2 Positive Charge Pump Tripler

If the application needs a higher voltage for $V_O3$ than a doubler charge pump can generate, use the tripler configuration shown in Figure 4. Connect an additional flying capacitor between pins C2–/Mode and C2+.

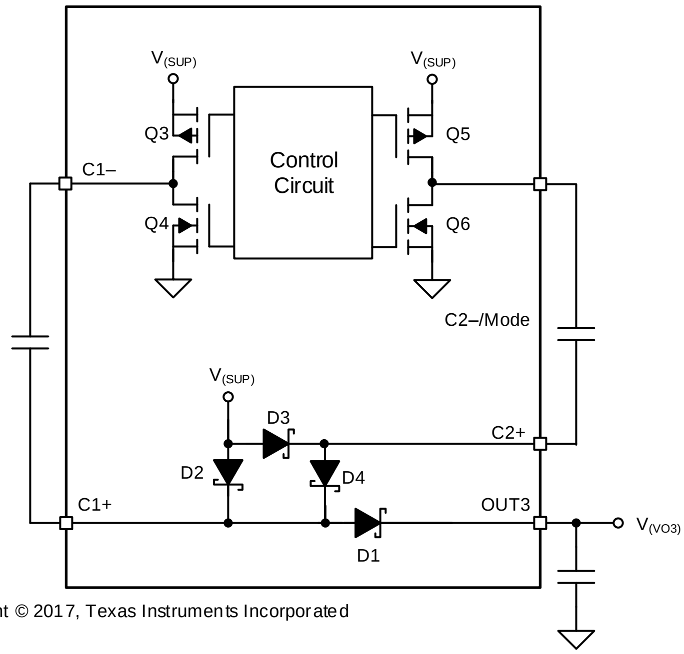


**Figure 4. Tripler Positive Charge-Pump Circuit**

The maximum output voltage of the tripler circuit is given by:

$$V_O3_{(trp)} = 3 \times V_O1 - 4 \times V_F - 2 \times I_O3 \times (3 \times r_{DS(on)Q5} + r_{DS(on)Q4} + r_{DS(on)Q3}) \quad (4)$$

Where,

- $V_O1$ is the output voltage of the boost converter (shown as $V_{(SUP)}$ in Figure 4)
- $V_F$ = 0.5 V (taken from the data sheet of the BAT54 diode)
- $I_o3$ is the output current of the positive charge pump
- $r_{DS(ON)Q3}$ = 9.9 Ω at $I_{DS}$ = 20 mA
- $r_{DS(ON)Q4}$ = 1.1 Ω at $I_{DS}$ = 20 mA
- $r_{DS(ON)Q5}$ = 4.6 Ω at $I_{DS}$ = 20 mA

**NOTE:** The data sheets of the TPS6510x and TPS6514x devices specify a maximum value for $V_O3$ of 30 V. Even if the tipler charge pump indicates higher output voltages can be generated in the application, the maximum output voltage is limited to 30 V.

The minimum output voltage for a tripler is given by Equation 2.

Figure 5 shows a graphical representation of the output voltages that these devices can generate doubler and tripler configurations. The light gray area between indicates the additional headroom gained if the output current is only up to 20 mA. In the second figure it is also indicated the area (red filling) that is not available if you are using a tripler configuration.

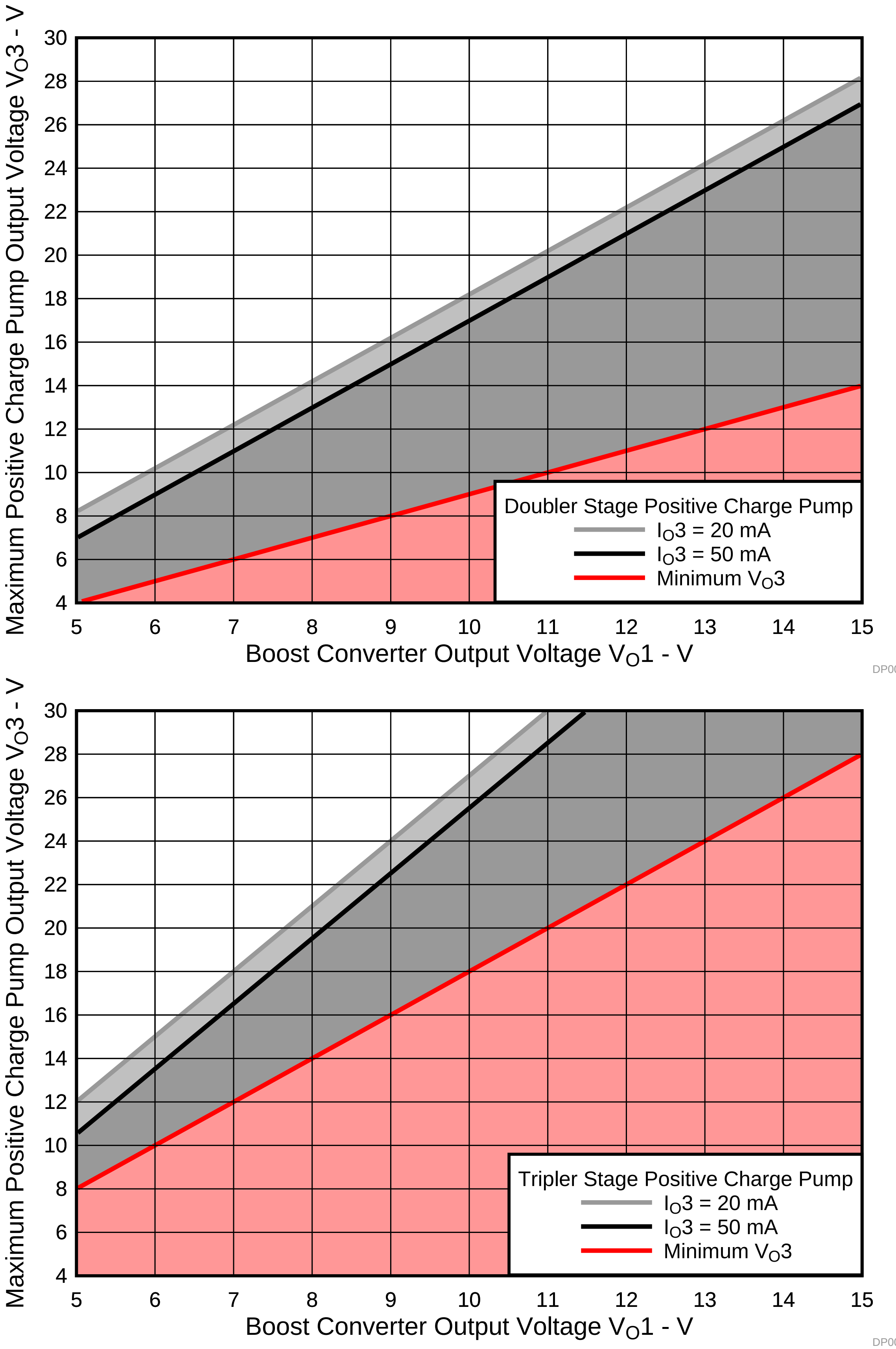


**Figure 5. Positive Charge Pump Output Voltage Ranges**

Ensure that the output voltage is in the gray area of Figure 5. The light gray filling shows the additional level the charge pump can provide if the load is only up to 20 mA. The red areas are not available in the according configuration.

The boundaries of each area also indicate what output results if an output voltage outside the available range is generated. For example:

- If $V_O1$ = 11 V and you try to generate $V_O3$ = 24 V with a doubler stage charge pump, approximately 20.6 V is achieved (found by following the $V_O1$ = 11 V grid line up until it hits the top boundary of the gray area).
- If $V_O1$ = 11 V and you try to generate $V_O3$ = 16 V with a tripler charge pump, you will find that this is in the red filled area. As a result, the device will regulate up to its minimum which is at about 20 V (found by following the $V_O1$ = 11 V grid line up to the red line).

## 4 Summary

The charge pumps in the TPS6510x and the TPS6514x devices can regulate the output voltage if it is in the available range. Use Figure 2 and Figure 5 in this document to see the available output voltage range of the application. If the application operates close to the edge of the permitted range, ensure the design has enough margin to operate correctly under all conditions.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265