Keywords: Switching regulator, buck regulator, buck converter, buck, step-down, multi-phase, quad-phase, phase configuration, external resistor divider, output voltage

APPLICATION NOTE 6823
GENERATING A HIGHER OUTPUT VOLTAGE THAN 1.525V USING THE MAX77812

Abstract: The MAX77812 is a quad-phase, high-current, step-down (buck) converter for high-end gaming consoles, VR/AR headsets, DSLR cameras, drones, network switches and routers, and FPGA systems that use multicore processors. The maximum output voltage of the MAX77812 is 1.525V per register setting. However, the output voltage can be increased up to 2.7V with an external resistive voltage-divider. This document provides a formula that determines the external resistor values for a given output voltage and explains practical considerations for it.

Introduction
The MAX77812 supports programmable output voltage from 0.25V to 1.525V in 5mV steps through an I²C interface. For some applications, an output voltage higher than 1.525V is required. The MAX77812 supports the higher output voltage with the addition of an external voltage-divider network.

External Voltage-Divider Network
A buck converter regulates the output voltage to the target value by comparing the sensed output voltage ($V_{\text{SNSxP}}$) to the internal reference. If $V_{\text{SNSxP}}$ is lower than the actual output voltage ($V_{\text{OUTx}}$), $V_{\text{OUTx}}$ will be higher than the nominal output voltage set through the I²C interface.

As shown in Figure 1, the external voltage-divider network consists of feedback resistors ($R_{FB1}$ and $R_{FB2}$) and a feed-forward capacitor ($C_{FF}$). The resistors divide $V_{\text{OUTx}}$ to the lower value $V_{\text{SNSxP}}$ at the remote sense input (SNSxP):

$$V_{\text{SNSxP}} = \frac{R_{FB2} \| R_{SNS}}{R_{FB2} \| R_{SNS} + R_{FB1}} \times V_{\text{OUTx}}$$

(Eq. 1)

The internal sensing resistor at SNSxP is $R_{SNS}$. Voltage $V_{\text{SNSxP}}$ is then compared to the internal reference set by the output voltage setting register (Mx_VOUT[7:0]). Therefore, the relation between the actual and the nominal output voltages is:

$$V_{\text{OUTx}} = \frac{R_{FB2} \| R_{SNS} + R_{FB1}}{R_{FB2} \| R_{SNS}} \times V_{\text{OUTx\_nominal}}$$

(Eq. 2)

An output voltage higher than 1.525V can be achieved by adjusting Mx_VOUT[7:0], and the voltage-dividing ratio is:

$$\frac{R_{FB2} \| R_{SNS}}{R_{FB2} \| R_{SNS} + R_{FB1}}$$
Value Selection

The selection of \( R_{FB1} \) and \( R_{FB2} \) must guarantee the accuracy of output regulation and minimize the power loss on these resistors. The resistance of \( R_{FB2} \) should be significantly smaller than \( R_{SNS} \) to be dominant. Because the resistance of \( R_{SNS} \) is approximately 350k\( \Omega \), the recommended value for \( R_{FB2} \) is around 51.1k\( \Omega \). To minimize the difference between the actual and the nominal output voltages, \( \text{Mx\_VOUT[7:0]} \) is selected as close to 1.525V as possible. Once \( R_{FB2} \) and \( \text{Mx\_VOUT[7:0]} \) are fixed, \( R_{FB1} \) can be selected based on equation (2). The accuracy of the output voltage highly relies on the accuracy of the voltage-dividing ratio, thus ±1% or better resistors are recommended for \( R_{FB1} \) and \( R_{FB2} \).

The external voltage-divider network creates an additional pole and zero at \( (R_{FB2} || R_{SNS}) || R_{FB1} \) for simplified calculation:

\[
 f_p = \frac{1}{2\pi \times C_{FF} \times (R_{FB1} || R_{FB2})} \tag{Eq. 3}
\]

\[
 f_z = \frac{1}{2\pi \times C_{FF} \times R_{FB1}} \tag{Eq. 4}
\]

To maintain the loop stability, the recommended value for \( C_{FF} \) is around tens of picofarads and is determined by the values of \( R_{FB1} \) and \( R_{FB2} \).

Table 1 shows a few examples of the value selection recommendation for common output voltages.

Table 1. Value Selection Recommendation and Measured Maximum Load Current
Considerations
Although the output voltage can be higher than 1.525\(V\), it is still limited by the input voltage and load current. Theoretically speaking, the constant on-time is proportional to the ratio of the actual output voltage (\(V_{OUTx}\)) to the input voltage (\(V_{IN}\)). The MAX77812 calculates the on-time by sensing \(V_{SNSxp}\) and \(V_{IN}\). Because \(V_{SNSxp}\) is lower than \(V_{OUTx}\), the on-time is insufficient. As a result, more switching cycles are needed and thus the switching frequency (\(f_{SW}\)) increases. The constant on-time control architecture also exhibits higher \(f_{SW}\) when the load current increases. Therefore, supporting a high \(V_{OUTx}\) under the heavy load condition leads to a substantial increase of \(f_{SW}\), which may be ultimately limited by the control architecture. For the same \(V_{IN}\), the higher the actual output voltage is, the lower the maximum load current that can be supported. Table 1 provides examples of the maximum load current measured on the bench. To mitigate the switching frequency increase, Mx_VOUT[7:0] needs to be selected as close to 1.525\(V\) as possible for a longer on-time.

<table>
<thead>
<tr>
<th>(V_{OUTx}) (V)</th>
<th>(R_{FB1}) (k(\Omega))</th>
<th>(R_{FB2}) (k(\Omega))</th>
<th>(C_{FF}) (pF)</th>
<th>Mx_VOUT[7:0]</th>
<th>Maximum Load Current (with a 0.22(\mu)H inductor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8</td>
<td>9.09</td>
<td>51.1</td>
<td>100</td>
<td>0xF9 = 1.495V</td>
<td>4.0A at (V_{IN}) = 3.8V</td>
</tr>
<tr>
<td>2.4</td>
<td>27.4</td>
<td>51.1</td>
<td>39</td>
<td>0xF8 = 1.490V</td>
<td>2.5A at (V_{IN}) = 3.8V</td>
</tr>
<tr>
<td>2.7</td>
<td>34.8</td>
<td>51.1</td>
<td>27</td>
<td>0xFE = 1.520V</td>
<td>2.0A at (V_{IN}) = 3.8V</td>
</tr>
</tbody>
</table>

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