MAX828, MAX829

Switched Capacitor Voltage Converter

The MAX828 and MAX829 are CMOS charge pump voltage inverters that are designed for operation over an input voltage range of 1.15 V to 5.5 V with an output current capability in excess of 50 mA. The operating current consumption is only 68 µA for the MAX828 and 118 µA for the MAX829. The devices contain an internal oscillator that operates at 12 kHz for the MAX828 and 35 kHz for the MAX829. The oscillator drives four low resistance MOSFET switches, yielding a low output resistance of 26 Ω and a voltage conversion efficiency of 99.9%. These devices require only two external capacitors, 10 µF for the MAX828 and 3.3 µF for the MAX829, for a complete inverter making it an ideal solution for numerous battery powered and board level applications. The MAX828 and MAX829 are available in the TSOP–5 package.

Features

- Operating Voltage Range of 1.15 V to 5.5 V
- Output Current Capability in Excess of 50 mA
- Low Current Consumption of 68 µA (MAX828) or 118 µA (MAX829)
- Operation at 12 kHz (MAX828) or 35 kHz (MAX829)
- Low Output Resistance of 26 Ω
- Space Saving TSOP–5 Package
- Pb–Free Packages are Available

Typical Applications

- LCD Panel Bias
- Cellular Telephones
- Pagers
- Personal Digital Assistants
- Electronic Games
- Digital Cameras
- Camcorders
- Hand–Held Instruments

This device contains 77 active transistors.

Figure 1. Typical Application
MAX828, MAX829

MAXIMUM RATINGS*

<table>
<thead>
<tr>
<th>Rating</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage Range (Vin to GND)</td>
<td>Vin</td>
<td>−0.3 to 6.0</td>
<td>V</td>
</tr>
<tr>
<td>Output Voltage Range (Vout to GND)</td>
<td>Vout</td>
<td>−6.0 to 0.3</td>
<td>V</td>
</tr>
<tr>
<td>Output Current (Note 1)</td>
<td>Iout</td>
<td>100 mA</td>
<td>mA</td>
</tr>
<tr>
<td>Output Short Circuit Duration (Vout to GND, Note 1)</td>
<td>ISC</td>
<td>Indefinite</td>
<td>sec</td>
</tr>
<tr>
<td>Operating Junction Temperature</td>
<td>TJ</td>
<td>150 °C</td>
<td>°C</td>
</tr>
</tbody>
</table>

Power Dissipation and Thermal Characteristics
- Thermal Resistance, Junction to Air (TA = 70 °C)
  - RJA
  - PD
  - C/W

Maximum Power Dissipation @ TA = 70 °C
- PD
- mW

Storage Temperature
- Tstg
- °C

Maximum ratings are those values beyond which device damage can occur. Maximum ratings applied to the device are individual stress limit values (not normal operating conditions) and are not valid simultaneously. If these limits are exceeded, device functional operation is not implied, damage may occur and reliability may be affected.

*ESD Ratings
- ESD Machine Model Protection up to 200 V, Class B
- ESD Human Body Model Protection up to 2000 V, Class 2

ELECTRICAL CHARACTERISTICS (Vin = 5.0 V for MAX828 C1 = C2 = 10 μF, for MAX829 C1 = C2 = 3.3 μF, TA = −40 °C to 85 °C, typical values shown are for TA = 25 °C unless otherwise noted. See Figure 20 for test setup.)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Supply Voltage Range (RL = 10 k)</td>
<td>Vin</td>
<td>1.5 to 5.5</td>
<td>1.15 to 6.0</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Supply Current Device Operating (RL = ∞)</td>
<td>Iin</td>
<td>–</td>
<td>68</td>
<td>90</td>
<td>μA</td>
</tr>
<tr>
<td>TA = 25 °C</td>
<td>–</td>
<td>118</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX828</td>
<td>–</td>
<td>73</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX829</td>
<td>–</td>
<td>128</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TA = 85 °C</td>
<td>–</td>
<td>128</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oscillator Frequency</td>
<td>fOSC</td>
<td>8.4</td>
<td>12</td>
<td>15.6</td>
<td>kHz</td>
</tr>
<tr>
<td>TA = 25 °C</td>
<td>–</td>
<td>24.5</td>
<td>35</td>
<td>45.6</td>
<td></td>
</tr>
<tr>
<td>MAX828</td>
<td>–</td>
<td>6.0</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX829</td>
<td>–</td>
<td>19</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TA = −40 °C to 85 °C</td>
<td>–</td>
<td>19</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX828</td>
<td>–</td>
<td>6.0</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX829</td>
<td>–</td>
<td>6.0</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Resistance (Iout = 25 mA, Note 2)</td>
<td>Rout</td>
<td>–</td>
<td>26</td>
<td>50</td>
<td>Ω</td>
</tr>
<tr>
<td>MAX828</td>
<td>–</td>
<td>26</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX829</td>
<td>–</td>
<td>26</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage Conversion Efficiency (RL = ∞)</td>
<td>VEFF</td>
<td>99</td>
<td>99.9</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>MAX828</td>
<td>–</td>
<td>99</td>
<td>99.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX829</td>
<td>–</td>
<td>99</td>
<td>99.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Conversion Efficiency (RL = 1.0 k)</td>
<td>PEFF</td>
<td>–</td>
<td>96</td>
<td>–</td>
<td>%</td>
</tr>
</tbody>
</table>

Maximum Package power dissipation limits must be observed to ensure that the maximum junction temperature is not exceeded.

1. Maximum Package power dissipation limits must be observed to ensure that the maximum junction temperature is not exceeded. 
   \[ T_J = T_A + (PD \cdot R_{JA}) \]
2. Capacitors C1 and C2 contribution is approximately 20% of the total output resistance.
Figure 2. Output Resistance vs. Supply Voltage

Figure 3. Output Resistance vs. Supply Voltage

Figure 4. Output Resistance vs. Ambient Temperature

Figure 5. Output Resistance vs. Ambient Temperature

Figure 6. Output Current vs. Capacitance

Figure 7. Output Current vs. Capacitance
Figure 8. Output Voltage Ripple vs. Capacitance MAX828

Figure 9. Output Voltage Ripple vs. Capacitance MAX829

Figure 10. Supply Current vs. Supply Voltage MAX828

Figure 11. Supply Current vs. Supply Voltage MAX829

Figure 12. Oscillator Frequency vs. Ambient Temperature MAX828

Figure 13. Oscillator Frequency vs. Ambient Temperature MAX829
Figure 14. Output Voltage vs. Output Current
MAX828

Figure 15. Output Voltage vs. Output Current
MAX829

Figure 16. Power Conversion Efficiency vs.
Output Current MAX828

Figure 17. Power Conversion Efficiency vs.
Output Current MAX829

Figure 18. Output Voltage Ripple and Noise
MAX828

Figure 19. Output Voltage Ripple and Noise
MAX829
DETAILED OPERATING DESCRIPTION

The MAX828/829 charge pump converters inverts the voltage applied to the Vin pin. Conversion consists of a two-phase operation (Figure 21). During the first phase, switches S2 and S4 are open and S1 and S3 are closed. During this time, C1 charges to the voltage on Vin and load current is supplied from C2. During the second phase, S2 and S4 are closed, and S1 and S3 are open. This action connects C1 across C2, restoring charge to C2.

APPLICATIONS INFORMATION

Output Voltage Considerations

The MAX828/829 performs voltage conversion but does not provide regulation. The output voltage will drop in a linear manner with respect to load current. The value of this equivalent output resistance is approximately 26 Ω nominal at 25°C and Vin = 5.0 V. Vout is approximately −5.0 V at light loads, and drops according to the equation below:

\[
\begin{align*}
V_{\text{drop}} &= I_{\text{out}} \times R_{\text{out}} \\
V_{\text{out}} &= -(V_{\text{in}} - V_{\text{drop}})
\end{align*}
\]

Figure 20. Test Setup/Voltage Inverter

Figure 21. Ideal Switched Capacitor Charge Pump

Charge Pump Efficiency

The overall power efficiency of the charge pump is affected by four factors:

1. Losses from power consumed by the internal oscillator, switch drive, etc. (which vary with input voltage, temperature and oscillator frequency).
2. I^2R losses due to the on–resistance of the MOSFET switches on–board the charge pump.
3. Charge pump capacitor losses due to Equivalent Series Resistance (ESR).
4. Losses that occur during charge transfer from the commutation capacitor to the output capacitor when a voltage difference between the two capacitors exists.

Most of the conversion losses are due to factors 2, 3 and 4. These losses are given by Equation 1.

\[
P_{\text{loss}}(2,3,4) = I_{\text{out}}^2 \times R_{\text{out}} \approx I_{\text{out}}^2 \times \frac{1}{\left(\frac{t_{\text{osc}}}{C_1}\right) + 8R_{\text{SWITCH}} + 4ER_{C_1} + ER_{C_2}}
\]

(eq. 1)

The 1/(fOSC)(C1) term in Equation 1 is the effective output resistance of an ideal switched capacitor circuit (Figures 22 and 23).

The losses due to charge transfer above are also shown in Equation 2. The output voltage ripple is given by Equation 3.

\[
P_{\text{loss}} = [0.5C_1 (V_{\text{in}}^2 - V_{\text{out}}^2) + 0.5C_2 (V_{\text{RIPPLE}}^2 - 2V_{\text{out}}V_{\text{RIPPLE}})] \times f_{\text{osc}}
\]

(eq. 2)

\[
V_{\text{RIPPLE}} = \frac{I_{\text{out}}}{(f_{\text{osc}})} + (2I_{\text{out}})(ER_{C_2})
\]

(eq. 3)

Figure 22. Ideal Switched Capacitor Model

Figure 23. Equivalent Output Resistance

http://onsemi.com
Capacitor Selection

In order to maintain the lowest output resistance and output ripple voltage, it is recommended that low ESR capacitors be used. Additionally, larger values of C1 will lower the output resistance and larger values of C2 will reduce output voltage ripple. (See Equation 3).

Table 1 shows various values of C1, C2 and C3 with the corresponding output resistance values at 25°C. Table 2 shows the output voltage ripple for various values of C1, C2 and C3. The data in Tables 1 and 2 was measured not calculated.

### Table 1. Output Resistance vs. Capacitance

<table>
<thead>
<tr>
<th>C1 = C2 = C3 (µF)</th>
<th>MAX828 R_out (Ω)</th>
<th>MAX829 R_out (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>127.2</td>
<td>55.7</td>
</tr>
<tr>
<td>1.4</td>
<td>67.7</td>
<td>36.8</td>
</tr>
<tr>
<td>3.3</td>
<td>36</td>
<td>26.0</td>
</tr>
<tr>
<td>7.3</td>
<td>26.7</td>
<td>24.9</td>
</tr>
<tr>
<td>10</td>
<td>25.9</td>
<td>25.1</td>
</tr>
<tr>
<td>24</td>
<td>24.3</td>
<td>25.2</td>
</tr>
<tr>
<td>50</td>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>

### Table 2. Output Voltage Ripple vs. Capacitance

<table>
<thead>
<tr>
<th>C1 = C2 = C3 (µF)</th>
<th>MAX828 Ripple (mV)</th>
<th>MAX829 Ripple (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>377.5</td>
<td>320</td>
</tr>
<tr>
<td>1.4</td>
<td>360.5</td>
<td>234</td>
</tr>
<tr>
<td>3.3</td>
<td>262</td>
<td>121</td>
</tr>
<tr>
<td>7.3</td>
<td>155</td>
<td>62.1</td>
</tr>
<tr>
<td>10</td>
<td>126</td>
<td>51.25</td>
</tr>
<tr>
<td>24</td>
<td>55.1</td>
<td>25.2</td>
</tr>
<tr>
<td>50</td>
<td>36.6</td>
<td>27.85</td>
</tr>
</tbody>
</table>

Voltage Inverter

The most common application for a charge pump is the voltage inverter (Figure 20). This application uses two or three external capacitors. The capacitors C1 (pump capacitor) and C2 (output capacitor) are required. The input bypass capacitor C3, may be necessary depending on the application. The output is equal to \(-V_{\text{in}}\) plus any voltage drops due to loading. Refer to Tables 1 and 2 for capacitor selection. The test setup used for the majority of the characterization is shown in Figure 20.

Layout Considerations

As with any switching power supply circuit, good layout practice is recommended. Mount components as close together as possible to minimize stray inductance and capacitance. Also use a large ground plane to minimize noise leakage into other circuitry.

Capacitor Resources

Selecting the proper type of capacitor can reduce switching loss. Low ESR capacitors are recommended. The MAX828 and MAX829 were characterized using the capacitors listed in Table 3. This list identifies low ESR capacitors for the voltage inverter application.

### Table 3. Capacitor Types

<table>
<thead>
<tr>
<th>Manufacturer/Contact</th>
<th>Part Types/Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVX</td>
<td>TPS</td>
</tr>
<tr>
<td>843–448–9411</td>
<td><a href="http://www.avxcorp.com">www.avxcorp.com</a></td>
</tr>
</tbody>
</table>

| Cornell Dubilier     | ESRD              |
| 508–996–8561         | www.cornell-dubilier.com |

| Sanyo/Os–con          | SN SVP            |
| 619–661–6835          | www.sanyovideo.com/oscon.htm |

| Vishay               | 593D 594         |
| 603–224–1961         | www.vishay.com   |

Input Supply Bypassing

The input voltage, \(V_{\text{in}}\) should be capacitively bypassed to reduce AC impedance and minimize noise effects due to the switching internals in the device. If the device is loaded from \(V_{\text{out}}\) to GND, it is recommended that a large value capacitor (at least equal to \(C_1\)) be connected from \(V_{\text{in}}\) to GND. If the device is loaded from \(V_{\text{in}}\) to \(V_{\text{out}}\) a small (0.7 µF) capacitor between the pins is sufficient.

Figure 24. Voltage Inverter

---

http://onsemi.com 7
The MAX828 / 829 primary function is a voltage inverter. The device will convert 5.0 V into −5.0 V with light loads. Two capacitors are required for the inverter to function. A third capacitor, the input bypass capacitor, may be required depending on the power source for the inverter. The performance for this device is illustrated below.

Two or more devices can be cascaded for increased output voltage. Under light load conditions, the output voltage is approximately equal to \(-V_{in}\) times the number of stages. The converter output resistance increases dramatically with each additional stage. This is due to a reduction of input voltage to each successive stage as the converter output is loaded. Note that the ground connection for each successive stage must connect to the negative output of the previous stage. The performance characteristics for a converter consisting of two cascaded devices are shown below.
A single device can be used to construct a negative voltage doubler. The output voltage is approximately equal to \(-2V_{in}\), minus the forward voltage drop of each external diode. The performance characteristics for the above converter are shown below. Note that curves A and C show the circuit performance with economical 1N4148 diodes, while curves B and D are with lower loss MBRA120E Schottky diodes.
A single device can be used to construct a negative voltage tripler. The output voltage is approximately equal to $-3V_{in}$ minus the forward voltage drop of each external diode. The performance characteristics for the above converter are shown below. Note that curves A and C show the circuit performance with economical 1N4148 diodes, while curves B and D are with lower loss MBRA120E Schottky diodes.
A single device can be used to construct a positive voltage doubler. The output voltage is approximately equal to $2V_{in}$ minus the forward voltage drop of each external diode. The performance characteristics for the above converter are shown below. Note that curves A and C show the circuit performance with economical 1N4148 diodes, while curves B and D are with lower loss MBRA120E Schottky diodes.
A single device can be used to construct a positive voltage tripler. The output voltage is approximately equal to $3V_{in}$ minus the forward voltage drop of each external diode. The performance characteristics for the above converter are shown below. Note that curves A and C show the circuit performance with economical 1N4148 diodes, while curves B and D are with lower loss MBRA120E Schottky diodes.
An increase in converter output current capability with a reduction in output resistance can be obtained by paralleling two or more devices. The output current capability is approximately equal to the number of devices paralleled. A single shared output capacitor is sufficient for proper operation but each device does require its own pump capacitor. Note that the output ripple frequency will be complex since the oscillators are not synchronized. The output resistance is approximately equal to the output resistance of one device divided by the total number of devices paralleled. The performance characteristics for a converter consisting of two paralleled devices is shown below.
The output current capability of the MAX828 and MAX829 can be extended beyond 600 mA with the addition of two external switch transistors and two Schottky diodes. The output voltage is approximately equal to $-V_{in}$ minus the sum of the base emitter drops of both transistors and the forward voltage of both diodes. The performance characteristics for the converter are shown below. Note that the output resistance is reduced to 0.9 and 1.0 ohms for the 828 and 829 respectively.
The MAX828/829 can be configured to produce a positive output voltage doubler with current capability in excess of 500 mA. This is accomplished with the addition of two external switch transistors and two Schottky diodes. The output voltage is approximately equal to $2V_{in}$ minus the sum of the base emitter drops of both transistors and the forward voltage of both diodes. The performance characteristics for the converter are shown below. Note that the output resistance is reduced to 1.8 $\Omega$. 

**Figure 48. Positive Output Voltage Doubler with High Current Capability**

- MAX828: Capacitors = 220 $\mu$F
- Q1 = PZT751
- Q2 = PZT651

**Figure 49. Positive Doubler with Current Boosted Load Regulation, Output Voltage vs. Output Current, MAX828**

- $V_{in} = 5.0$ V
- $R_{out} = 1.8 \Omega$
- $T_A = 25^\circ$C

**Figure 50. Positive Doubler with Current Boosted Load Regulation, Output Voltage vs. Output Current, MAX829**

- $V_{in} = 5.0$ V
- $R_{out} = 1.8 \Omega$
- $T_A = 25^\circ$C

**Figure 51. A Positive Doubler, with a Negative Inverter**

- MAX828: Capacitors = 10 $\mu$F
- MAX829: Capacitors = 3.3 $\mu$F
All of the previously shown converter circuits have only single outputs. Applications requiring multiple outputs can be constructed by incorporating combinations of the former circuits. The converter shown above combines Figures 24 and 36 to form a negative output inverter with a positive output doubler. Different combinations of load regulation are shown below. In Figures 52 and 53 the positive doubler has a constant $I_{\text{out}} = 15$ mA while the negative inverter has the variable load. In Figures 54 and 55 the negative inverter has the constant $I_{\text{out}} = 15$ mA and the positive doubler has the variable load.
MECHANICAL CASE OUTLINE

PACKAGE DIMENSIONS

TSOP-5
CASE 483
ISSUE N

DATE 12 AUG 2020

NOTES:
2. CONTROLLING DIMENSION: MILLIMETERS.
3. MAXIMUM LEAD THICKNESS INCLUDES LEAD FINISH THICKNESS. MINIMUM LEAD THICKNESS IS THE MINIMUM THICKNESS OF BASE MATERIAL.
4. DIMENSIONS A AND B DO NOT INCLUDE MOLD FLASH, PROTRUSIONS, OR GATE BURRS. MOLD FLASH, PROTRUSIONS, OR GATE BURRS SHALL NOT EXCEED 0.15 PER SIDE. DIMENSION A.
5. OPTIONAL CONSTRUCTION: AN ADDITIONAL TRIMMED LEAD IS ALLOWED IN THIS LOCATION. TRIMMED LEAD NOT TO EXTEND MORE THAN 0.2 FROM BODY.

SOLDERING FOOTPRINT*

*For additional information on our Pb−Free strategy and soldering details, please download the onsemi Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

G 0.95 0.037

H 0.7 0.028

SCALE 10:1 (mm inches)

GENERAL MARKING DIAGRAM*

XXX = Specific Device Code
A = Assembly Location
Y = Year
W = Work Week
M = Date Code

(Note: Microdot may be in either location)

*This information is generic. Please refer to device data sheet for actual part marking. Pb−Free indicator, “G” or microdot “*”, may or may not be present. Some products may not follow the Generic Marking.

DOCUMENT NUMBER: 98ARB18753C
DESCRIPTION: TSOP-5

© Semiconductor Components Industries, LLC, 2018 www.onsemi.com

onsemi and ON Semiconductor are trademarks of Semiconductor Components Industries, LLC dba onsemi or its subsidiaries in the United States and/or other countries. onsemi reserves the right to make changes without further notice to any products herein. onsemi makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does onsemi assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. onsemi does not convey any license under its patent rights nor the rights of others.