FAN4603
500mA, Fully Integrated, Buck Power Supply Module

Features
- Solder and Play DC/DC Converter; No External Components Required
- Up to 91% Efficiency
- 500mA Output Current Capability
- 2.3V to 5.5V Input Voltage Range
- Fixed Output Voltages from 1.2V to 1.8V
- 35µA PFM Quiescent Current
- Best-in-Class Load and Line Transient Response
- ±4% PWM DC Voltage Accuracy
- No External Components Required
- High-Efficiency, Low-Ripple, Light-Load PFM
- Thermal Shutdown (TSD), Under-Voltage Lockout, (UVLO), and Short-Circuit (SCP) Protection
- 4.0 x 2.5mm MLP Package
- Maximum Height: 1.1mm

Description
The FAN4603 is a fully integrated synchronous DC/DC buck converter that provides up to 500mA of output current over an input voltage ranging from 2.3V to 5.5V. It provides a fixed output voltage level ranging from 1.2V to 1.8V. Other voltage options are available on request.

The FAN4603 converter is offered as an ultra-miniature “Solder and Play” solution that requires no external components and is able to achieve a DC accuracy of ±4% PWM and an output ripple less than 12mV.

Total footprint is 4.0 x 2.5mm with a maximum height of 1mm. It can be used in small battery-powered devices and applications with distributed DC POL requirements.

At moderate and light loads, pulse frequency modulation is used to operate the device in power-save mode with a typical quiescent current of 35µA. Even with such a low quiescent current, the part exhibits excellent transient response during large load swings. At higher loads, the system automatically switches to fixed-frequency control.

In shutdown mode, the supply current drops below 2µA, reducing power consumption.

Applications
- POL and Distributed DC-DC Module Applications
- Small Form Factor, Battery-Powered Applications
- POL Core Power for FPGA, DSP, CPU, and GPU with Fast-Transient, Wide Dynamic Load Requirements
- Wireless Cards, Meters, Hearing Aids, Bluetooth Headsets, POS Equipment, VOIP, PDAs, MIDs, Netbooks, and Servers

Ordering Information

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Output Voltage(1)</th>
<th>Package</th>
<th>Temperature Range</th>
<th>Packing</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAN4603MM18X</td>
<td>1.82V</td>
<td>6 Lead Molded Leadless Package (MLP), 4 x 2.5 x 1mm</td>
<td>–40 to 85°C</td>
<td>Tape and Reel</td>
</tr>
<tr>
<td>FAN4603MM15X</td>
<td>1.5V</td>
<td>6 Lead Molded Leadless Package (MLP), 4 x 2.5 x 1mm</td>
<td>–40 to 85°C</td>
<td>Tape and Reel</td>
</tr>
<tr>
<td>FAN4603MM12X</td>
<td>1.23V</td>
<td>6 Lead Molded Leadless Package (MLP), 4 x 2.5 x 1mm</td>
<td>–40 to 85°C</td>
<td>Tape and Reel</td>
</tr>
</tbody>
</table>

Note:
1. Other voltage options are available on request. Contact a Fairchild representative.
Typical Application

Figure 1. Typical Application

Pin Configuration

Figure 2. MLP 4.0 x 2.5 mm (Top View)  Figure 3. 3D Package View

Pin Definitions

<table>
<thead>
<tr>
<th>Pin #</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VIN</td>
<td>Input Voltage. Connect to input power source</td>
</tr>
<tr>
<td>2</td>
<td>EN</td>
<td>Enable. The device is in shutdown mode when voltage to this pin is &lt;0.4V and enabled when &gt;1.2V. Do not leave this pin floating.</td>
</tr>
<tr>
<td>3</td>
<td>SW</td>
<td>Switching Node. Leave this pin floating.</td>
</tr>
<tr>
<td>4</td>
<td>VOUT</td>
<td>Output Voltage. Connect to Load.</td>
</tr>
<tr>
<td>5</td>
<td>FB</td>
<td>Feedback/V&lt;sub&gt;OUT&lt;/sub&gt;. This pin must be shorted directly to VOUT (Pin 4)</td>
</tr>
<tr>
<td>6</td>
<td>GND</td>
<td>Ground. Power and IC ground. All signals are referenced to this pin.</td>
</tr>
<tr>
<td>P1</td>
<td>GND</td>
<td>Optional Ground Connection. Not typically used.</td>
</tr>
</tbody>
</table>
Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Min.</th>
<th>Max.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIN</td>
<td>Input Voltage with Respect to GND</td>
<td>-0.3</td>
<td>6.0</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>Voltage on Any Other Pin with Respect to GND</td>
<td>-0.3</td>
<td>VIN</td>
<td>V</td>
</tr>
<tr>
<td>TJ</td>
<td>Junction Temperature</td>
<td>-40</td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>TSTG</td>
<td>Storage Temperature</td>
<td>-65</td>
<td>+150</td>
<td>°C</td>
</tr>
<tr>
<td>TL</td>
<td>Lead Temperature (Soldering, 10 Seconds)</td>
<td></td>
<td>+260</td>
<td>°C</td>
</tr>
<tr>
<td>ESD</td>
<td>Electrostatic Discharge Capability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Human Body Model JESD22-A114</td>
<td>6</td>
<td></td>
<td>kV</td>
</tr>
<tr>
<td></td>
<td>Charged Device Model, JESD22-C101</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Recommended Operating Conditions

The Recommended Operating Conditions table defines the conditions for actual device operation. Recommended operating conditions are specified to ensure optimal performance to the datasheet specifications. Fairchild does not recommend exceeding them or designing to Absolute Maximum Ratings.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Min.</th>
<th>Max.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCC</td>
<td>Supply Voltage Range</td>
<td>2.3</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>IOUT</td>
<td>Output Current</td>
<td>0</td>
<td>500</td>
<td>mA</td>
</tr>
<tr>
<td>TA</td>
<td>Operating Ambient Temperature</td>
<td>-40</td>
<td>+85</td>
<td>°C</td>
</tr>
<tr>
<td>TJ</td>
<td>Operating Junction Temperature</td>
<td>-40</td>
<td>+125</td>
<td>°C</td>
</tr>
</tbody>
</table>

Thermal Properties

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Typical</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΘJA</td>
<td>Junction-to-Ambient Thermal Resistance$^{(2)}$</td>
<td>120</td>
<td>°C/W</td>
</tr>
</tbody>
</table>

Note:

2. Junction-to-ambient thermal resistance is a function of application and board layout. This data is measured with a two-layer 2s0p board in accordance to the JESD51- JEDEC standard. Special attention must be paid not to exceed junction temperature $T_J(\text{max})$ at a given ambient temperature $T_A$.  

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## Electrical Specifications

Unless otherwise noted, $V_{IN}$ = 2.5 to 5.5V, EN = $V_{IN}$. $T_A$ = -40°C to +85°C, using circuit of Figure 1. Typical values are at 3.6$V_{IN}$, $T_A$ = 25°C.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_Q$</td>
<td>Quiescent Current</td>
<td></td>
<td>35</td>
<td>55</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>$I_{SD}$</td>
<td>Shutdown Supply Current</td>
<td>$V_{IN}$ = 3.6V, EN = GND</td>
<td>0.1</td>
<td>2.0</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>$V_{UVLO}$</td>
<td>Under-Voltage Lockout Threshold</td>
<td>Rising $V_{IN}$</td>
<td>2.15</td>
<td>2.25</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>$V_{UVHYST}$</td>
<td>Under-Voltage Lockout Hysteresis</td>
<td></td>
<td>150</td>
<td>mV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{ENH}$</td>
<td>Enable HIGH-Level Input Voltage</td>
<td></td>
<td>1.2</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{ENL}$</td>
<td>Enable LOW-Level Input Voltage</td>
<td></td>
<td>0.4</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{EN_HYS}$</td>
<td>Enable Logic Input Hysteresis</td>
<td></td>
<td>100</td>
<td>mV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{EN}$</td>
<td>Enable Input Leakage Current</td>
<td>EN = $V_{IN}$ or GND</td>
<td>0.01</td>
<td>1.00</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>$f_{OSC}$</td>
<td>Oscillator Frequency</td>
<td>PWM Mode</td>
<td>5.4</td>
<td>6.0</td>
<td>6.6</td>
<td>MHz</td>
</tr>
<tr>
<td>$V_O$</td>
<td>Output Voltage Accuracy</td>
<td></td>
<td>1.82V</td>
<td>1.750</td>
<td>1.820</td>
<td>1.890</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>1.50V</td>
<td>1.440</td>
<td>1.500</td>
<td>1.560</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.23V</td>
<td>1.185</td>
<td>1.233</td>
<td>1.283</td>
</tr>
<tr>
<td>$t_{SS}$</td>
<td>Soft-Start Time</td>
<td>Rising EN to $V_{OUT}$ Regulation</td>
<td>180</td>
<td>300</td>
<td>µs</td>
<td></td>
</tr>
<tr>
<td>$I_{UM}$</td>
<td>Peak Input Current Limit</td>
<td></td>
<td>850</td>
<td>1050</td>
<td>1250</td>
<td>mA</td>
</tr>
<tr>
<td>$T_{SD}$</td>
<td>Thermal Shutdown</td>
<td>CCM Only</td>
<td></td>
<td>+150</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>$HYS_{TSD}$</td>
<td>Thermal Shutdown Hysteresis</td>
<td></td>
<td></td>
<td>15</td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>
Typical Performance

Unless otherwise specified, $V_{IN} = 3.7V$, $T_A = 25^\circ C$.

Figure 4. 1.82V$_{OUT}$ Efficiency

Figure 5. 1.82V$_{OUT}$ Efficiency Over Temperature

Figure 6. 1.82V$_{OUT}$ Regulation (Normalized)

Figure 7. 1.82V$_{OUT}$ Regulation (Normalized) Over Temperature

Figure 8. Quiescent Current Over Temperature (EN=V$_{IN}$)

Figure 9. Shutdown Current Over Temperature (EN=0V)
Typical Performance

Unless otherwise specified, $V_{IN} = 3.7V$, $T_A = 25°C$.

Figure 10. 1.82V\textsubscript{OUT} Output Ripple with Optional 2.2\mu F C\textsubscript{OUT} (1.5\mu F Actual)

Figure 11. 1.82V\textsubscript{OUT} Regulation (Normalized) with Optional 2.2\mu F C\textsubscript{OUT} (1.5\mu F Actual)

Figure 12. 1.23 V\textsubscript{OUT} Efficiency

Figure 13. 1.23 V\textsubscript{OUT} Efficiency Over Temperature

Figure 14. 1.23V\textsubscript{OUT} Regulation (Normalized)

Figure 15. 1.23V\textsubscript{OUT} Regulation (Normalized) Over Temperature
Typical Performance

Unless otherwise specified, \( V_{IN} = 3.7 \text{V}, T_A = 25^\circ \text{C} \).

Figure 16. 1.82\( V_{OUT} \) PFM / PWM Boundary

Figure 17. 1.23\( V_{OUT} \) PFM / PWM Boundary

Figure 18. 1.82\( V_{OUT} \) Startup, 3.7\( V_{IN} \), No Load

Figure 19. 1.82\( V_{OUT} \) Startup, 3.7\( V_{IN} \), 3.6\( \Omega \) Load

Figure 20. 1.82\( V_{OUT} \) Startup into Pre-Charged Output, 3.7\( V_{IN} \), 300mA Load

Figure 21. Over-Current Protection, 300mA Load Transition to 300\( \Omega \) Fault
Typical Performance

Unless otherwise specified, \( V_{\text{IN}} = 3.7 \text{V} \), \( T_A = 25^\circ \text{C} \).

Figure 22. 1.82V\textsubscript{OUT} Load Transient, 10-160mA, 
\( t_r/t_f=100\text{ns} \)

Figure 23. 1.82V\textsubscript{OUT} Load Transient, 150-500mA,  
\( t_r/t_f=100\text{ns} \)

Figure 24. 1.82V\textsubscript{OUT} Load Transient, 10-160mA,  
\( t_r/t_f=100\text{ns} \) with Optional 2.2µF \( C_{\text{OUT}} \)

Figure 25. 1.82V\textsubscript{OUT} Load Transient, 150-500mA,  
\( t_r/t_f=100\text{ns} \) with Optional 2.2µF \( C_{\text{OUT}} \)

Figure 26. 1.82V\textsubscript{OUT} Line Transient, 3.6-4.2VIN, 
\( t_b/t_f=10\mu\text{s} \), with 10mA Load

Figure 27. 1.82V\textsubscript{OUT} Line Transient, 3.6-4.2VIN,  
\( t_b/t_f=10\mu\text{s} \), with 300mA Load
Operation Description

The FAN4603 is a 500mA, step-down, switching-voltage regulator that delivers a fixed output from an input voltage supply of 2.3V to 5.5V. Using a proprietary architecture with synchronous rectification, the FAN4603 is capable of delivering a peak efficiency of >90%, while maintaining efficiency over 80% at load currents as low as 1mA. The regulator operates at a nominal PWM frequency of 6MHz.

Control Scheme

The FAN4603 uses a proprietary, non-linear, fixed-frequency PWM modulator to deliver a fast load transient response, while maintaining a constant switching frequency over a wide range of operating conditions. Regulator stability is not dependent on output capacitor ESR, which allows the use of ceramic capacitors. Although this type of operation normally results in a switching frequency that varies with input voltage and load current, an internal frequency loop holds the switching frequency constant over a large range of input voltages and load currents.

For very light loads, FAN4603 incorporates a discontinuous current (DCM) single-pulse PFM mode, which produces lower output ripple when compared with other PFM architectures. Transition between PWM and PFM is seamless, with a glitch of less than 20mV at VOUT during the transition between DCM and CCM modes.

Combined with exceptional transient response characteristics, the very low quiescent current of the controller (35µA) maintains high efficiency; even at very light loads, while preserving fast transient response for applications requiring tight output regulation.

Enable and Soft-Start

When EN is LOW, all circuits in FAN4603 are off and the IC draws ~100nA of current. When EN is HIGH and VIN is above its UVLO threshold, the regulator begins a soft-start cycle. The output ramp during soft-start is a fixed slew rate of 50mV/µs from 0 to VOUT, then 12.5mV/µs until the output reaches its setpoint.

PWM mode operation is prohibited during the soft-start cycle to prevent COUT from being discharged. This allows glitchless starting into a pre-charged output.

Startup into Large COUT

The IC may fail to start if heavy load is applied during startup and a large external COUT is present. This is due to the current-limit fault response, which protects the IC in an overload condition during soft-start.

The current required to charge COUT during soft-start, referred to as “displacement current,” is given as:

\[ I_{\text{DISP}} = C_{\text{OUT}} \cdot \frac{dV}{dt} \]  

(1)

where \( \frac{dV}{dt} \) refers to the soft-start slew rate.

To prevent shutdown during soft-start, the following condition must be met:

\[ I_{\text{DISP}} + I_{\text{LOAD}} < I_{\text{MAX(DC)}} \]  

(2)

where \( I_{\text{MAX(DC)}} \) is the maximum load current the IC is guaranteed to support (500mA).

Table 1 shows combinations of external COUT that allow the IC to start successfully with the minimum RLOAD that can be supported at each.

<table>
<thead>
<tr>
<th>COUT</th>
<th>Minimum RLOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2µF, 0402</td>
<td>VOUT / 0.50</td>
</tr>
<tr>
<td>4.7µF, 0402</td>
<td>VOUT / 0.50</td>
</tr>
<tr>
<td>10µF, 0603</td>
<td>VOUT / 0.45</td>
</tr>
</tbody>
</table>

Multiple soft-start cycles may be required for COUT>10µF (15µF with no load). The IC shuts down for 85µs when \( I_{\text{DISP}} + I_{\text{LOAD}} \) exceeds \( I_{\text{MAX}} \) for more than 21µs of current limit. The IC then begins a new soft-start cycle. Subsequent soft-start cycles begin with any charge retained by COUT while the IC is off, allowing VOUT to incrementally reach regulation over multiple soft-start attempts.

Current Limit, Fault Shutdown, and Restart

A heavy load or short circuit on the output causes the current to increase until a maximum current threshold is reached. Upon reaching this point, the high-side switch turns off, preventing high currents from causing damage. The regulator continues to limit the current cycle-by-cycle. After 21µs of current limit, the regulator triggers an over-current fault, causing the regulator to shut down for about 85µs before attempting an automatic restart.

If the fault is caused by short circuit, the soft-start circuit attempts to restart and produces an over-current fault after about 32µs, which results in a duty cycle of less than 30%, limiting power dissipation.
Under-Voltage Lockout (UVLO)
When EN is HIGH, the under-voltage lockout keeps the part from operating until the input supply voltage rises high enough to properly operate. This ensures no misbehavior of the regulator during startup or shutdown.

Thermal Shutdown
When the die temperature increases, due to a high load condition and/or a high ambient temperature, the output switching is disabled until the temperature on the die has fallen sufficiently. The junction temperature at which the thermal shutdown activates is nominally 150°C with 15°C hysteresis. After cooling, the IC automatically restarts, with a soft-start cycle.

Reducing PFM Output Ripple
PFM output ripple amplitude can be reduced by adding external $C_{OUT}$, with negligible impact on efficiency.

Reduced output ripple also results in less DC voltage excursion at very light loads. Maximum PFM ripple occurs at no load and is $V_{IN}$ and $V_{OUT}$ proportional.

![Figure 28. Typical 1.82V_{OUT} No Load PFM Ripple vs. V_{IN}](image)

Note:
3. Ripple is less for lower $V_{OUT}$ levels.

The effective value of external $C_{OUT}$ for a desired ripple amplitude can be determined using:

$$C_{OUT, \mu F} = \left( \frac{V_{IN} - V_{OUT}}{V_{OUT} \times 62} \right) \times \frac{V_{OUT}}{V_{IN} \times V_{R}} - 1$$  \hspace{1cm} (3)

where $V_{R}$ is the desired output ripple amplitude in mV and $V_{IN}$ and $V_{OUT}$ are in Volts.

The simplified equation above is representative of nominal component values and does not account for device tolerances. The bias level effects associated with case size, voltage rating, and dielectric type of ceramic capacitors should be considered when selecting $C_{OUT}$.

Minimum Off-Time Effect on Switching Frequency
$t_{OFF(MIN)}$ is 50ns. This imposes constraints on the maximum $\frac{V_{OUT}}{V_{IN}}$ that the FAN4603 can provide or the maximum output voltage it can provide at low $V_{IN}$, while maintaining a fixed switching frequency in PWM mode.

When $V_{IN}$ is LOW, fixed switching is maintained as long as $\frac{V_{OUT}}{V_{IN}} \leq 1 - t_{OFF(MIN)} \cdot f_{SW} \approx 0.7$.

The switching frequency drops when the regulator cannot provide sufficient duty cycle at 6MHz to maintain regulation.

The calculation for reduced switching frequency to maintain regulation is given by:

$$f_{SW} = \frac{1}{t_{SW(MAX)}}$$  \hspace{1cm} (4)

where:

$$t_{SW(MAX)} = 50ns \cdot \left( 1 + \frac{V_{OUT} + 0.36 \cdot I_{OUT}}{V_{IN} - V_{OUT} - 0.52 \cdot I_{OUT}} \right)$$  \hspace{1cm} (5)

where V and I terms are in Volts and Amperes, respectively.

PCB Layout Guideline

FB (pin 5) must be directly connected to VOUT (pin 4).

Figure 29 shows the recommended locations of optional $C_{IN}$ and $C_{OUT}$, shown as 0603 size devices.

Pad P1 shown in Figure 30 “Land Pattern” is for reference only and should not be connected on PCB.
Physical Dimensions

Figure 30.6-Lead, MicroModule QFN 2.5 x 4 x 1mm

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**ANTI-COUNTERFEITING POLICY**
Fairchild Semiconductor Corporation's Anti-Counterfeiting Policy. Fairchild's Anti-Counterfeiting Policy is also stated on our external website, www.fairchildsemi.com, under Sales Support.

Counterfeiting of semiconductor parts is an growing problem in the industry. All manufacturers of semiconductor products are experiencing counterfeiting of their parts.

Customers who inadvertently purchase counterfeit parts experience many problems such as loss of brand reputation, substandard performance, failed applications, and increased cost of production and manufacturing delays. Fairchild is taking strong measures to protect ourselves and our customers from the proliferation of counterfeit parts. Fairchild strongly encourages customers to purchase Fairchild parts either directly from Fairchild or from Authorized Fairchild Distributors who are listed by country on our web site cited above. Products customers buy either from Fairchild directly or from Authorized Fairchild Distributors are genuine parts, have full traceability, meet Fairchild's quality standards for handling and storage and provide access to Fairchild's full range of up-to-date technical and product information.

Fairchild and our Authorized Distributors will stand behind all warranties and will appropriately address any warranty issues that may arise. Fairchild will not provide any warranty coverage or other assistance for parts bought from Unauthorized Sources. Fairchild is committed to combat this global problem and encourage our customers to use parts from proper Fairchild and authorized distributors.

**PRODUCT STATUS DEFINITIONS**

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<thead>
<tr>
<th>Definition of Terms</th>
<th>Datasheet Identification</th>
<th>Product Status</th>
<th>Definition</th>
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<td>Advance Information</td>
<td>Formative / In Design</td>
<td>Datasheet contains the design specifications for product development. Specifications may change in any manner without notice.</td>
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<td>Preliminary</td>
<td>First Production</td>
<td>Datasheet contains preliminary data; supplementary data will be published at a later date. Fairchild Semiconductor reserves the rights to make changes at any time without notice to improve design.</td>
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<td>Datasheet contains final specifications. Fairchild Semiconductor reserves the rights to make changes at any time without notice to improve the design.</td>
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<td>Datasheet contains specifications on a product that is discontinued by Fairchild Semiconductor. The datasheet is for reference information only.</td>
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