

FEATURES

- Peak efficiency: 92%
- Operating frequency: 6 MHz
- Typical quiescent current in auto mode: 36 μ A
- Fixed output voltage: 1.8 V, 1.82 V, 1.85 V, 1.875 V, 2.3 V
- Maximum guaranteed load current: 600 mA at $V_{IN} = 2.7$ V to 5.5 V
- Input voltage: 2.3 V to 5.5 V
- Typical shutdown supply current: 0.3 μ A
- Automatic power-saving mode
- Compatible with tiny multilayer inductors
- Internal synchronous rectifier
- Internal compensation
- Internal soft start
- Output to ground short-circuit protection
- Cycle-by-cycle current-limit protection
- Enable/shutdown logic input
- Undervoltage lockout
- Thermal shutdown protection
- Ultrasmall 6-ball, 0.4 mm pitch, 1.17 mm² WLCSP

APPLICATIONS

- Mobile phones
- Digital cameras
- Digital audio
- Portable equipment

GENERAL DESCRIPTION

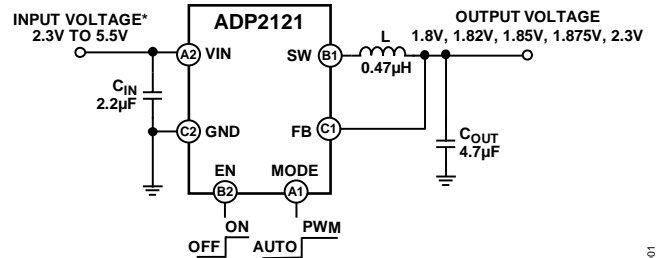
The ADP2121 is a high frequency, low quiescent current step-down dc-to-dc converter optimized for portable applications in which board area and battery life are critical constraints. The 6 MHz operating frequency enables the use of tiny ceramic inductors and capacitors. Additionally, the synchronous rectification improves efficiency and results in fewer external components.

At high load currents, the device uses a voltage regulating pulse-width modulation (PWM) mode that maintains a constant frequency with excellent stability and transient response. In forced PWM mode, the converter continues operating in PWM for light loads. At light load conditions in auto mode, the ADP2121 can automatically enter a power-saving mode that uses pulse-frequency modulation (PFM) to reduce the effective switching frequency and ensure the longest battery life in portable applications. During logic controlled shutdown ($EN \leq 0.4$ V), the input is disconnected from the output and draws less than 0.3 μ A current (typical) from the source.

Rev. B

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TYPICAL APPLICATION CIRCUIT



*FOR OUTPUT VOLTAGE = 2.3 V, INPUT VOLTAGE = 2.9 V TO 5.5V.

Figure 1.

TYPICAL PERFORMANCE

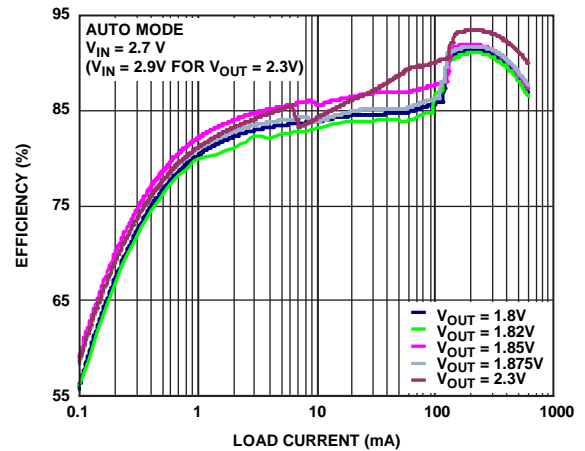


Figure 2. Efficiency vs. Load Current for Each Voltage Option

The ADP2121 has an input voltage range of 2.3 V to 5.5 V (2.9 V to 5.5 V for $V_{OUT} = 2.3$ V), allowing the use of a single Li+/Li-polymer cell, 3-cell alkaline or Ni-MH cell, and other standard power sources. The converter can source up to 600 mA and is internally compensated to minimize external components. Other key features, such as cycle-by-cycle peak current limit, soft start, undervoltage lockout (UVLO), output-to-ground short-circuit protection, and thermal shutdown, protect the internal and external circuit components.

Table 1. Output Voltage Options

| Input Voltage Range (V) | Typical Start-Up Time (μ s) | Fixed Output Voltage (V) |
|-------------------------|----------------------------------|--------------------------|
| 2.3 to 5.5 | 75 | 1.8, 1.85, 1.875 |
| 2.3 to 5.5 | 275 | 1.82 |
| 2.9 to 5.5 | 100 | 2.3 |

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REVISION HISTORY

1/11—Rev. A to Rev. B

| | |
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| Changes to Table 2 Summary..... | 3 |
| Changes to Undervoltage Lockout Threshold Parameter and Output Voltage Accuracy Parameter in Table 2 | 3 |

6/10—Rev. 0 to Rev. A

| | |
|---|---|
| Changes to Features, General Description, Figure 1, and Figure 2; Added Table 1; Renumbered Sequentially..... | 1 |
| Changes to Table 2..... | 3 |
| Changes to Table 3..... | 4 |
| Change to Typical Performance Characteristics Condition Statement; Reorganized Typical Performance Characteristics Section; Changes to Figure 4, Figure 6, Figure 7, and Figure 9; Added Figure 5 and Figure 8; Renumbered Sequentially | 6 |
| Changes to Figure 10 to Figure 12; Added Figure 13 to Figure 15... | 7 |

| | |
|--|----|
| Changes to Figure 16, Figure 17, Figure 19, and Figure 20..... | 8 |
| Changes to Figure 22; Added Figure 23 and Figure 24 | 9 |
| Added Figure 40, Figure 42, Figure 43, and Figure 45 | 12 |
| Added Figure 46 and Figure 48; Changes to Figure 47 | 13 |
| Changes to Figure 51 and the Overview Section | 14 |
| Changes to the Auto Mode (PFM and PWM Switching) Section, Figure 53, the Mode Transition Section, and the Enable/Shutdown Section..... | 15 |
| Changes to the Output Short-Circuit Protection Section and Figure 55 | 16 |
| Changes to the Output Capacitor Selection Section | 17 |
| Changes to Table 6, Table 7, and Table 8..... | 18 |
| Changes to Ordering Guide | 20 |

4/09—Revision 0: Initial Version

SPECIFICATIONS

$V_{IN} = EN = 3.6\text{ V}$; $V_{OUT} = 1.8\text{ V}, 1.82\text{ V}, 1.85\text{ V}, 1.875\text{ V}, \text{ and } 2.3\text{ V}$; typical values are at $T_A = 25^\circ\text{C}$; and minimum/maximum limits guaranteed for $T_J = -40^\circ\text{C}$ to $+125^\circ\text{C}$,¹ unless otherwise noted.

Table 2.

| Parameters | Conditions | Min | Typ | Max | Unit |
|--|--|--------------------------|--------------------------|-------------------|---|
| SUPPLY | | | | | |
| Input Voltage Range | $V_{OUT} = 1.8\text{ V}, 1.82\text{ V}, 1.85\text{ V}, 1.875\text{ V}$ $V_{OUT} = 2.3\text{ V}$ | 2.3 2.9 | | 5.5 5.5 | V |
| Quiescent Current | Auto mode, no load, not switching, $T_A = -40^\circ\text{C}$ to 85°C PWM mode, no load | | 36 10 | 56 | μA mA |
| Shutdown Current | $V_{OUT} = 1.8\text{ V}, 1.82\text{ V}, 1.85\text{ V}, 1.875\text{ V}, V_{EN} = 0\text{ V}, T_A = -40^\circ\text{C}$ to 85°C $V_{OUT} = 2.3\text{ V}, V_{EN} = 0\text{ V}, T_A = -40^\circ\text{C}$ to 85°C | | 0.3 0.4 | 1 1.5 | μA μA |
| UNDERVOLTAGE LOCKOUT | | | | | |
| Undervoltage Lockout Threshold | $V_{OUT} = 1.8\text{ V}, 1.82\text{ V}, 1.85\text{ V}, 1.875\text{ V}, V_{IN}$ rising $V_{OUT} = 1.8\text{ V}, 1.82\text{ V}, 1.85\text{ V}, 1.875\text{ V}, V_{IN}$ falling $V_{OUT} = 2.3\text{ V}, V_{IN}$ rising $V_{OUT} = 2.3\text{ V}, V_{IN}$ falling | | 2.1 1.6 2.4 1.9 | 2.3 2.0 2.6 | V V V V |
| OUTPUT | | | | | |
| Maximum Continuous Output Current ² | $V_{OUT} = 1.8\text{ V}, 1.82\text{ V}, 1.85\text{ V}, 1.875\text{ V}, V_{IN} = 2.3\text{ V}$ $V_{OUT} = 1.8\text{ V}, 1.82\text{ V}, 1.85\text{ V}, 1.875\text{ V}, V_{IN} = 2.5\text{ V}$ $V_{OUT} = 1.8\text{ V}, 1.82\text{ V}, 1.85\text{ V}, 1.875\text{ V}, V_{IN} = 2.7\text{ V to } 5.5\text{ V}$ $V_{OUT} = 2.3\text{ V}, V_{IN} = 2.9\text{ V to } 5.5\text{ V}$ | 300 500 600 600 | | | mA mA mA mA |
| Output Voltage Accuracy ³ | Auto mode, $V_{IN} = 3.6\text{ V}, T_A = 25^\circ\text{C}$, no load, with respect to V_{OUT} PWM mode, $V_{IN} = 2.5\text{ V to } 4.5\text{ V}$, no load, with respect to V_{OUT} | -3 -3 | | +3 +3 | % % |
| Load Regulation ⁴ | PWM mode, $I_{LOAD} = 1\text{ mA to } 600\text{ mA}$ | | -0.2 | | %/A |
| Feedback Bias Current | $V_{OUT} = 1.8\text{ V}, V_{FB} = 1.8\text{ V}$ and $V_{OUT} = 1.82\text{ V}, V_{FB} = 1.82\text{ V}$ $V_{OUT} = 1.85\text{ V}, V_{FB} = 1.85\text{ V}$ and $V_{OUT} = 1.875\text{ V}, V_{FB} = 1.875\text{ V}$ $V_{OUT} = 2.3\text{ V}, V_{FB} = 2.3\text{ V}$ | | 3.8 4.1 6.4 | 8 8 8 | μA μA μA |
| SWITCHING CHARACTERISTICS | | | | | |
| SW On Resistance (R_{DSON}) | P-channel switch N-channel synchronous rectifier | | 220 260 | 440 550 | $\text{m}\Omega$ $\text{m}\Omega$ |
| SW Leakage Current | $V_{IN} = 5.5\text{ V}, V_{SW} = 0\text{ V}$ and 5.5 V | | | 5 | μA |
| SW Current Limit | P-channel switch, open loop, $T_A = -40^\circ\text{C}$ to 125°C P-channel switch, open loop, $T_A = -40^\circ\text{C}$ to 85°C | 790 828 | 1000 1000 | 1222 1222 | mA mA |
| Oscillator Frequency | | 5.36 | 6 | 6.64 | MHz |
| EN/MODE INPUT LOGIC | | | | | |
| High Threshold Voltage | $V_{IN} = 2.3\text{ V to } 5.5\text{ V}$ | 1.3 | | | V |
| Low Threshold Voltage | | | | 0.4 | V |
| Leakage Current | $V_{IN} = V_{EN} = V_{MODE} = 5.5\text{ V}$ | | 0.01 | 1 | μA |
| SOFT START | | | | | |
| Soft Start Period ⁵ | Time from $EN \geq 1.2\text{ V}$ to stable V_{OUT} $V_{OUT} = 1.82\text{ V}, R_{LOAD} = 5.1\ \Omega$ $V_{OUT} = 1.8\text{ V}, 1.85\text{ V}, 1.875\text{ V}, R_{LOAD} = 5.1\ \Omega$ $V_{OUT} = 2.3\text{ V}, R_{LOAD} = 5.1\ \Omega$ | | 275 75 100 | 310 85 115 | μs μs μs |
| SHORT-CIRCUIT THRESHOLD | | | | | |
| | | | 1.24 | | V |
| THERMAL SHUTDOWN | | | | | |
| Thermal Shutdown Threshold | | | 150 | | $^\circ\text{C}$ |
| Thermal Shutdown Hysteresis | | | 15 | | $^\circ\text{C}$ |

¹ All limits at temperature extremes are guaranteed via correlation using standard statistical quality control (SQC); typical values are at $T_A = 25^\circ\text{C}$.

² Guaranteed by design. The maximum output current guarantee for 2.3 V to 2.5 V increases linearly from 300 mA to 500 mA. The maximum output current guarantee for 2.5 V to 2.7 V increases linearly from 500 mA to 600 mA. For greater than 2.7 V, the maximum output current guarantee is 600 mA.

³ Transients not included in voltage accuracy specifications. For PFM mode, the VOUT accuracy specification is for the upper point of the ripple.

⁴ The load regulation typical value includes all voltage options. The typical value is different for each voltage option, but can be up to $-0.2\%/A$.

⁵ Typical value characterized on bench. Maximum specification guaranteed by design. $C_{IN} = 2.2\ \mu\text{F}$ (GRM155R60J225M), $L = 0.47\ \mu\text{H}$ (LQM2HPNR47MG0L), $C_{OUT} = 4.7\ \mu\text{F}$ (GRM155R60J475ME87D).

ABSOLUTE MAXIMUM RATINGS

Table 3.

| Parameter | Rating |
|--|-----------------------|
| VIN to GND | −0.3 V to +6 V |
| EN, MODE to GND | −0.3 V to VIN |
| FB, SW to GND | −0.3 V to VIN + 0.2 V |
| Operating Ambient Temperature Range ($I_{LOAD} \leq 600$ mA) | −40°C to +85°C |
| Operating Junction Temperature Range | −40°C to +125°C |
| Storage Temperature | −45°C to +150°C |
| Soldering Conditions | JEDEC J-STD-020 |
| ESD (Electrostatic Discharge) Human Body Model | ±4 kV |

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

THERMAL DATA

Absolute maximum ratings apply individually only, not in combination. The ADP2121 can be damaged when the junction temperature limits are exceeded. Monitoring ambient temperature does not guarantee that the junction temperature (T_J) is within the specified temperature limits. In applications with high power dissipation and poor PCB thermal resistance, the maximum ambient temperature may need to be derated. In applications with moderate power dissipation and low PCB thermal resistance, the maximum ambient temperature can exceed the maximum limit as long as the junction temperature is within specification limits.

The junction temperature (T_J) of the device is dependent on the ambient temperature (T_A), the power dissipation of the device (P_D), and the junction-to-ambient thermal resistance of the package (θ_{JA}). Maximum junction temperature (T_J) is calculated from the ambient temperature (T_A) and power dissipation (P_D) using the following formula:

$$T_J = T_A + (P_D \times \theta_{JA})$$

The junction-to-ambient thermal resistance (θ_{JA}) of the package is based on modeling and calculation using a 2- and 4-layer board. The junction-to-ambient thermal resistance is highly dependent on the application and board layout. In applications where high maximum power dissipation exists, close attention to thermal board design is required.

The value of θ_{JA} may vary, depending on PCB material, layout, and environmental conditions. Refer to JEDEC JESD51-9 for detailed information about board construction.

THERMAL RESISTANCE

The junction-to-ambient thermal resistance of the system (θ_{JA}) is specified for worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages.

Table 4.

| Package Type | θ_{JA} | Unit |
|---------------|---------------|------|
| 6-Ball WLCSP | | |
| 2-Layer Board | 198 | °C/W |
| 4-Layer Board | 105 | °C/W |

ESD CAUTION



ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

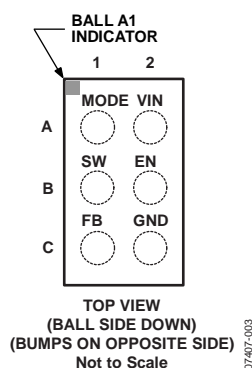


Figure 3. Pin Configuration

Table 5. Pin Function Descriptions

| Pin No. | Mnemonic | Description |
|---------|----------|--|
| A1 | MODE | Mode Select. This pin toggles between auto mode (PFM and PWM switching) and PWM mode. Set MODE low to allow the part to operate in auto mode. Pull MODE high to force the part to operate in PWM mode. The voltage applied to MODE should never be higher than the voltage applied to VIN. Do not leave this pin floating. |
| B1 | SW | Switch Node. |
| C1 | FB | Feedback Divider Input. Connect the output capacitor from FB to GND as close as possible to the ADP2121 to set the output voltage ripple and to complete the control loop. |
| A2 | VIN | Power Supply Input. Connect the input capacitor from VIN to GND as close as possible to the ADP2121. |
| B2 | EN | Enable. Pull this pin high to enable the part. Set this pin low to disable the part. Do not leave this pin floating. |
| C2 | GND | Ground Pin. |

TYPICAL PERFORMANCE CHARACTERISTICS

$V_{IN} = 3.6\text{ V}$, $V_{OUT} = 1.82\text{ V}$, $L = 0.47\text{ }\mu\text{H}$ (1800 mA, 1008, LQM2HPNR47MG0L), $C_{IN} = 2.2\text{ }\mu\text{F}$ (6.3 V, 0402, X5R, GRM155R60J225M), $C_{OUT} = 4.7\text{ }\mu\text{F}$ (6.3 V, 0402, X5R, GRM155R60J475ME87D), $EN = V_{IN}$, and $T_A = 25^\circ\text{C}$, unless otherwise noted.

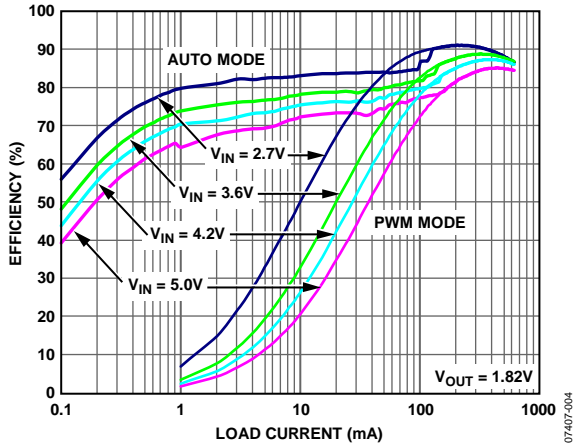


Figure 4. Efficiency vs. Load Current

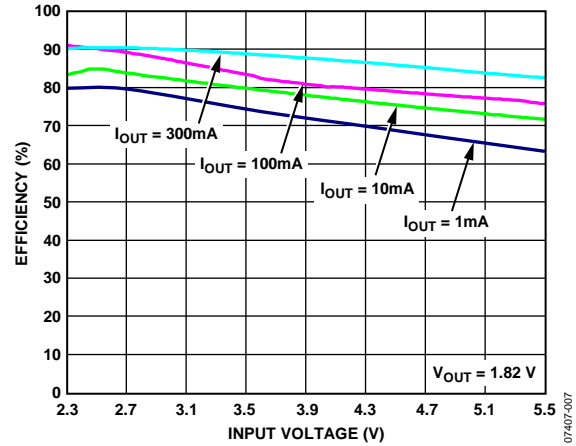


Figure 7. Efficiency vs. Input Voltage (Auto Mode)

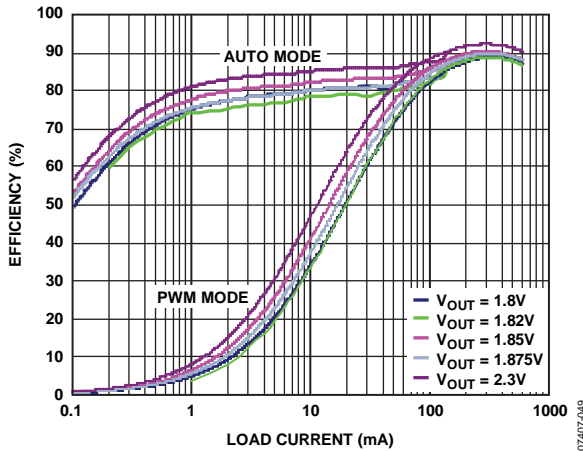


Figure 5. Efficiency vs. Load Current for All Output Voltages

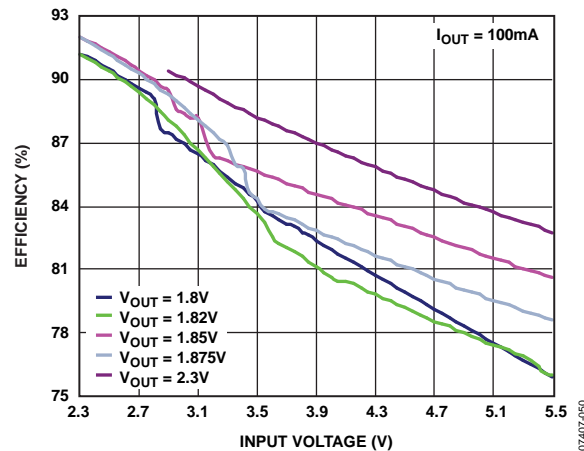


Figure 8. Efficiency vs. Input Voltage for All Output Voltages (Auto Mode)

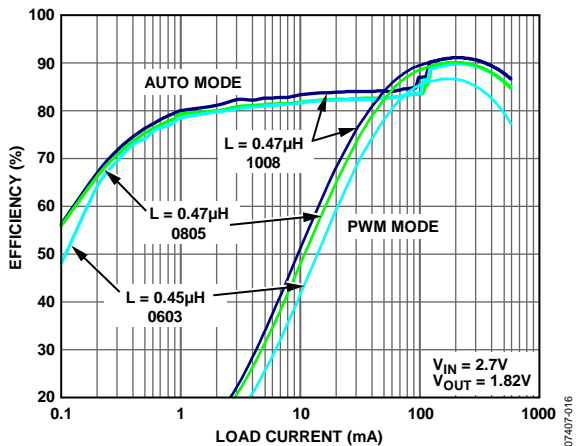


Figure 6. Efficiency vs. Load Current for Various Inductor Sizes

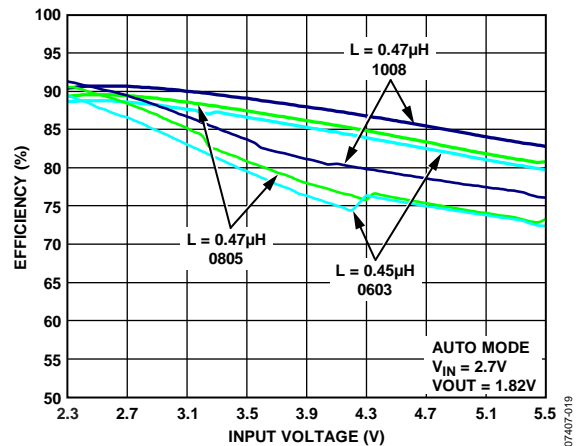


Figure 9. Efficiency vs. Input Voltage for Various Inductor Sizes

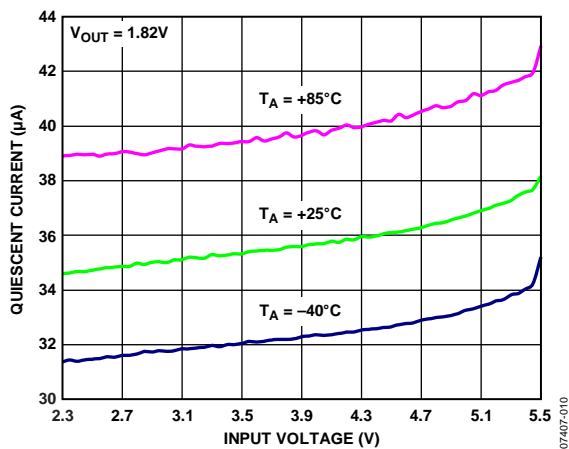


Figure 10. Auto Mode Quiescent Current vs. Input Voltage Over Temperature (Nonswitching, No Load)

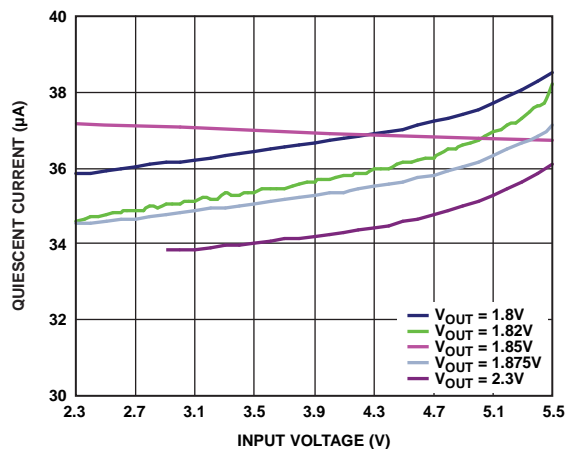


Figure 13. Auto Mode Quiescent Current vs. Input Voltage for All Voltage Options (Nonswitching, No Load)

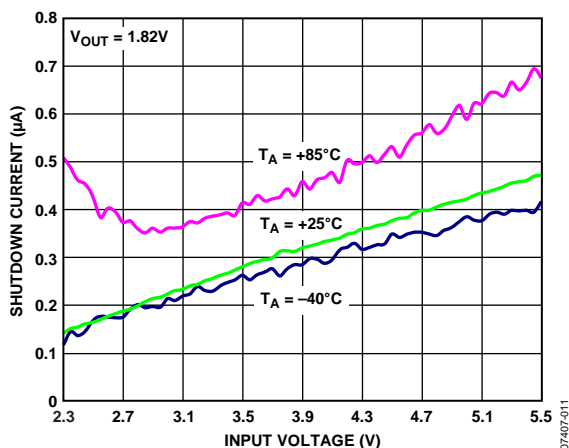


Figure 11. Shutdown Current vs. Input Voltage Over Temperature

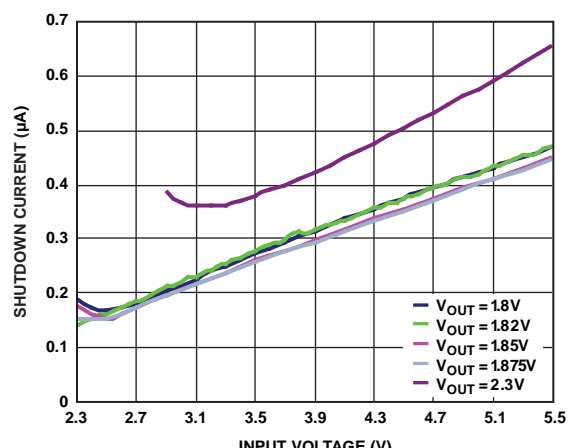


Figure 14. Shutdown Current vs. Input Voltage for All Voltage Options

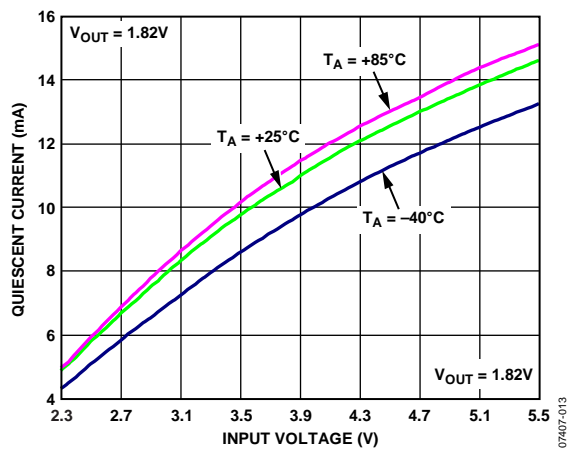


Figure 12. PWM Mode Quiescent Current vs. Input Voltage Over Temperature (Switching, No Load)

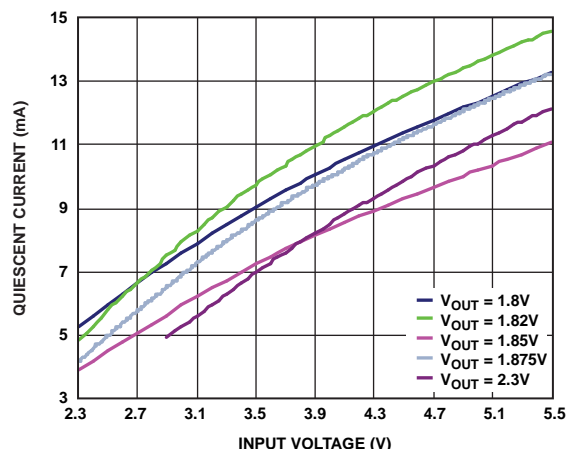


Figure 15. PWM Mode Quiescent Current vs. Input Voltage for All Voltage Options (Switching, No Load)

ADP2121

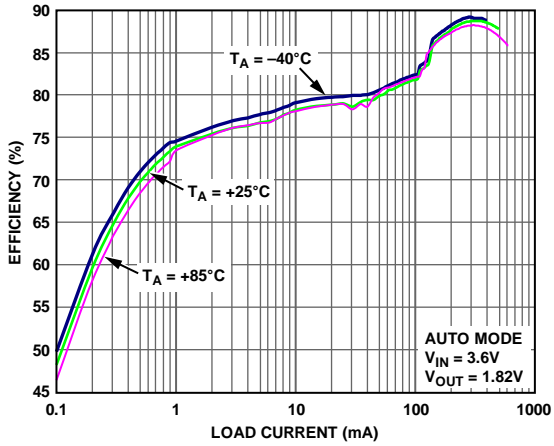


Figure 16. Efficiency vs. Load Current Over Temperature

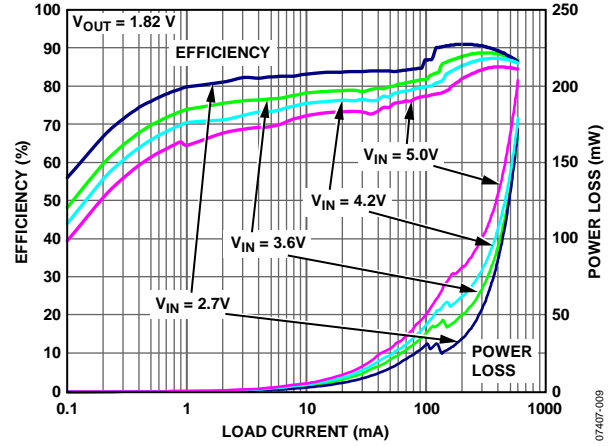


Figure 19. Efficiency and Power Loss vs. Load Current (Auto Mode)

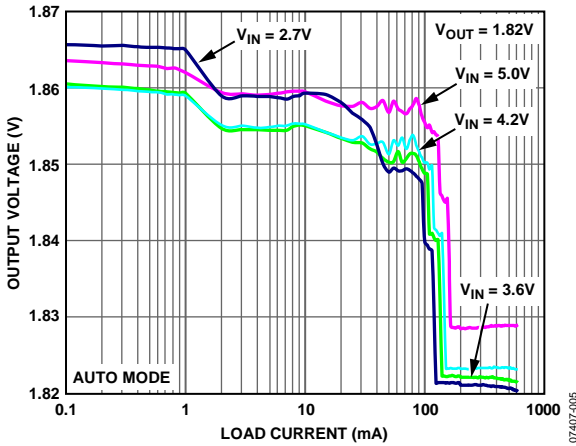


Figure 17. Output Voltage Accuracy (Auto Mode)

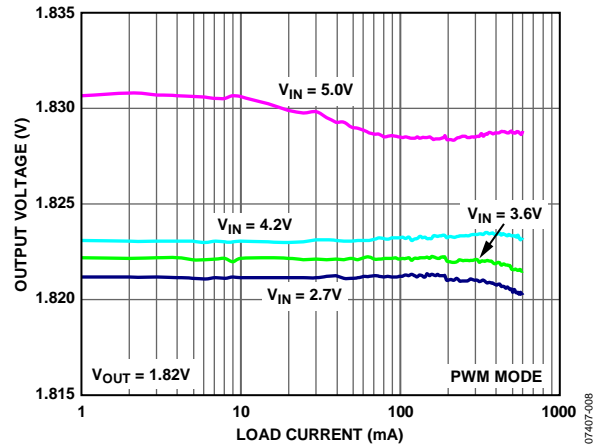


Figure 20. Output Voltage Accuracy (PWM Mode)

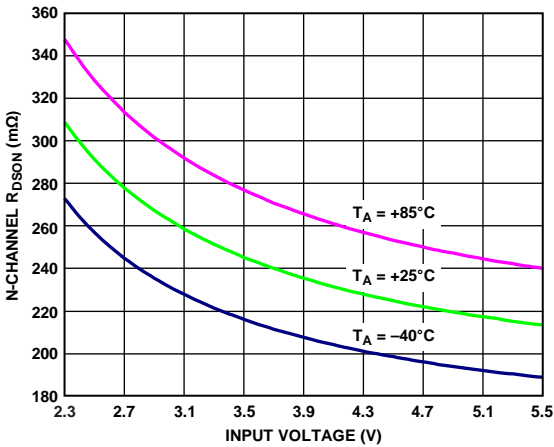


Figure 18. N-Channel Drain-Source On Resistance

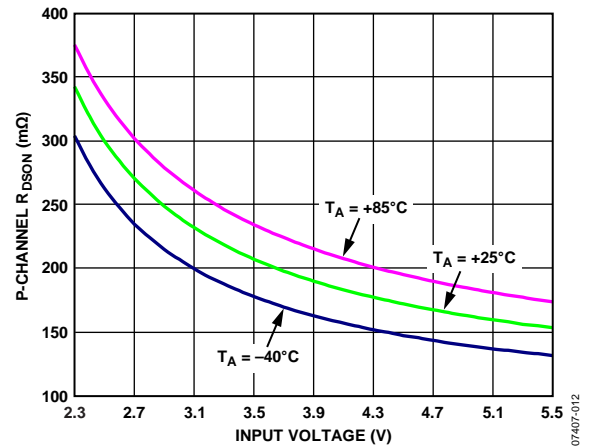


Figure 21. P-Channel Drain-Source On Resistance

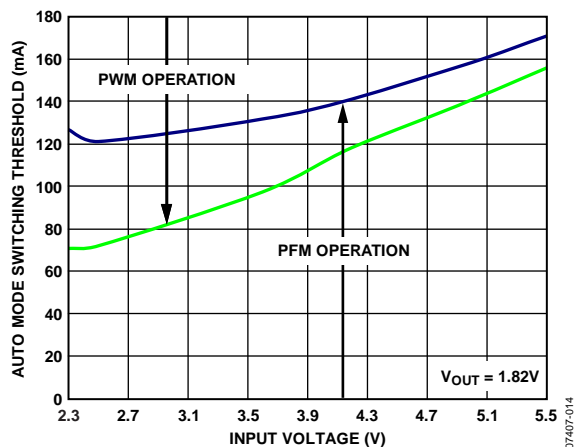


Figure 22. Auto Mode Switching Threshold vs. Input Voltage

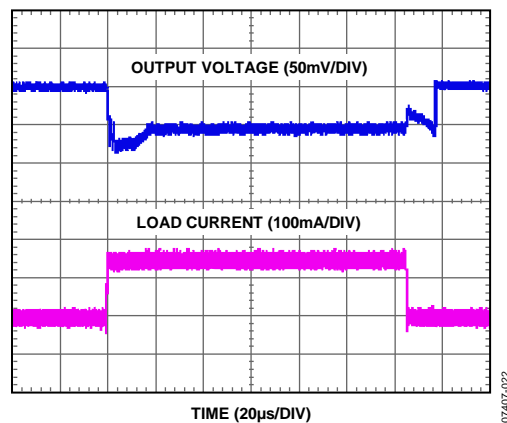


Figure 25. Load Transient Response, 0 mA to 150 mA ($V_{IN} = 2.5\text{ V}$, Auto Mode)

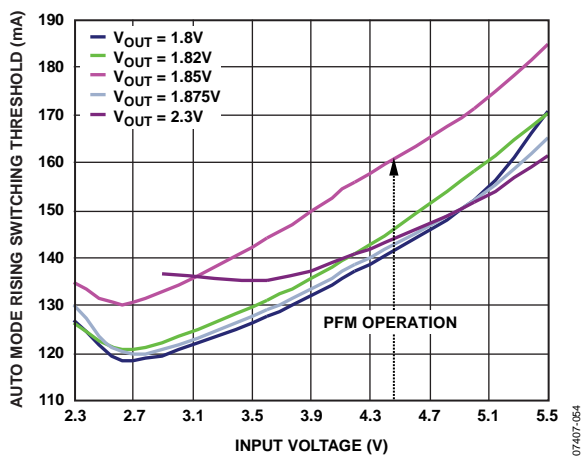


Figure 23. Auto Mode Rising Switching Threshold vs. Input Voltage for All Voltage Options

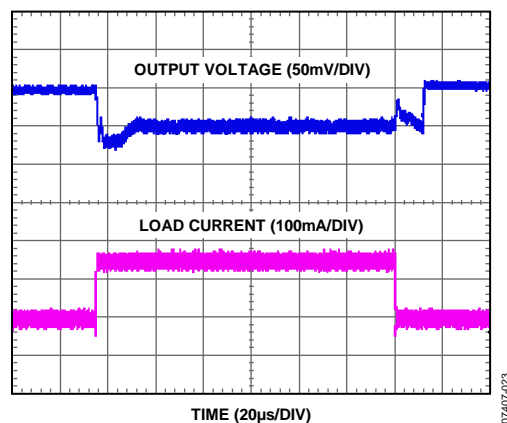


Figure 26. Load Transient Response, 0 mA to 150 mA ($V_{IN} = 3.6\text{ V}$, Auto Mode)

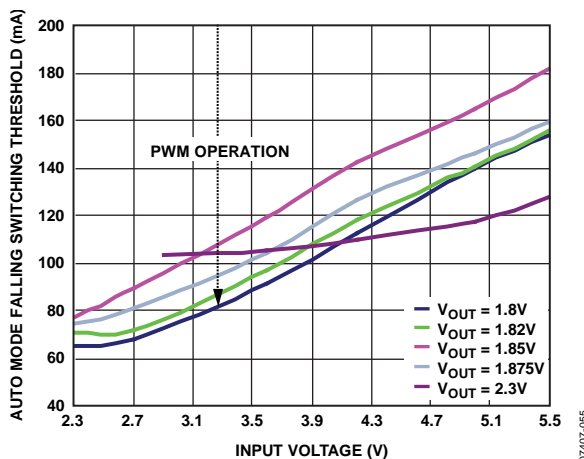


Figure 24. Auto Mode Falling Switching Threshold vs. Input Voltage for All Voltage Options

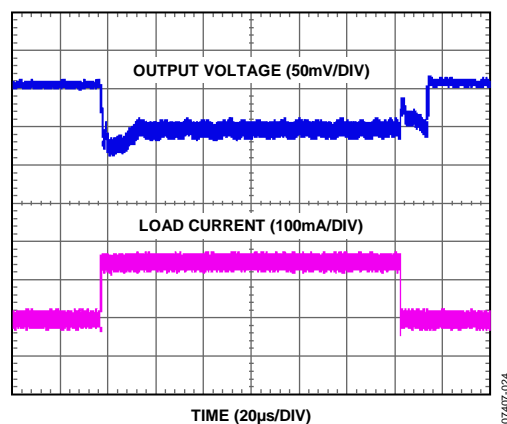


Figure 27. Load Transient Response, 0 mA to 150 mA ($V_{IN} = 4.5\text{ V}$, Auto Mode)

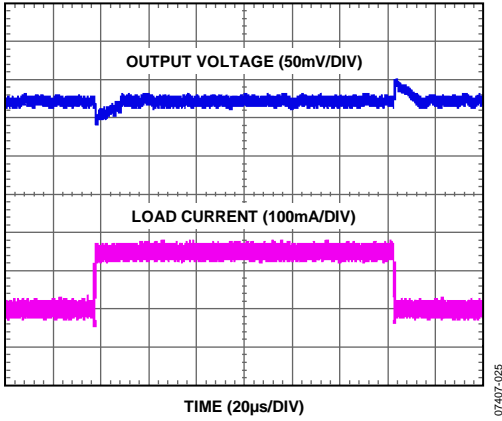


Figure 28. Load Transient Response, 0 mA to 150 mA ($V_{IN} = 2.5\text{ V}$, PWM Mode)

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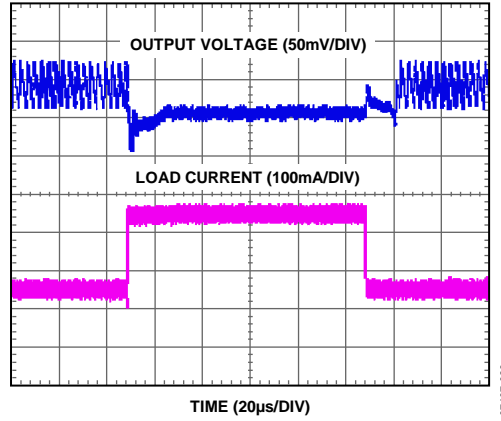


Figure 31. Load Transient Response, 50 mA to 250 mA ($V_{IN} = 2.5\text{ V}$, Auto Mode)

07407-028

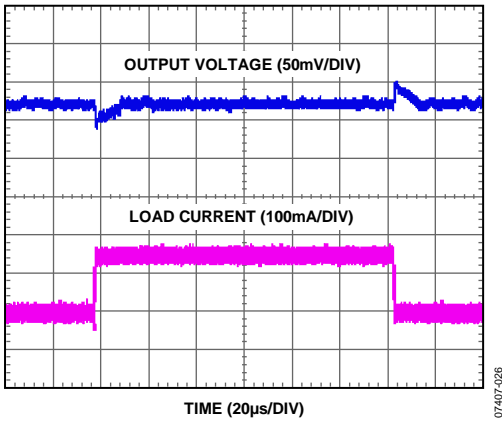


Figure 29. Load Transient Response, 0 mA to 150 mA ($V_{IN} = 3.6\text{ V}$, PWM Mode)

07407-026

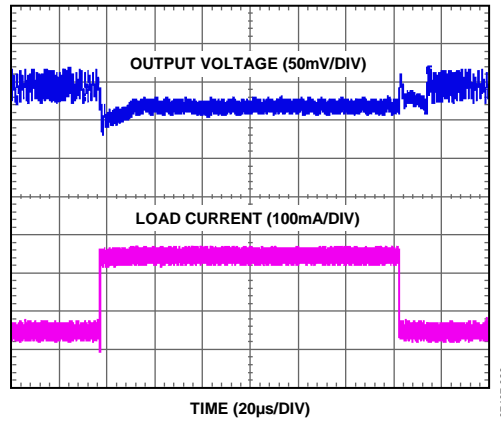


Figure 32. Load Transient Response, 50 mA to 250 mA ($V_{IN} = 3.6\text{ V}$, Auto Mode)

07407-029

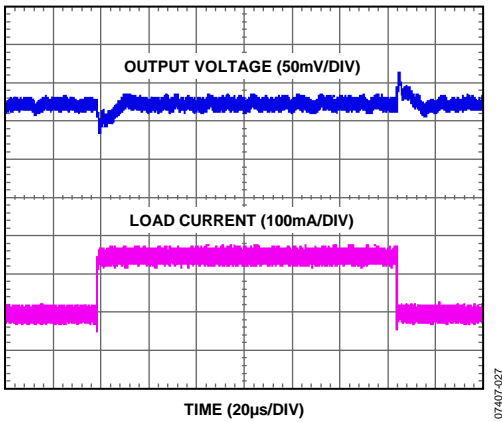


Figure 30. Load Transient Response, 0 mA to 150 mA ($V_{IN} = 4.5\text{ V}$, PWM Mode)

07407-027

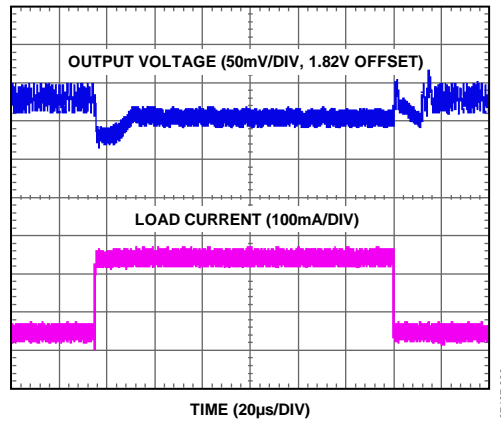


Figure 33. Load Transient Response, 50 mA to 250 mA ($V_{IN} = 4.5\text{ V}$, Auto Mode)

07407-030

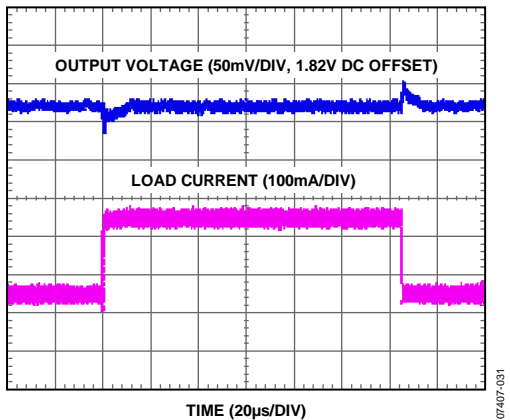


Figure 34. Load Transient Response, 50 mA to 250 mA ($V_{IN} = 2.5\text{ V}$, PWM Mode)

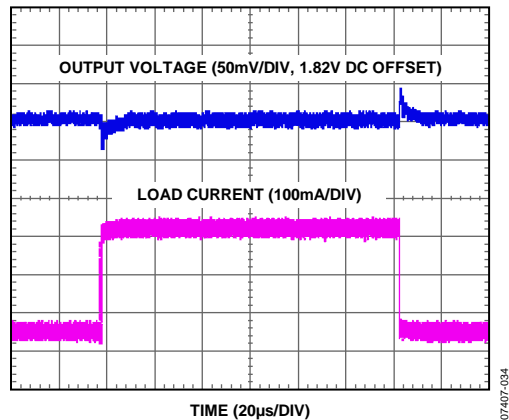


Figure 37. Load Transient Response, 150 mA to 400 mA ($V_{IN} = 2.5\text{ V}$, PWM Mode)

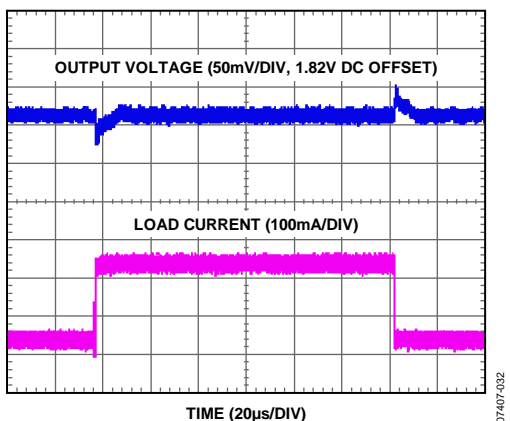


Figure 35. Load Transient Response, 50 mA to 250 mA ($V_{IN} = 3.6\text{ V}$, PWM Mode)

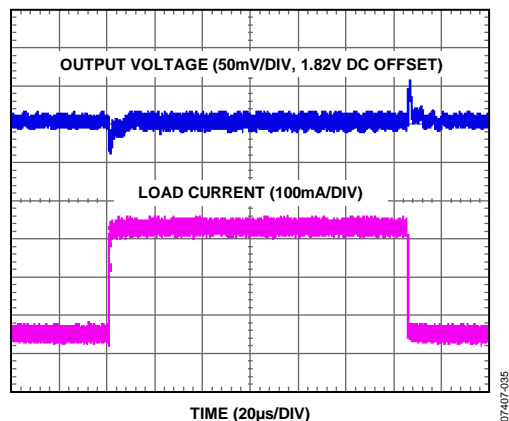


Figure 38. Load Transient Response, 150 mA to 400 mA ($V_{IN} = 3.6\text{ V}$, PWM Mode)

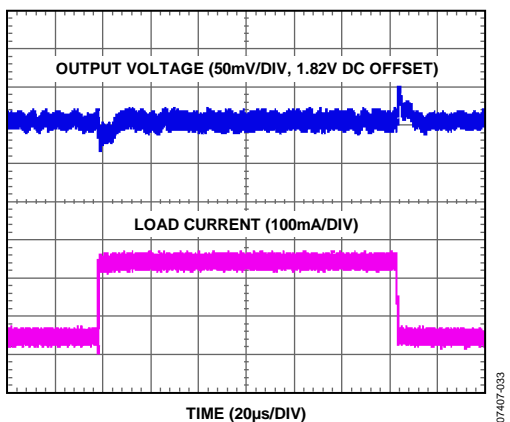


Figure 36. Load Transient Response, 50 mA to 250 mA ($V_{IN} = 4.5\text{ V}$, PWM Mode)

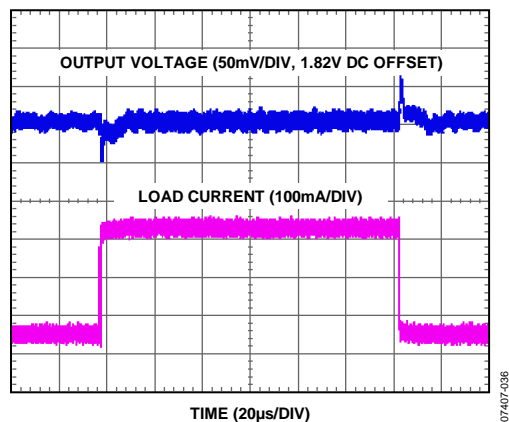


Figure 39. Load Transient Response, 150 mA to 400 mA ($V_{IN} = 4.5\text{ V}$, PWM Mode)

ADP2121

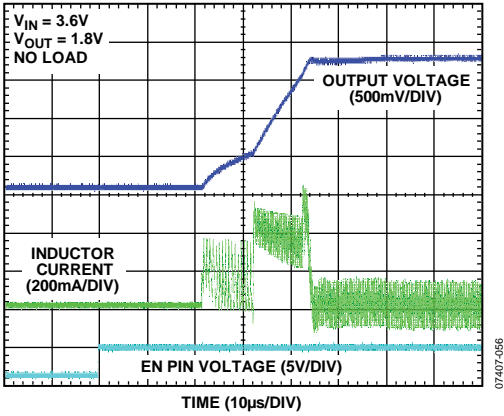


Figure 40. Start-Up Waveform, No Load

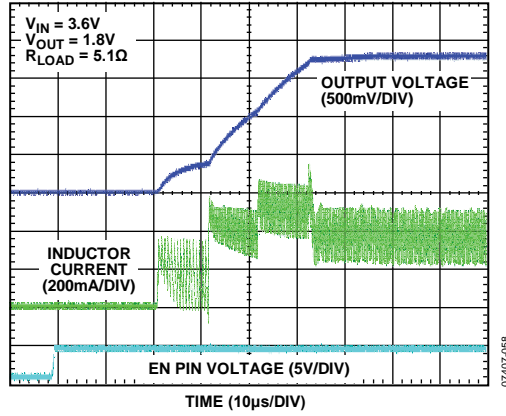


Figure 43. Start-Up Waveform, Heavy Load

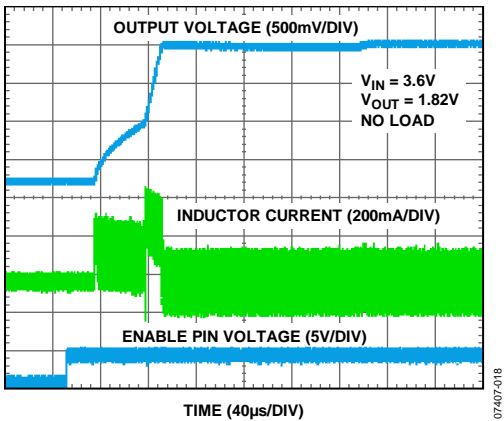


Figure 41. Start-Up Waveform, No Load

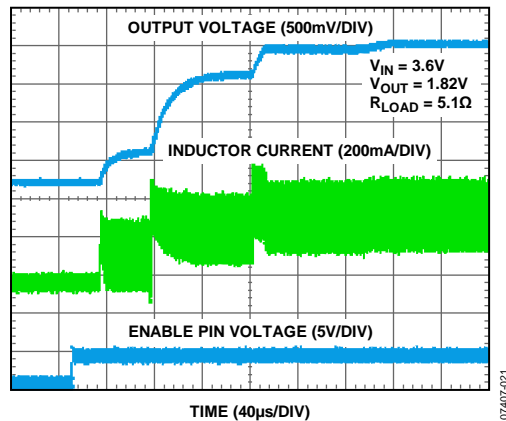


Figure 44. Start-Up Waveform, Heavy Load

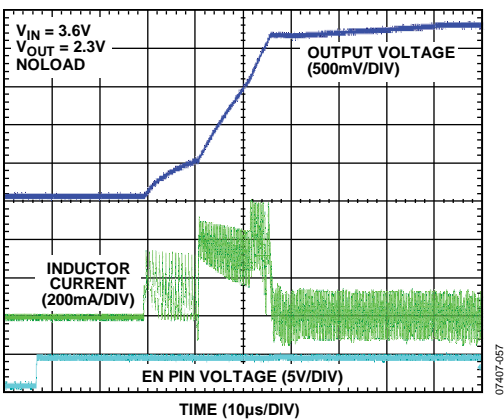


Figure 42. Start-Up Waveform, No Load

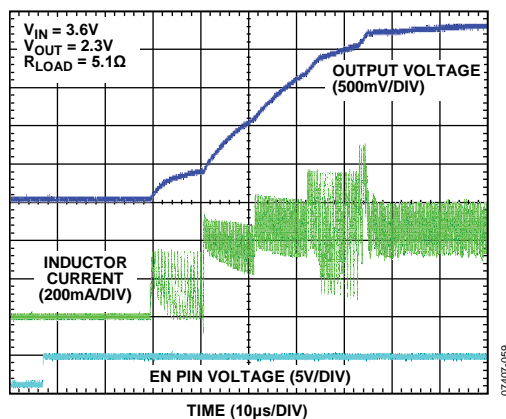


Figure 45. Start-Up Waveform, Heavy Load

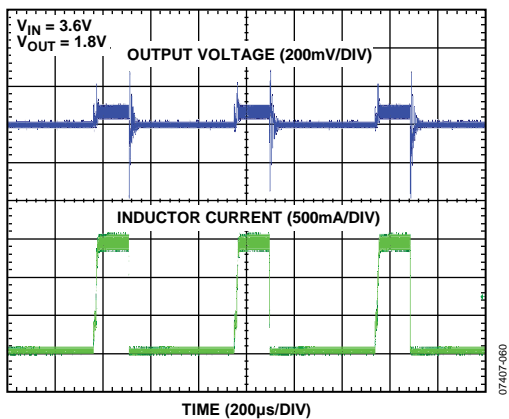


Figure 46. Output Short-Circuit Response

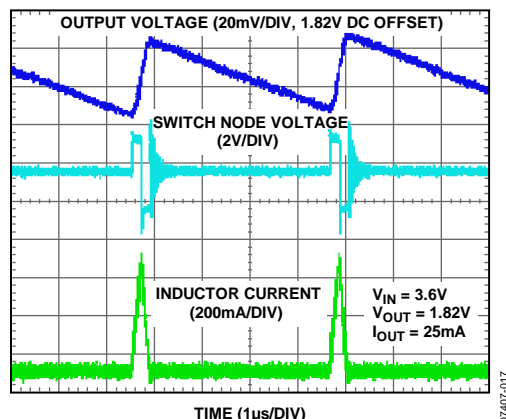


Figure 49. PFM Mode Operation

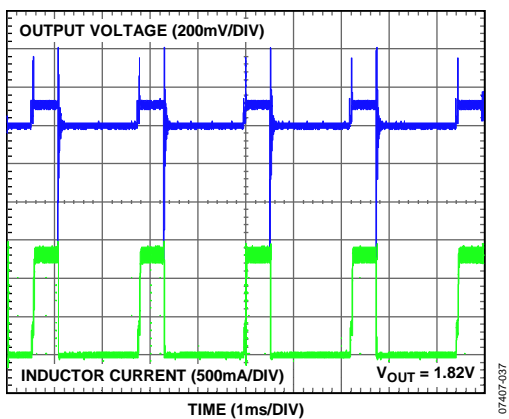


Figure 47. Output Short-Circuit Response

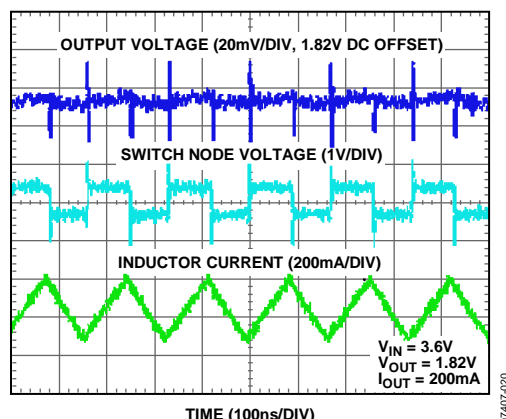


Figure 50. PWM Mode Operation

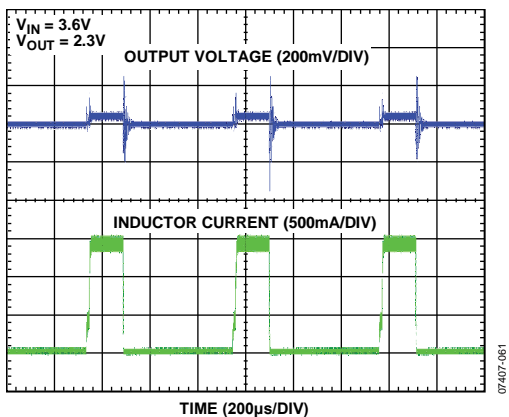


Figure 48. Output Short-Circuit Response

THEORY OF OPERATION

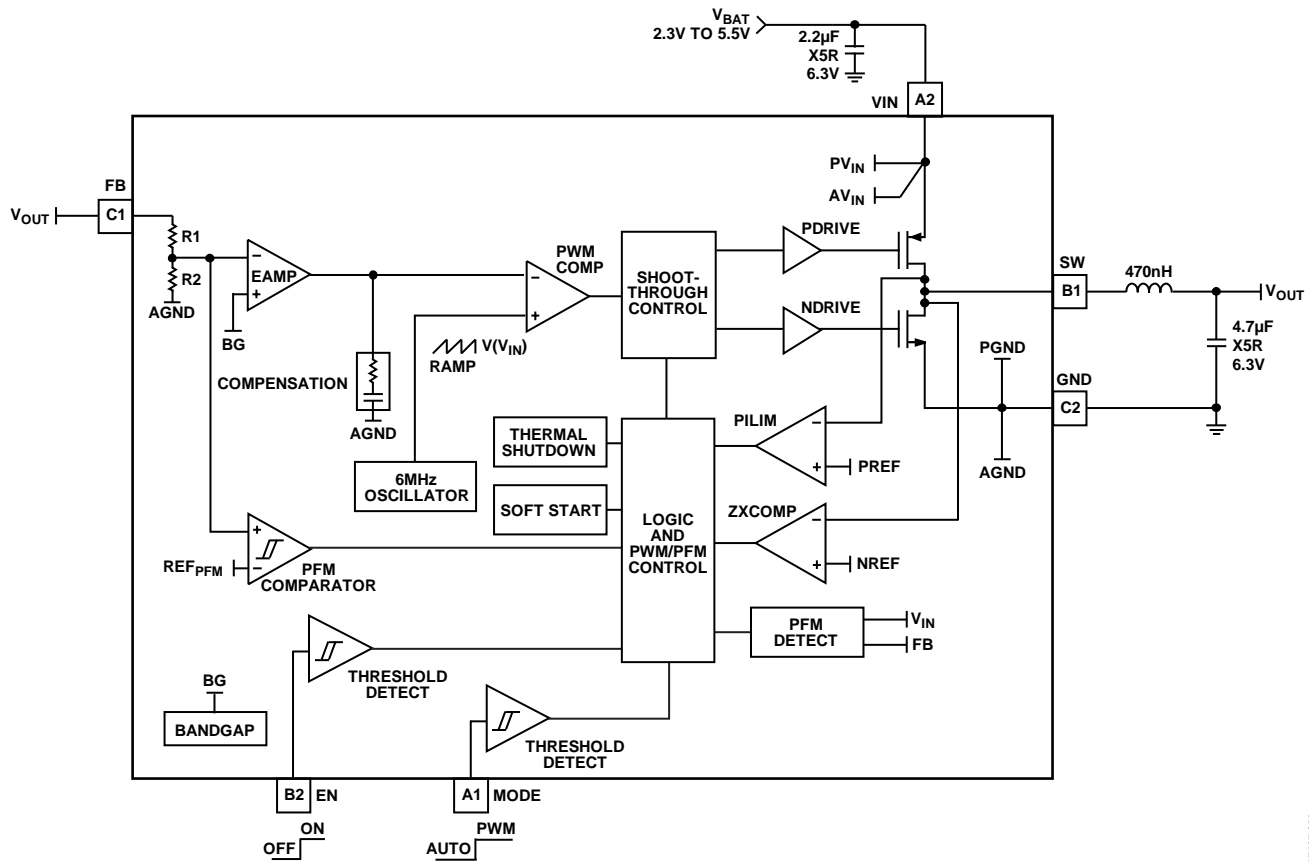


Figure 51. Internal Block Diagram

OVERVIEW

The ADP2121 is a high efficiency, synchronous step-down dc-to-dc converter that provides up to 600 mA of continuous output current. It operates from a 2.3 V to 5.5 V input voltage for the 1.8 V, 1.82 V, 1.85 V, and 1.875 V (typical) fixed-output voltages, and from a 2.9 V to 5.5 V input voltage for the 2.3 V (typical) output voltage. The 6 MHz operating frequency enables the use of tiny external components. The internal control schemes of the ADP2121 give excellent stability and transient response. External control for mode selection and device enable provide power-saving options that are aided by internal features such as synchronous rectification and compensation. Other internal features, such as cycle-by-cycle peak current limit, soft start, undervoltage lockout, output-to-ground short-circuit protection, and thermal shutdown, protect the internal and external circuit components.

MODE SELECTION

The ADP2121 has two modes of operation (PWM mode and auto mode), determined by the state of the MODE pin.

Pull the MODE pin high to force the converter to operate in PWM mode regardless of the output current. Otherwise, set MODE low to allow the converter to automatically enter the power-saving PFM mode at light load currents. Do not leave this pin floating. The MODE pin is not designed for dynamic control and should not be changed after the ADP2121 is enabled.

Pulse-Width Modulation (PWM) Mode

The PWM mode forces the part to maintain a fixed frequency of 6 MHz (typical) over all load conditions. The ADP2121 uses a hybrid proprietary voltage mode control scheme to control the duty cycle over load current and line voltage variation. This control provides excellent stability, transient response, and output regulation but results in lower efficiencies at light load currents.

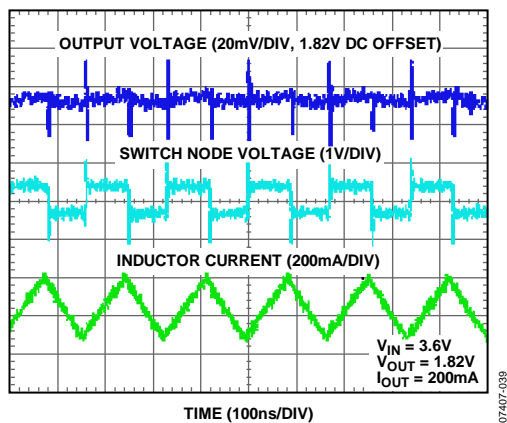
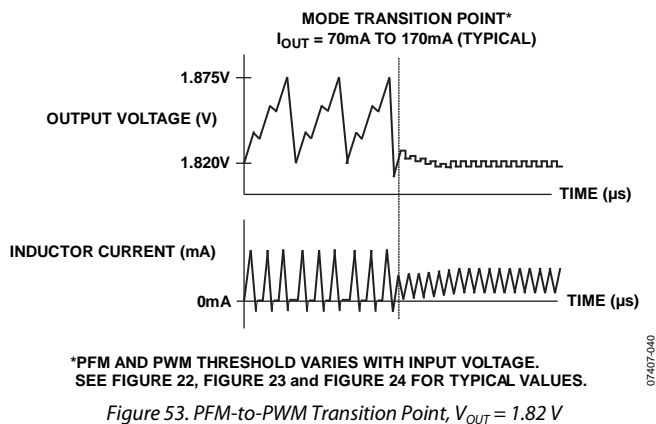


Figure 52. Typical PWM Operation

Auto Mode (PFM and PWM Switching)

Auto mode is a power-saving feature that enables the converter to switch between PWM and PFM in response to the output load. Auto mode is enabled when the MODE pin is pulled low. In auto mode, the ADP2121 operates in PFM mode for light load currents and switches to PWM mode for medium and heavy load currents. Figure 53 uses the typical threshold values of the 1.82 V output voltage option to demonstrate the behavior of the ADP2121 in auto mode. The threshold values will shift accordingly for other output voltages.



*PFM AND PWM THRESHOLD VARIES WITH INPUT VOLTAGE. SEE FIGURE 22, FIGURE 23 and FIGURE 24 FOR TYPICAL VALUES.

Figure 53. PFM-to-PWM Transition Point, $V_{OUT} = 1.82\text{ V}$

Pulse Frequency Modulation (PFM)

When the converter is operating under light load conditions, the effective switching frequency and supply current are decreased and varied using PFM to regulate the output voltage. This results in improved efficiencies and lower quiescent currents. In PFM mode, the converter only switches when necessary to keep the output voltage within the PFM limits set by an internal comparator (see Figure 53). Switching stops when the upper limit is reached and resumes when the lower limit is reached.

When the upper level is reached, the output stage and oscillator turn off to reduce the quiescent current. During this stage, the output capacitor supplies the current to the load. As the output capacitor discharges and the output voltage reaches the lower PFM comparator threshold, switching resumes and the process

repeats. The output voltage, switching node voltage, and inductor current during this process are shown in Figure 54.

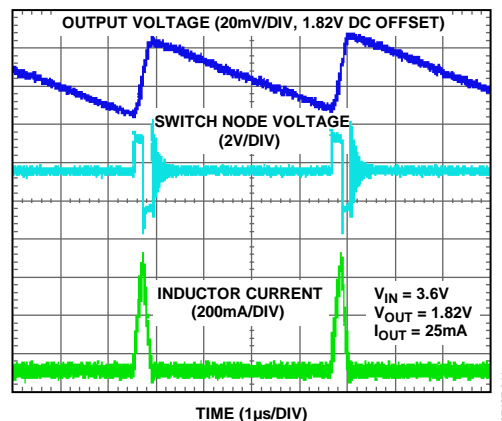


Figure 54. Typical PFM Operation

Mode Transition

When the MODE pin is low, the converter switches between PFM and PWM modes automatically to maintain optimal transient response and efficiency. The mode transition point depends on the input voltage. Hysteresis exists in the transition point to prevent instability and decreased efficiencies that could result if the converter were able to oscillate between PFM and PWM for a fixed input voltage and load current. See Figure 22, Figure 23, and Figure 24 for typical values.

A switch from PFM to PWM occurs when the output voltage dips below the nominal value of the output voltage option. Switching to PWM allows the converter to maintain efficiency and supply a larger current to the load.

The switch from PWM to PFM occurs when the output current is below the PFM threshold for multiple consecutive switching cycles. Switching to PFM allows the converter to save power by supplying the lighter load current with fewer switching cycles.

Figure 53 shows that the output voltage in PFM mode is slightly higher to keep the ADP2121 from oscillating between modes, ensuring stable operation.

ENABLE/SHUTDOWN

The EN input turns the ADP2121 on or off. Connect EN to GND or logic low to shut down the part and reduce the current consumption to 1.0 μA (maximum). Connect EN to V_{IN} or to logic high to enable the part. Do not leave this pin floating.

INTERNAL CONTROL FEATURES

Overcurrent Protection

To ensure that excessively high currents do not damage the inductor, the ADP2121 incorporates cycle-by-cycle overcurrent protection. This function is accomplished by monitoring the instantaneous peak current on the power PMOS switch. If this current exceeds the maximum level (1 A typical), the PMOS is immediately turned off. This minimizes the potential for damage to power components during certain faults and transient events. The value listed in Table 2 is an open loop dc tested value. Inherent

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delays in the current-limit comparator allow a slight increase and variation in this specification.

Soft Start

To prevent excessive input inrush current at startup, the ADP2121 operates with an internal soft start. When EN goes high, or when the part recovers from a fault (UVLO, TSD, or short-circuit protection), a soft start timer begins. The soft start timer corresponds to the maximum soft start period for the given fixed output voltage. During this time, the peak current limit is gradually increased to its maximum. As seen in Figure 40 through Figure 45, the output voltage passes through several stages to ensure that the converter is able to start up effectively and in proper sequence. After the soft start period has expired, the peak current limit remains at 1 A (typical), and the part enters the operating mode determined by the MODE pin.

Synchronous Rectification

In addition to the P-channel MOSFET switch, the ADP2121 includes an N-channel MOSFET switch to build the synchronous rectifier. The synchronous rectifier improves efficiency, especially for small load currents, and reduces cost and board space by eliminating the need for an external rectifier.

Compensation

The control loop is internally compensated to deliver maximum performance with no additional external components. The ADP2121 is designed to work with 0.47 μH chip inductors and 4.7 μF capacitors (see Table 6, Table 7, and Table 8.) Other values may reduce performance and/or stability.

Undervoltage Lockout (UVLO)

If the input voltage is below the UVLO threshold, the ADP2121 automatically turns off the power switches and places the part into a low power consumption mode. This prevents potentially erratic operation at low input voltages. The UVLO levels have approximately 100 mV of hysteresis to ensure glitch-free startup.

Output Short-Circuit Protection

If the output voltage is inadvertently shorted to GND, a standard dc-to-dc controller delivers maximum power into that short. This may result in a potentially catastrophic failure. To prevent this, the ADP2121 senses when the output voltage is below the short-circuit protection threshold (typically 1.24 V).

At this point, the controller turns off for approximately 1.8 ms ($V_{\text{OUT}} = 1.82 \text{ V}$), 0.44 ms ($V_{\text{OUT}} = 1.8 \text{ V}$ and 1.85 V), or 0.48 ms ($V_{\text{OUT}} = 2.3 \text{ V}$), and then automatically initiates a soft start sequence. This cycle repeats until the short is removed or the part is disabled. This dramatically reduces the power delivered into the short circuit, yet still allows the converter to recover if the fault is removed.

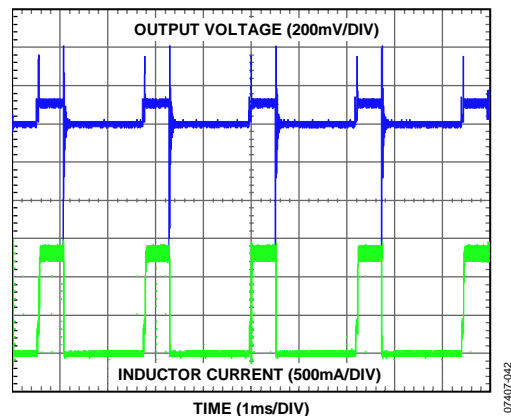


Figure 55. Output Short-Circuit Protection, $V_{\text{OUT}} = 1.82 \text{ V}$

Thermal Shutdown (TSD) Protection

The ADP2121 also includes TSD protection. If the die temperature exceeds 150°C (typical), the TSD protection activates and turns off the power devices. They remain off until the die temperature falls below 135°C (typical), at which point the converter restarts.

APPLICATIONS INFORMATION

The external component selection for the ADP2121 applications circuit is driven by the load requirement and begins with the selection of the inductor. After the inductor is chosen, C_{IN} and C_{OUT} can be selected. Components can be identified using the selection guide and recommended selection tables in this section.

INDUCTOR SELECTION

The high switching frequency of the ADP2121 allows for minimal output voltage ripple, even with small inductors. Inductor sizing is a trade-off between efficiency and transient response. A small inductor leads to a larger inductor current ripple, which provides better transient response but degrades efficiency. Due to the high switching frequency of the ADP2121, multilayer ceramic inductors can be used for an overall smaller solution size. Shielded ferrite core inductors are recommended for their low core losses and low electromagnetic interference (EMI).

As a guideline, the peak-to-peak current ripple of the inductor is typically set to

$$\Delta I_L = 0.45 \times I_{LOAD} \quad (1)$$

where I_{LOAD} is the maximum output current. The largest ripple current, ΔI_L , occurs at the maximum input voltage.

It is important that the inductor be capable of handling the maximum peak inductor current, I_{PK} , determined by the following equation:

$$I_{PK} = I_{LOAD(MAX)} + \Delta I_L/2 \quad (2)$$

The dc current rating of the inductor should be greater than the calculated I_{PK} to prevent core saturation. The ADP2121 is designed for applications with a 0.47 μ H inductor. Other values are not recommended, and stable operation over all conditions is not guaranteed with their use. Table 6 shows the available 0.47 μ H surface-mount inductors that have been tested with the ADP2121.

INPUT CAPACITOR SELECTION

The input capacitor must be able to support the maximum input operating voltage and the maximum rms input current. Select an input capacitor capable of withstanding the rms input current for the maximum load current in the application using the following equation:

$$I_{rms} = I_{OUT(MAX)} \times \frac{\sqrt{V_{OUT} \times (V_{IN} - V_{OUT})}}{V_{IN}} \quad (3)$$

The input capacitor reduces the input voltage ripple caused by the switch currents on the VIN pin. Place the input capacitor as close as possible to the VIN pin.

In principle, different types of capacitors can be considered, but for battery-powered applications, the best choice is the multilayer

ceramic capacitor, due to its small size and low equivalent series resistance (ESR). Table 7 offers suggestions for suitable input capacitors. All capacitors listed in the table are multilayer ceramic capacitors.

It is recommended that the VIN pin be bypassed with a 2.2 μ F or larger ceramic input capacitor if the supply line has a distributed capacitance of at least 10 μ F. If not, then at least a 10 μ F capacitor is recommended on the input supply pin. The input capacitor can be increased without any limit for better input voltage filtering. X5R or X7R dielectrics with a voltage rating of 6.3 V or 10 V are recommended. Y5U and Z5U dielectrics are not recommended, due to their poor temperature and dc bias characteristics.

OUTPUT CAPACITOR SELECTION

The output capacitor selection affects both the output voltage ripple and the loop dynamics of the converter. For a given loop crossover frequency (the frequency at which the loop gain drops to 0 dB), the maximum voltage transient excursion (overshoot) is inversely proportional to the value of the output capacitor. The ADP2121 has been designed to operate with small ceramic capacitors in the 4.7 μ F to 10 μ F range that have low ESR and equivalent series inductance (ESL). These components are able, therefore, to meet stringent output voltage ripple specifications. X5R or X7R dielectrics with a voltage rating of 6.3 V are recommended. Table 8 shows a list of output MLCC capacitors recommended for ADP2121 applications. The minimum effective capacitance required for stable operation is 1.5 μ F.

When choosing output capacitors, it is also important to account for the loss of capacitance due to output voltage dc bias. This may result in using a capacitor with a higher rated voltage to achieve the desired capacitance value. Additionally, if ceramic output capacitors are used, the capacitor rms ripple current rating should always meet the application requirements. The rms ripple current is calculated as

$$I_{rms(COUT)} = \frac{1}{2\sqrt{3}} \times \frac{V_{OUT} \times (V_{IN(MAX)} - V_{OUT})}{L \times f_{SW} \times V_{IN(MAX)}} \quad (4)$$

At nominal load currents, the converter operates in pulse frequency mode (PFM), and the overall output voltage ripple is the sum of the voltage spike caused by the output capacitor ESR plus the voltage ripple caused by charging and discharging the output capacitor.

$$\Delta V_{OUT} = \Delta I_L \times (ESR + 1/(8 \times C_{OUT} \times f_{SW})) \quad (5)$$

The largest voltage ripple occurs at the highest input voltage. At light load currents, if MODE is set low, then the converter operates in the power-saving mode (PFM), and the output voltage ripple increases.

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Table 6. Recommended Inductor Selection

| Manufacturer | Series | Inductance (μ H) | DCR ($m\Omega$) | Current Rating (mA) | Size (L \times W \times H) (mm) | Package |
|--------------|------------------|-----------------------|-------------------|---------------------|-------------------------------------|---------|
| Murata | LQM2HPNR47MG0L | 0.47 \pm 20% | 40 \pm 25% | 1800 | 2.50 \times 2.00 \times 0.90 | 1008 |
| | LQM21PNR47MC0D | 0.47 \pm 20% | 120 \pm 25% | 1100 | 2.00 \times 1.25 \times 0.50 | 0805 |
| Taiyo Yuden | BRC1608TR45M | 0.45 \pm 20% | 90 \pm 30% | 800 | 1.60 \times 0.80 \times 0.80 | 0603 |
| TDK | MLZ2012DR47MT | 0.47 \pm 20% | 180 \pm 30% | 550 | 2.00 \times 1.25 \times 1.25 | 0805 |
| | GLFR1608TR47M-LR | 0.47 \pm 20% | 50 \pm 30% | 475 | 1.6 \times 0.80 \times 0.80 | 0603 |

Table 7. Recommended Input Capacitor Selection

| Manufacturer | Part Number | Capacitance (μ F) | Voltage Rating (V) | Temperature Coefficient | Size (L \times W \times H) (mm) | Package |
|--------------|-----------------|------------------------|--------------------|-------------------------|-------------------------------------|---------|
| Murata | GRM155R60J225M | 2.2 | 6.3 | X5R | 1.0 \times 0.5 \times 0.5 | 0402 |
| Taiyo Yuden | JMK105BJ225MV-F | 2.2 | 6.3 | X5R | 1.0 \times 0.5 \times 0.5 | 0402 |

Table 8. Recommended Output Capacitor Selection

| Manufacturer | Part Number | Capacitance (μ F) | Voltage Rating (V) | Temperature Coefficient | Size (L \times W \times H) (mm) | Package |
|--------------|--------------------|------------------------|--------------------|-------------------------|-------------------------------------|---------|
| Murata | GRM188R60J475KE19D | 4.7 | 6.3 | X5R | 1.6 \times 0.8 \times 0.8 | 0603 |
| | GRM155R60J475ME87D | 4.7 | 6.3 | X5R | 1.0 \times 0.5 \times 0.5 | 0402 |
| Taiyo Yuden | AMK105BJ475MV-F | 4.7 | 4 | X5R | 1.0 \times 0.5 \times 0.5 | 0402 |

PCB LAYOUT GUIDELINES

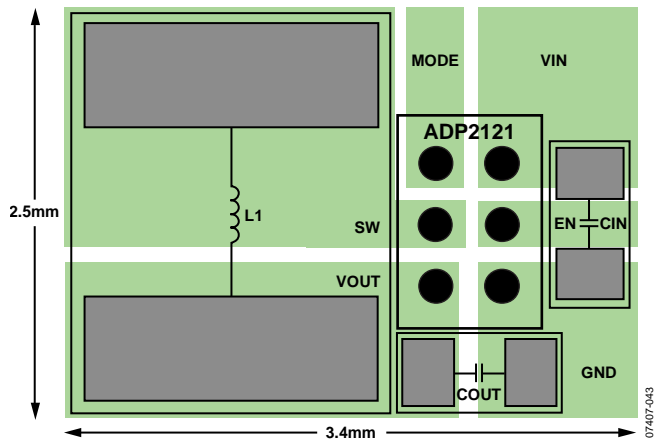


Figure 56. Solution Size with a 1008 Inductor

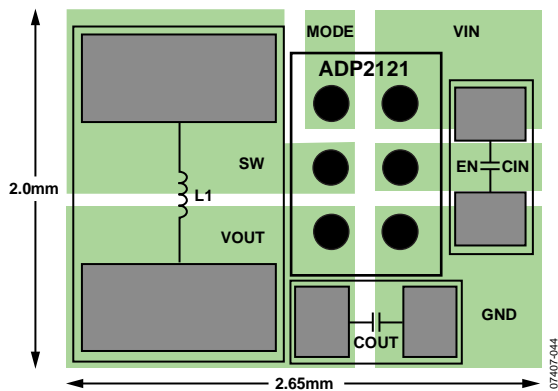


Figure 57. Solution Size with a 0805 Inductor

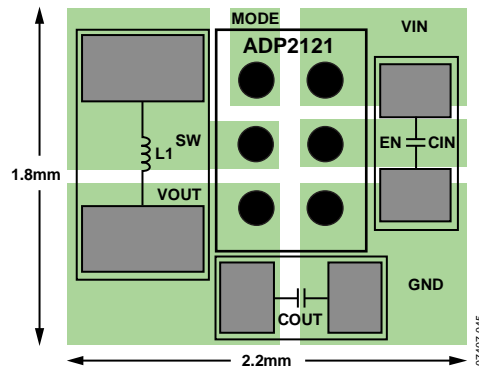


Figure 58. Solution Size with a 0603 Inductor

For high efficiency, good regulation, and stability with the ADP2121, a well-designed PCB is required.

Use the following guidelines when designing PCBs:

- Keep the low ESR input capacitor, CIN, close to VIN and GND.
- Keep high current traces as short and as wide as possible.
- Avoid routing high impedance traces near any node connected to SW or near the inductor to prevent radiated noise injection.
- Keep the low ESR output capacitor, COUT, close to FB and GND of the ADP2121. Long trace lengths from the part to the output capacitor add series inductance and may cause instability or increased ripple.

OUTLINE DIMENSIONS

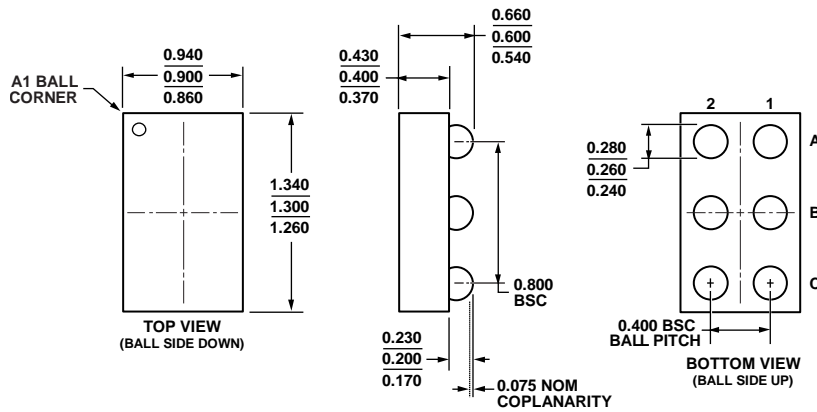


Figure 59. 6-Ball Wafer Level Chip Scale Package (WLCSP)
(CB-6-4)
Dimensions shown in millimeters

021508F-A

ORDERING GUIDE

| Model ¹ | Temperature Range | Output Voltage (V) | Package Description | Package Option ² | Branding |
|---------------------|-------------------|--------------------|---|-----------------------------|----------|
| ADP2121ACBZ-1.8-R7 | -40 °C to +85 °C | 1.8 | 6-Ball Wafer Level Chip Scale Package [WLCSP] | CB-6-4 | L92 |
| ADP2121ACBZ-1.82R7 | -40 °C to +85 °C | 1.82 | 6-Ball Wafer Level Chip Scale Package [WLCSP] | CB-6-4 | L7N |
| ADP2121ACBZ-1.85R7 | -40 °C to +85 °C | 1.85 | 6-Ball Wafer Level Chip Scale Package [WLCSP] | CB-6-4 | L94 |
| ADP2121ACBZ-1.875R7 | -40 °C to +85 °C | 1.875 | 6-Ball Wafer Level Chip Scale Package [WLCSP] | CB-6-4 | L95 |
| ADP2121ACBZ-2.3-R7 | -40 °C to +85 °C | 2.3 | 6-Ball Wafer Level Chip Scale Package [WLCSP] | CB-6-4 | L9G |
| ADP2121-1.8-EVALZ | | 1.8 | Evaluation Board for 1.8 V | | |
| ADP2121-1.82-EVALZ | | 1.82 | Evaluation Board for 1.82 V | | |
| ADP2121-1.85-EVALZ | | 1.85 | Evaluation Board for 1.85 V | | |
| ADP2121-1.875EVALZ | | 1.875 | Evaluation Board for 1.875 V | | |
| ADP2121-2.3-EVALZ | | 2.3 | Evaluation Board for 2.3 V | | |

¹ Z = RoHS Compliant Part.

² Halide free.