Application Note

Thermally-Enhanced Packages Improve Precision for Operational Amplifiers

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ABSTRACT

This document explains the precision benefits of using a thermally-enhanced packed, like the HVSSOP, over a typical package. Thermal dissipation is an important factor for high precision operational amplifiers (op amps), as changes in temperature cause thermal drift and error, specifically input offset voltage and bias current. Power dissipation on the device causes the internal die temperature (commonly referred to as junction temperature) to increase, which then negatively impacts the accuracy of the application. Most precision amplifiers are in leaded packages without any exposed pads for thermal dissipation. This does not typically have a significant impact on the overall performance because many precision circuits do not require significant power consumption. However, in cases with high supply voltages (for example, ±15 V) and high load currents (>10 mA), the power dissipation of the amplifier needs to be considered.

The OPA2828 is a recent TI power op amp introduction featuring a thermal pad, that is usable with power supplies up to 36 V. The amplifier is capable of an output current of up to 30 mA from a 3 mm × 4.9 mm, 8-pin HVSSOP PowerPAD™ package. This application note describes an OPA2828 op amp circuit, developed on the DAC8811EVM, is used to explore the precision benefit of using a thermal pad over a range of power requirements, with varying ambient temperatures. This circuit design successfully showcases the impact of a PowerPAD™ thermal pad on the OPA2828's junction temperature in a high power application. On average, it was found that the HVSSOP was 48.1°C cooler than a typical package, per watt of power dissipated.

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PowerPAD™ is a trademark of Texas Instruments.
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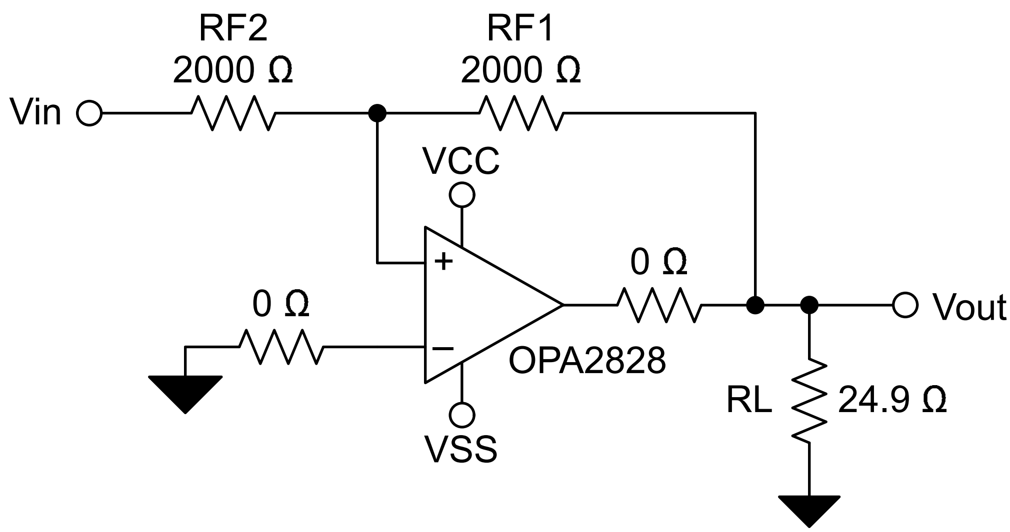
1 Introduction

The 36 V single, ±18 V dual-supply capability, 30 mA maximum output drive current OPA2828 op amp is finding design-in opportunities in different data acquisition, testing, and other precision applications. Such applications often require high precision over ranges of temperature and power demands, to lessen the effects of thermal drift on the system's accuracy.

The DAC8811EVM is an evaluation module to showcase the performance of both the DAC8811 and the OPA2828. The board features a configurable circuit for the OPA2828, allowing for the circuit design, seen in Figure 1-1, to be easily created and tested.



Note

The OPA2828 supports an isolated thermal pad, allowing the user to choose the net it is connected to. In this case, the device thermal pad is connected to VSS, the negative supply voltage.

Figure 1-1. Test Circuit Schematic

The report demonstrates how the addition of a thermal pad to a package greatly improves the thermal metrics of the OPA2828 and other op amps. The most commonly reported thermal metric is the junction-to-ambient thermal resistance (Θja). The Θja is the difference in temperature between the internal device junction temperature and the ambient temperature, divided by the dissipated power of the device. This thermal metric is important as it provides a way to compare the thermal performance of devices between companies. The thermal metric can easily be used to determine what the maximum junction temperature will be, if the ambient temperature, Θja, and power dissipation is known.

$$T_{Junction} = T_{Ambient} + \left(\Theta_{JA} \times Power\right) \quad (1)$$

The Θja is impacted by several other thermal resistances, including the board-to-ambient thermal resistance. The addition of a thermal pad greatly decreases the case-to-board thermal resistance, as more heat can be dissipated to the PCB and to the environment, which lowers the maximum junction temperature. If the internal temperature of the device is lower, many electrical characteristics, including accuracy parameters, can also be affected. This includes offset voltage (Vos) and input bias current (Ib), which typically become larger as temperature increases. The addition of a thermal pad can reduce these error sources and improve the accuracy of the device. For more information about thermal metrics, please refer to the *Semiconductor and IC Package Thermal Metrics* application note.

As the OPA2828IDGN is a closed package, the internal junction temperature cannot be measured by hand. The OPA2828 was designed to have a quiescent current (Iq) that directly relates to the junction temperature. The *OPAx828 Low-Offset, Low-Drift, Low-Noise, 45-MHz, 36-V, JFET-Input Operational Amplifiers* data sheet has a plot of quiescent current over temperature, but it is only for an unloaded setting. When the circuit in Figure 1-1 was simulated, it was verified that the non-driving supply current similarly has a direct relationship with junction temperature when the output is loaded with 1 V over 24.9 Ω. This current will be referred to as supply current for the remainder of the document.

By measuring the supply current over an ambient temperature range and calculating the respective junction temperature, the Θja of the HVSSOP was measured and compared to the verified value. To emulate a typical SOIC package without thermal enhancement, the same HVSSOP op amp was elevated slightly above the PCB and its thermal pad connection was severed. This process is visualized in Figure 1-2. The same characterization of the Θja was repeated for the emulated *SOIC* scenario. The observed difference was used to compare accuracy between the two package types.

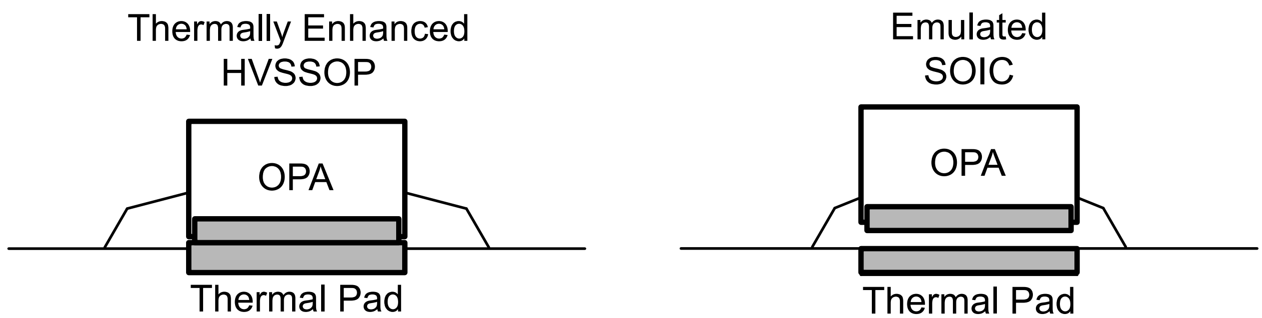


Figure 1-2. Detachment of Thermal Pad from PCB

The emulated SOIC package will have similar thermal characteristics to typical packages which are not thermally enhanced. The emulated package will be referred to as *typical package* for the remainder of this document.

2 Design Methodology

The circuit design in Figure 1-1 was used to have an output of 1 V over 24.9 Ω (40.16 mA). High-precision resistors and capacitors were used to reduce sources of error for the circuit, as well as reliable supply voltages. Four test cases were identified in order to quantify the difference in the junction-to-ambient thermal resistance (Θja) of the HVSSOP and emulated SOIC packages:

Table 2-1. Supply Current – Test Cases

Package	Supply Voltages	Output Voltage
HVSSOP	±5 V	1 V
HVSSOP	±15 V	1 V
Typical	±5 V	1 V
Typical	±15 V	1 V

In each of these test cases, the ambient temperature was swept from 20 °C to 80 °C and the supply current was recorded. Since the relationship between supply current and internal junction temperature was calculated through simulation results, the measured supply current could be immediately converted to a respective junction temperature. Next, the calculated temperatures were used to find the estimated Θja of both package types.

To demonstrate how to use the thermal resistance metrics, an estimation using the verified values in the OPA2828 data sheet can be made. The power dissipation of the circuit needed to be calculated, in order to convert thermal resistance to temperature change. The following equation shows the power calculation of the power dissipation on the amplifier for the cases listed in Table 2-1, with Vs being the respective supply the output is using.

$$\text{Power} = \left(\mathrm{V}_S - \mathrm{V}_{out}\right) \times \frac{V_{out}}{R_L} + \left(\mathrm{V}_+ - \mathrm{V}_-\right) \times \mathrm{I}_q \tag{2}$$

For both ±5 V and ±15 V supplies, the estimated amplifier power dissipation was calculated to be 0.275 W and 0.9 W respectively, when using a high temperature quiescent current of 11 mA. Using these power values, the estimated heating for the HVSSOP package can be determined by multiplying the Θja (49.9 °C/W) to the power values.

This can be directly compared to a package that doesn't include a thermal pad. The SOIC package has a Θja value in the datasheet for the single OPA828 (121.5 °C/W) which can be multiplied to the same power calculations.

Table 2-2. Estimated Temperature Delta

Package	Supply Voltages	Amplifier Power Dissipation	Temperature Delta (▲)
HVSSOP	±5 V	0.275 W	+13.72°C
HVSSOP	±15 V	0.9 W	+44.91°C
SOIC	±5 V	0.275 W	+33.41°C
SOIC	±15 V	0.9 W	+109.35°C

This estimation shows the benefit of using a thermal pad, as a SOIC package would be 19.69 °C and 64.44 °C hotter than the HVSSOP package for the ±5 V and ±15 V supply voltage cases respectively.

3 Bench Test Results

The circuit was simulated to establish the typical relationship between the supply current and internal junction temperature, while the output was driving 1 V over 24.9 Ω. The simulated relationship was found to be linear for both ±5 V and ±15 V supplies.

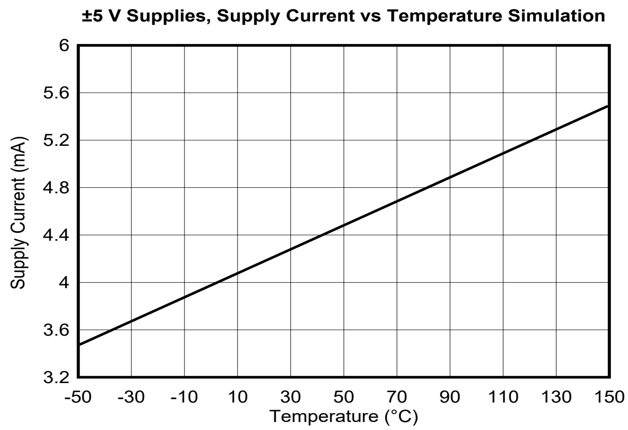


Figure 3-1. ±5 V Supplies, Supply Current vs Temperature Simulation

$$Current\ (mA) = 0.01012 \times Temperature\ (°C) + 3.97564 \quad (3)$$

Since the simulation used a single amplifier, Equation 3 can be restructured to convert the OPA2828's *dual* supply current to an estimated junction temperature.

$$Temperature\left(°C\right) = \frac{0.5 \times Current\ (mA) - 3.97564}{0.01012} \quad (4)$$

This same process can be repeated for simulating the supply current over junction temperature for ±15 V supplies.

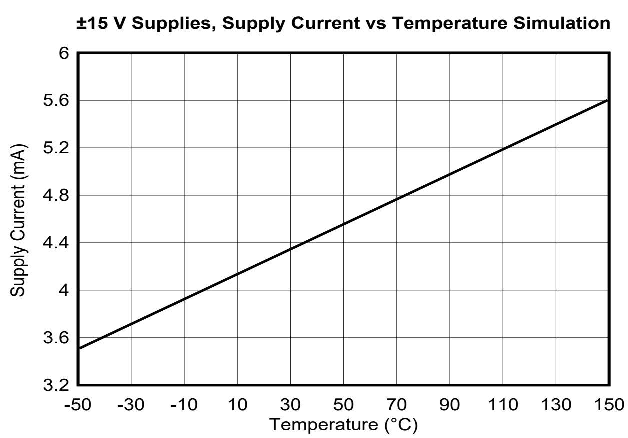


Figure 3-2. ±15 V Supplies, Supply Current vs Temperature Simulation

$$Current\ (mA) = 0.01052 \times Temperature\ (°C) + 4.02958 \quad (5)$$

Equation 5 was restructured to work for the OPA2828's supply current.

$$Temperature\left(°C\right) = \frac{0.5 \times Current\ (mA) - 4.02958}{0.01052} \quad (6)$$

Next, the supply current was measured over a range of ambient temperatures and converted into the respective internal junction temperature.

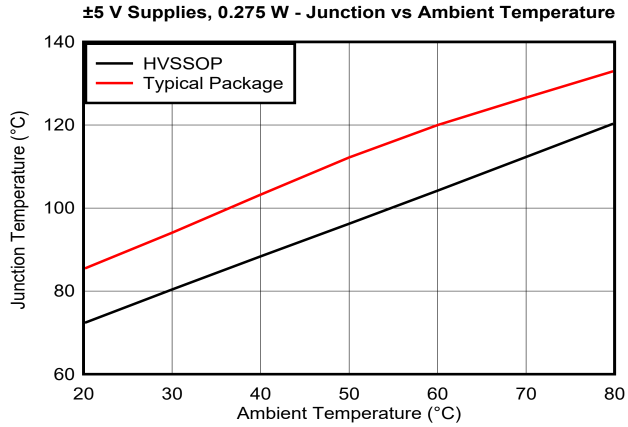
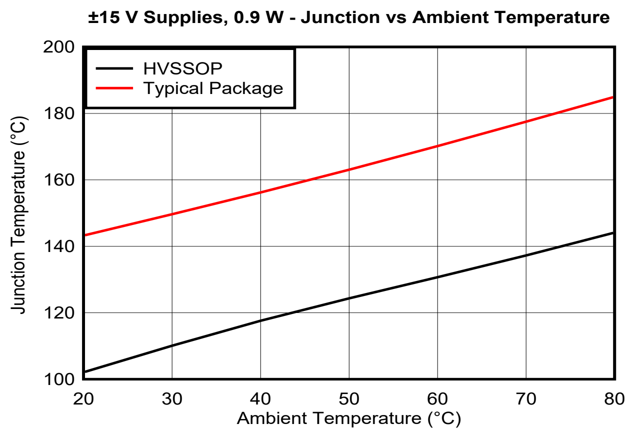


Figure 3-3. ±5 V Supplies, Junction vs Ambient Temperature

In the ±5 V supplies case, both package types heated up at a fairly uniform rate as ambient temperature increased. The HVSSOP package ranged from about 70 °C to 120 °C, while the typical package ranged from 85 °C to 130 °C.



Note

The OPA2828 features a thermal shutdown mode when the internal temperature reaches approximately 180 °C, this was measured and verified with the device being tested. The output is disabled until the internal temperature cools down to 160 °C, at which point the output resumes. The OPA2828's output is only guaranteed to be reliable up to 150 °C which is surpassed in the above situation. More information about thermal considerations is located in section 8.4.1.1 of the data sheet.

Figure 3-4. ±15 V Supplies, Junction vs Ambient Temperature

In the ±15 V supplies case, the difference between the two package temperature remained uniform. The HVSSOP package ranged from 100 °C to 145 °C, while the typical package ranged from 145 °C to 185 °C. The temperature delta for both the ±5 V and ±15 V supplies cases were plotted in Figure 3-5.

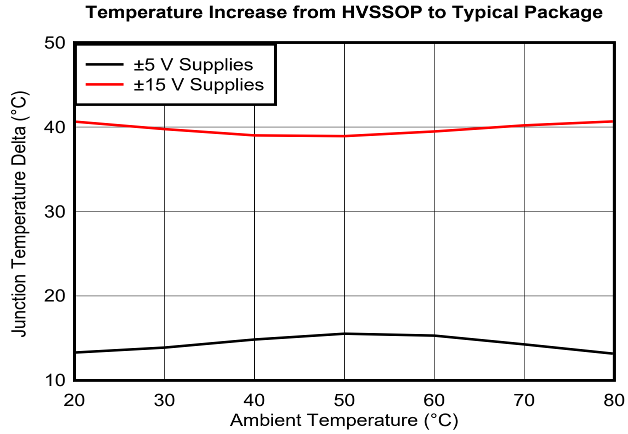


Figure 3-5. Temperature Delta from HVSSOP to Typical Package

As observed above, the ±5 V supplies case had an average of 14.3 °C temperature increase from the HVSSOP to the typical *SOIC* package, while the ±15 V case was an average of 39.8 °C temperature increase. This can be used to estimate the difference in input offset voltage drift and input bias current between the two packages. The OPA2828 has a typical offset voltage drift of ±0.3 uV/°C and a maximum drift of ±1.3 uV/°C. A theoretical input bias current drift of 30 pA/°C was used for comparisons.

Table 3-1. Error Increase from HVSSOP to Typical Package

Characteristic	Error Increase (Supply Voltages = ±5 V)	Error Increase (Supply Voltages = ±15 V)
Typical Offset Voltage	±4.29 uV	±11.94 uV
Maximum Offset Voltage	±18.59 uV	±51.74 uV
Input Bias Current	±429 pA	±1194 pA

By using the average temperature increases, the estimated Θja difference between the HVSSOP and the typical package is 48.1 °C/W. This is lower than the earlier estimations which can be attributed to physical differences between the modified HVSSOP and SOIC packages. The accuracy benefits seen in Table 3-1 show the importance of using a thermally-enhanced package in high precision applications.

4 Conclusion

The thermally-enhanced package HVSSOP was estimated to have a lower input offset voltage of 52 uV than a typical package, when dissipating 0.9 W of power. The HVSSOP was also estimated to have a lower input bias current by more than 1000 pA for the same test case. The measured junction-to-ambient thermal resistance for a typical package was 48.1 °C/W higher than the HVSSOP package. High precision applications require minimum sources of error to provide accurate results. Choosing a thermal-enhanced device greatly reduces thermal drift, ensuring the output is highly accurate over a wide temperature range.

5 References

- Texas Instruments, *OPAx828 Low-Offset, Low-Drift, Low-Noise, 45-MHz, 36-V, JFET-Input Operational Amplifiers*, data sheet.
- Texas Instruments, *DAC8811 16-Bit, Serial Input Multiplying Digital-to-Analog Converter*, data sheet.
- Texas Instruments, *Semiconductor and IC Package Thermal Metrics*, application note.