Thermal Management to Increase Density in PLC AO Modules

Introduction

Analog output modules for PLCs continue to increase in density while striving to achieve high accuracy analog performance. A key challenge in realizing this goal is managing power dissipation, and in turn, heat. In practical applications, many of these modules are connected side-by-side to the same backplane which can cause excessive heating to each PLC module if power dissipation is high. Elevated operating temperatures introduce error as circuit parameters fluctuate with temperature and can even decrease the life span of the system due to thermal stresses. This tech note will demonstrate how the adaptive power management of DAC8771 and DAC8775 significantly reduces the power dissipation and temperature of 3-wire and 4-wire group isolated, or channel-to-channel isolated current-output analog output modules.

3-Wire Analog Output Circuit

The basic current mode 3-wire analog output module consists of a DAC that drives a high-side V-to-I converter. A reference current flows through the R_A, R_{SET} and NMOS transistor based on the DAC output voltage. This current is gained by a current mirror and the loop current is sourced by the PMOS transistor. Figure 1 shows this common implementation and Equation 1 shows the transfer function from the DAC code to the current output.

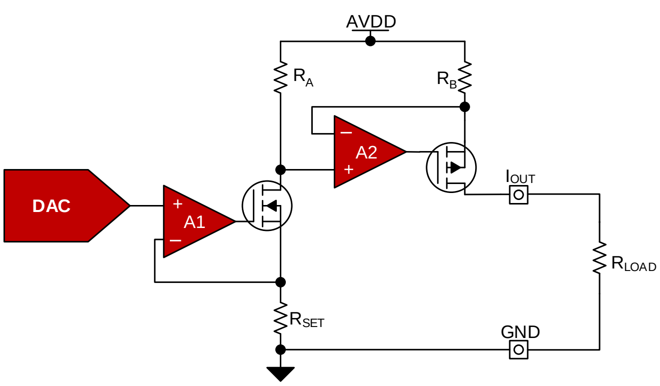

Figure 1. 3-Wire Current Transmitter Circuit

$$I_{OUT} = \frac{R_A}{R_B} \frac{V_{DAC}}{R_{SET}} \quad (1)$$

The biasing of the output PMOS, provided by the negative feedback loop of A2, ultimately controls the amount of current flowing from A_{VDD} to the load. Equation 2 shows the relationship between A_{VDD}, I_{OUT}, R_{LOAD} , and the compliance voltage V_C. A_{VDD} must be greater than the voltage drop of the resistors plus the compliance voltage to keep the PMOS transistor in saturation.

$$A_{VDD} > I_{OUT}(R_{LOAD} + R_B) + V_C \quad (2)$$

The draw-back to this topology is that it can lead to high on-board power dissipation. The bias point of the PMOS is related to the variables in Equation 2 as well as the output current set point. If A_{VDD} is much greater than the voltage at the point of load, the PMOS will be required to drop this additional voltage and dissipate the associated power. The on-board power dissipation due to the output current is shown in Equation 3. The power dissipated by the load resistor at the analog input module is not included.

$$P_{Diss} = A_{VDD} I_{OUT} - I_{OUT}^2 R_{LOAD} \quad (3)$$

The highest on-board power dissipation occurs when the resistance of R_{LOAD} is small and A_{VDD} is large. In this case most of the power is dissipated in the analog output module which causes the module to heat and performance to degrade. One solution to this problem is to reduce the voltage of A_{VDD}. This will reduce the power dissipation but the output module will no longer have the ability to drive large resistive loads. There is a trade-off between on board power dissipation and drivable load impedance.

Adaptive Power Management

By making a modification to the previous circuit, a circuit can be developed that has low power dissipation driving small loads but also the ability to efficiently drive large loads. This is achieved by varying the voltage at the source of the PMOS based on the load impedance and is referred to as adaptive power management. Figure 2 shows the 3-wire circuit modified to achieve adaptive power management.

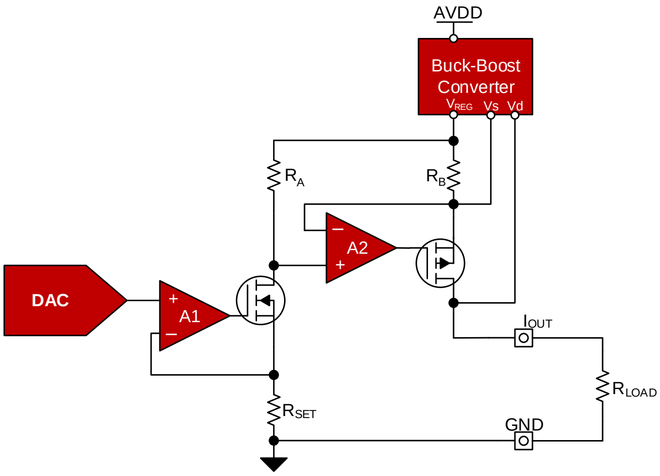

Figure 2. 3-Wire Transmitter With Adaptive Power Management

This circuit adds a buck-boost converter that can dynamically vary the voltage V_{REG}. The voltages at the drain and source of the output PMOS are measured to adjust the output of the buck-boost converter. If a large load is being driven V_{REG} is increased and if a small load is connected then the voltage is reduced. This avoids the situation where the output transistor must dissipate the full difference between A_{VDD} x I_{OUT} and I_{OUT}^2 x R_{LOAD}. Instead, the buck-boost regulates this voltage efficiently by varying the duty-cycle and switching frequency. V_{REG} is set to the voltage required to drive the load plus the compliance voltage required to keep the PMOS transistor in saturation. This topology leads to a significant improvement of on-board power dissipation and reduces heating.

Thermal Comparison

To illustrate the thermal impact of adaptive power management, the PCB temperature is visualized with thermal images for two different devices. The first device is DAC8760, a single channel voltage and current output DAC designed for 3-wire transmitters. The second device is DAC8771, which is also a 3-wire voltage and current output DAC, but the DAC8771 also includes adaptive power management, while the DAC8760 uses the topology seen in Figure 2.

The first comparison between the two devices is with A_{VDD} = 24V, R_{LOAD} = 250Ω, and I_{OUT} = 24mA. Figure 3 shows the PCB thermal images for DAC8760 and DAC8771. The maximum temperature in both cases is measured at the DAC IC. There is a significant difference of almost 10ºC between the device without adaptive power management and the device that includes this feature. The thermal impact can be even greater in the end application where the PCB is enclosed and multiple channels are required.

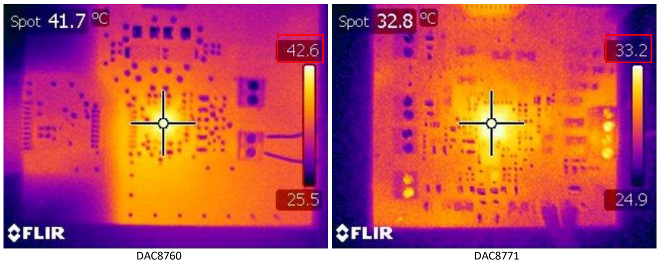

Figure 3. Thermal Comparison of DAC8760 and DAC8771 with Adaptive Power Management

The second comparison is a more extreme case where AVDD = 36V, Rload = 10Ω, and Iout = 24mA. In this case the on board power dissipation is greater due to the high input voltage and small load resistor.Figure 4 shows the PCB thermal images for the DAC8760 and DAC8771. DAC8771 is able to more efficiently regulate the supply voltage for the current output while the DAC8760 dissipates additional power in the output PMOS to regulate the current. This results in an IC temperature difference of approximately 19ºC.

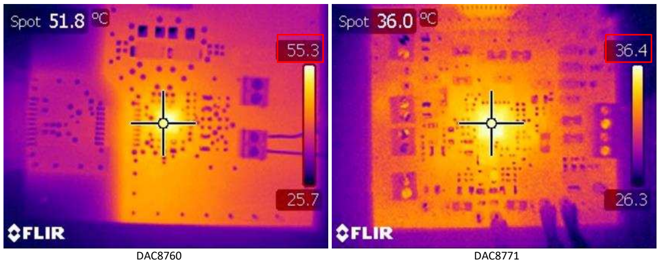

Figure 4. Thermal Comparison of DAC8760 and DAC8771 With Adaptive Power Management

Conclusion

The adaptive power management included in DAC8771 offers a significant thermal improvement and reduces on-chip power dissipation. The buck-boost converter in DAC8771 can also create all the supply voltages needed for bipolar operation from a single 12-V to 36-V input voltage. This simplifies power supply design requirements and makes the DAC8771 an ideal candidate for high density channel-to-channel isolated designs. The device can be programmed to many different output ranges and has alarm features that can improve system safety. For group-isolated designs, DAC8775 offers a quad-channel device with the same technology included.

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