Preventing Excess Current Consumption on Analog Switches

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Analog switches are extensively used for switching audio signals in battery-powered applications, such as mobile phones. In many cases, the switch is powered directly from the battery, but it receives control signals from a lower voltage processor GPIO. For most analog switches, this application condition leads to an excess supply current draw that catches system designers by surprise. This application report explains the cause of this excess current consumption and describes solutions to address it effectively.

Key Terms: TS, Analog Switch , Switch, I_{CCT}, ΔI_{CC}, Voltage Translation, Low Threshold Control Input

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1 Cause of Excess Current Consumption

CMOS logic circuits are typically designed to have an input threshold voltage equal to one-half the supply voltage (V_+). An input signal greater than $V_{IH(MIN)}$ is recognized as a valid logic high and an input signal lower than $V_{IL(MAX)}$ is recognized as a valid logic low. However, if the input signal is not driven all the way up to V_+ or all the way down to GND, it causes higher supply current as shown in Figure 1.

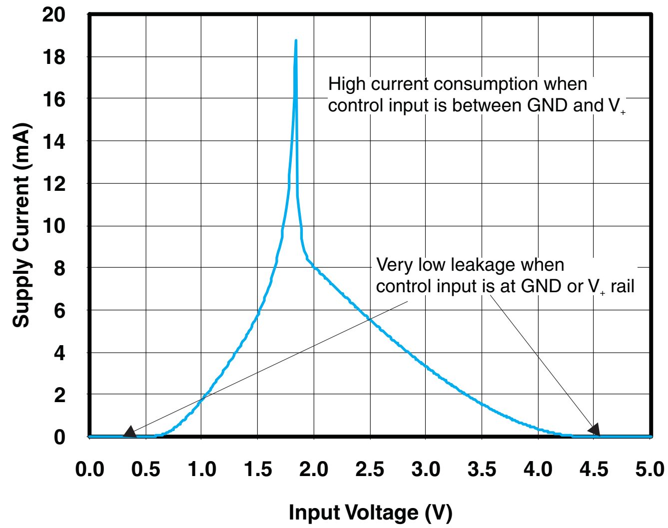

Figure 1. Supply Current vs. Control Input Voltage for the TS5A3159A (V_+ = 5 V)

The cause for this excess current can be understood by considering the structure of a simple CMOS inverter as shown in Figure 2. When a voltage equal to V_+ (high) is applied at the input, the upper p-channel transistor (P1) is off and the lower n-channel transistor (N1) is on. The output is pulled to GND (low) through the transistor N1. Similarly, when a voltage equal to GND (low) is applied at the input, N1 is off and P1 is on, pulling the output to V_+ (high) through the transistor P1. When changing output states from high to low, transistor P1 begins to turn off and transistor N1 begins to turn on. When V_{IN} is one transistor threshold voltage (V_{TT}) away from V_+ or GND, i.e. ($V_+ - V_{TT}$) > V_{IN} > (GND + V_{TT}), both P1 and N1 are partially on. This causes a through-current, I_+, to flow from V_+ to GND. This effect is most pronounced when $V_{IH(MIN)} > V_{IN} > V_{IL(MAX)}$ and a large current spike is observed. A similar situation exists when the output switches from low to high.

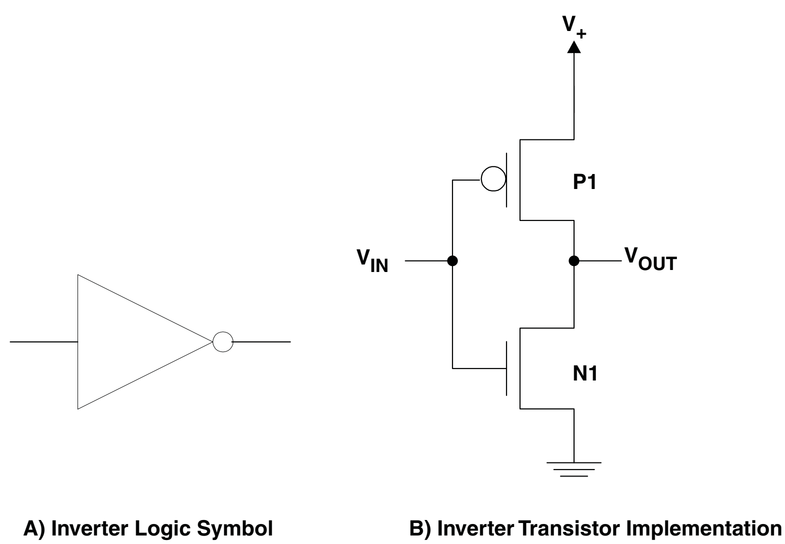

Figure 2. Simple CMOS Inverter

As shown in Figure 3, the control block of analog switches is built using CMOS logic circuitry and hence is susceptible to this same current consumption issue if the control input voltage is not at the rails (V_+ or GND). In battery-operated applications, any extra current consumption is intolerable, and so this issue must be understood and addressed from the start.

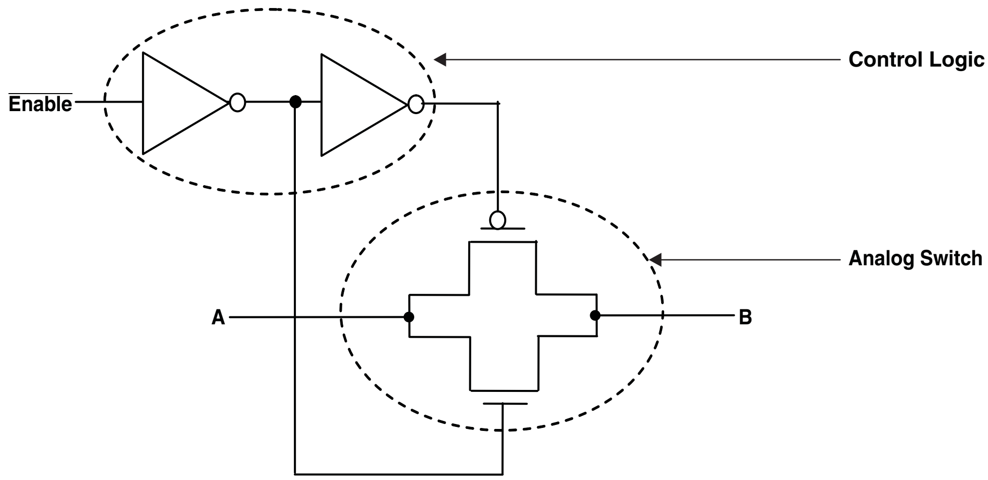

Figure 3. Internal Structure of a Typical Analog Switch

2 Excess Current Consumption in Analog Switch Applications

Analog switches are commonly used in many applications to route audio signals. A typical use case is highlighted in Figure 4. The analog switch is supplied with 5 V and the control input is from a 5-V processor GPIO as well. In this case, there are no concerns related to excess power consumption.

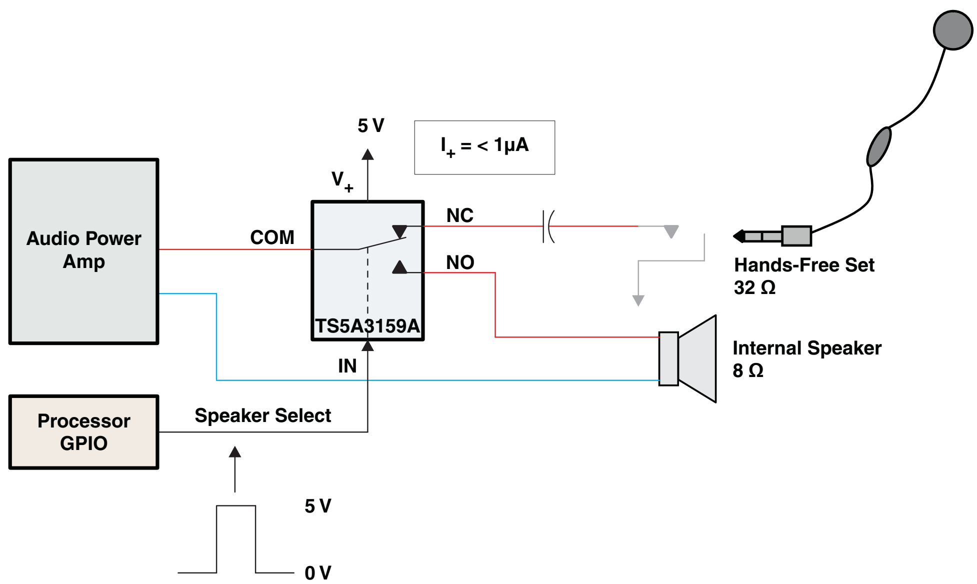

Figure 4. No Excess Current Consumption – Supply Voltage and Control Input Are at Same Voltage Level

In many battery-powered applications, the actual circuit setup is similar to that shown in Figure 5.

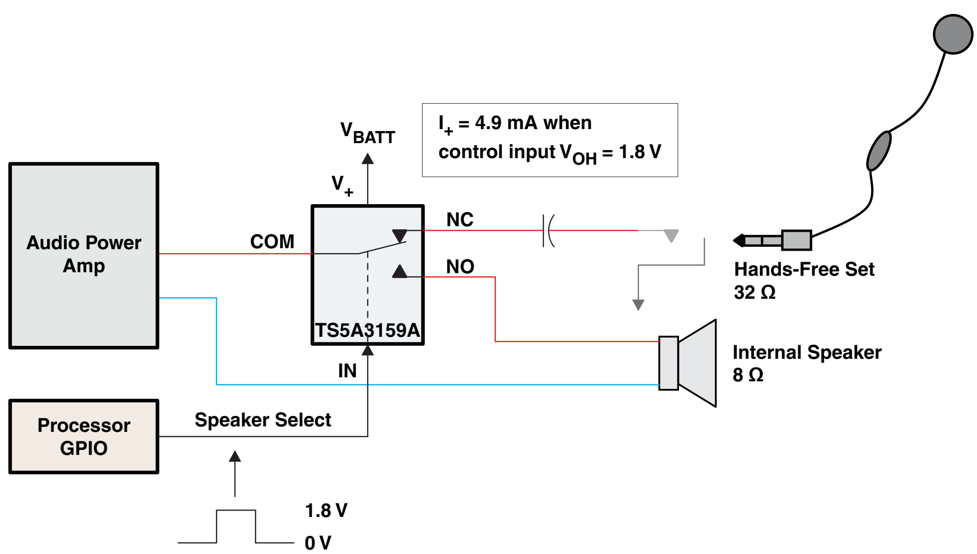

Figure 5. Excess Current Consumption – Control Input Is at Lower Voltage Than V_+

Figure 5 is described below:

- The analog switch supply voltage (V_+) is connected directly to the battery, which can range from 3 V to 4.2 V or 2.2 V to 4.5 V depending on battery technology. The system designer wants the analog switch to have a low and flat on-resistance (r_{ON}) for minimum distortion of the audio signal passing through the switch. Since the analog switch has lower and flatter r_{ON} performance when powered with a higher supply voltage, it is supplied directly using V_{BATT}, which is typically the highest supply voltage available on the board.
- The processor that controls the analog switch has lower voltage GPIOs, e.g., 1.8 V to lower the current consumption.

If V_+ is at 4.2 V, while the control input is at 1.8 V, it leads to an excess current draw from the V_+ supply pin due to the situation described in Section 1.

WARNING

Do not use a pullup resistor from the processor GPIO directly to V_{BATT} for level shifting.

To fix the excess current consumption issue, system designers sometimes try to add a pullup resistor from the processor GPIO to V_{BATT} to level shift the control signal (Figure 6). However, this technique has several flaws and should be avoided. One drawback is increased power consumption whenever the GPIO output switches low (N1 is on). Another problem occurs when the output of the CMOS driver is high. In this state, the lower N-channel transistor (N1) is off while the upper P-channel transistor (P1) is on. There is a back flow of current from the high supply to the low supply through the resistor R and the transistor P1. This current flow into the low supply could cause undesirable effects. A third drawback is that the processor GPIO might not be over-voltage tolerant and any I/O voltage higher than V_{DDIO} could damage the GPIO.

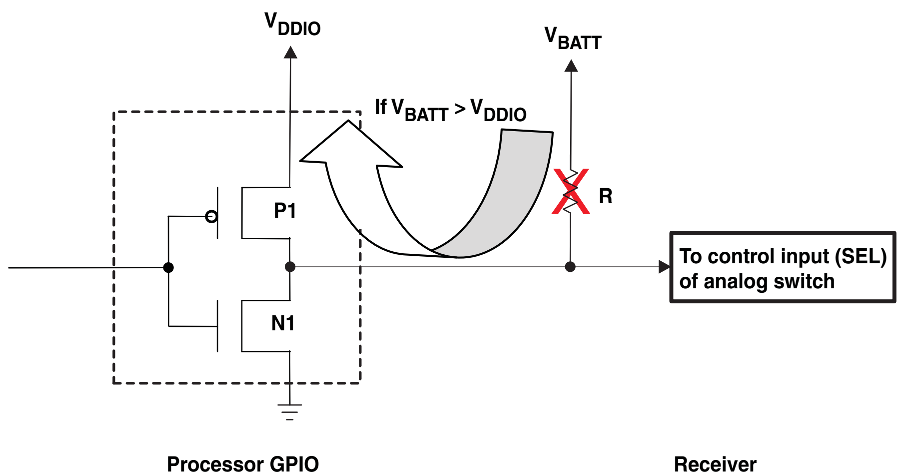

Figure 6. Drawbacks of Using a Pullup Resistor Directly From Processor GPIO to V_{BATT} for Up-Translation

3 How to Solve the Excess Current Consumption Issue

One option to fix the excess current consumption is to use a level shifter such as the SN74LVC1T45 to level shift the control signal. However, this increases board space and part count on the Bill of Material (BOM). Texas Instruments has several analog switches that are designed to accept control signals from a low-voltage microprocessor and solve the excess current consumption issue.

- Analog switches with low control input threshold – These are devices with control inputs designed to have a switching threshold voltage lower than half of V_+. This feature helps reduce current consumption when control signals are input from a low voltage GPIO. However, the control input threshold voltage is dependent on V_+. If V_+ is connected to V_{BATT}, the threshold decreases as the battery discharges. The TS3A44159 is an analog switch that uses this type of low-voltage control inputs.
- Dual supply analog switch – This analog switch has two supply voltage pins. One supply voltage is for the control inputs and the other supply voltage powers the analog switch. The advantage of this approach is that the control input threshold remains constand and is independent of V_+. Hence, even as the battery discharges, the control input threshold remains constant. However, the system designer has to route two supply rails to the analog switch. The TS5A6542 and TS5A26542 are analog switches with dual supply voltage pins.

To overcome drawbacks of the above-mentioned solutions, Texas Instruments has introduced an analog switch that has a single supply voltage pin as well as a low voltage control input threshold that does not vary with the supply voltage. The features and benefits of this analog switch are highlighted in Section 3.1.

3.1 *TS5A12301E – Analog Switch With Fixed Low Control Input Threshold*

The TS5A12301E is a SPDT analog switch specially designed to support low voltage control pins (see Figure 7 and Table 1). This analog switch features an ultra-low R_{ON} of 0.75 Ω, which makes it ideal for use in audio applications. The control input (IN) of this device can accept 1.2-V, 1.5-V, 1.8-V, 2.5-V, 3.3-V, and 5-V logic control signals without any excess current consumption regardless of the supply voltage V_+. The control input of this device, uses a circuit that keeps the input threshold constant, independent of V_+. This is demonstrated in Figure 8 where the control input threshold remains fixed at approximately 0.81 V (typical) over a wide range of V_+ values.

See Appendix A for the test setup for these waveforms.

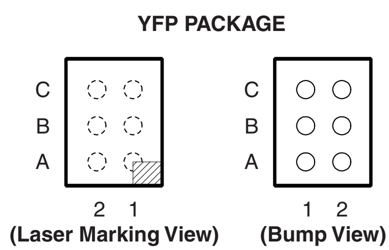

Figure 7. TS5A12301E Package Pinout

Table 1. YFP Package Terminal Assignments

C	NC	V_+
B	GND	COM
A	NO	IN
	1	**2**

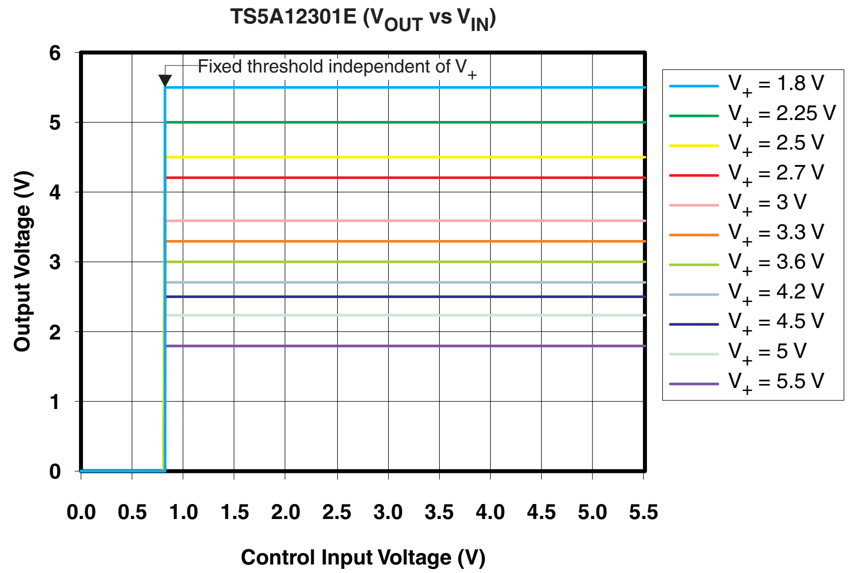

Figure 8. Control Input Threshold is Independent of V_+

Figure 9 shows a competitor solution that also has a low control input threshold. However, for this competitor device, the control input threshold varies as V_+ changes.

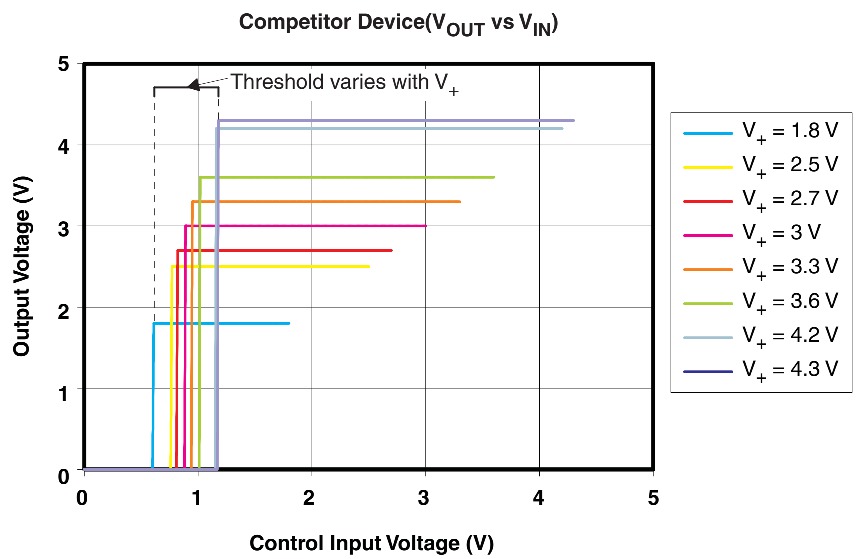

Figure 9. Input Threshold Variation on Competitor Device

If the TS5A12301E is powered directly from V_{BATT}, the input threshold ($V_{IH(MIN)}$ and $V_{IL(MAX)}$ requirements) of the control input remains constant even as the battery discharges as shown in Figure 10. However, with the competitor solution, the control input threshold is dependent on V_+ and decreases as the battery voltage discharges.

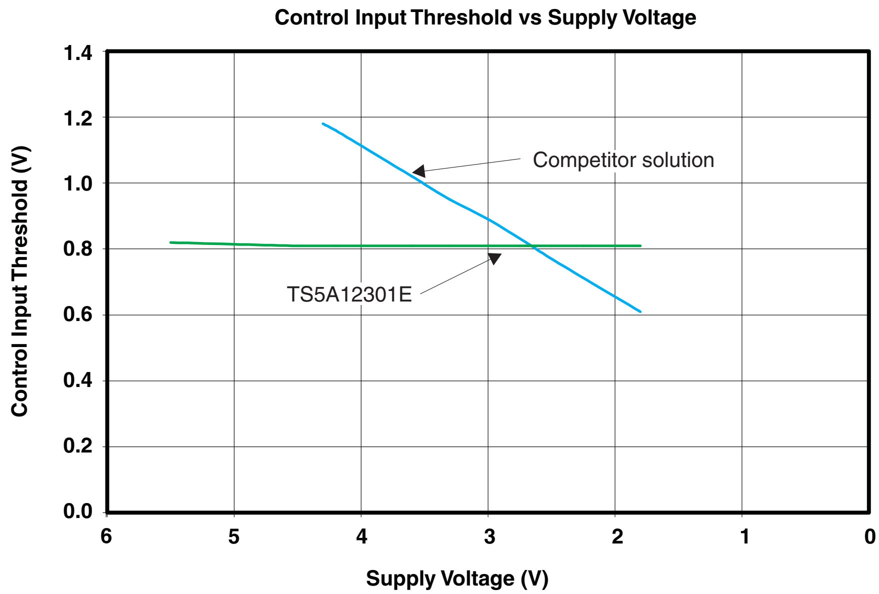

Figure 10. TS5A12301E Has a Constant Threshold Even as the Battery Discharges

The control input of the TS5A12301E is over-voltage tolerant; therefore, even if V_{OH} of the control input exceeds V_+, the device can operate normally. This is useful if the processor GPIO controlling the analog switch is at a higher voltage compared with the supply voltage of the analog switch. The competitor solution does not have over-voltage tolerant control inputs and cannot be used in such applications.

As shown in Figure 11, the peak current consumption of the TS5A12301E is very low and constant compared with that of the competitor solution. This helps lower current consumption during switching of the control input (IN).

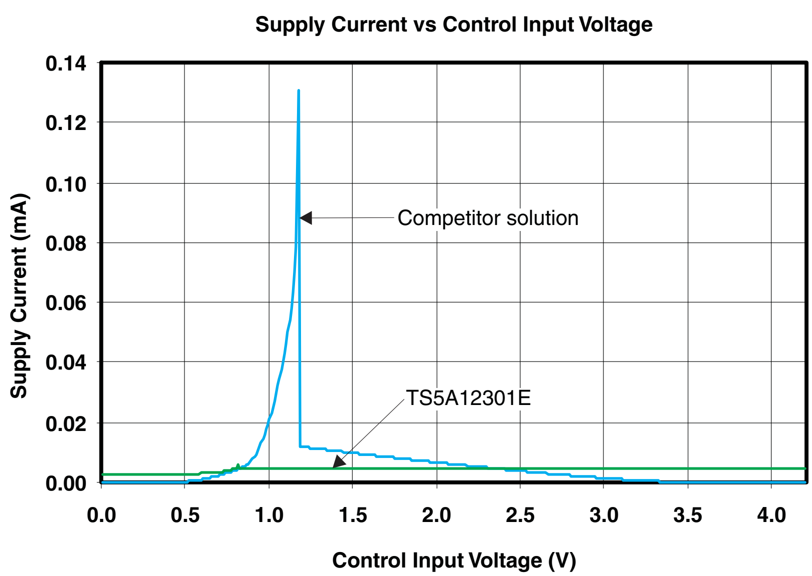

Figure 11. Comparison of Supply Current Between Competitor Solution and TS5A12301E

4 Summary and Conclusion

When the V_{OH} voltage of control signals to an analog switch is lower than its supply voltage, the system designer must ensure that there is no excess power consumption. One way to prevent excess power consumption is to use an external level shifter on the control input line. However, this solution adds to board space and part count. The TS5A12301E is an analog switch designed specifically to address this issue with a single chip solution. Table 2 provides a summary and shows the tradeoffs between different solutions.

Table 2. Summary of Power Consumption With Different Solutions

ANALOG SWITCH	CONTROL INPUT VOLTAGE		SUPPLY VOLTAGE	LEVEL TRANSLATOR NEEDED?	LEVEL TRANSLATOR USED	STATIC CURRENT CONSUMPTION (TYPICAL)
TS5A3159A	0 to 5 V swing	Logic low: 0 V	5 V	No	None	<0.5 µA
		Logic high: 5 V				<0.5 µA
TS5A3159A	0 to 1.8 V swing	Logic low: 0 V	4.2 V	Yes	None	<0.5 µA
		Logic high: 1.8 V				4.9 mA
TS5A3159A	0 to 1.8 V swing	Logic low: 0 V	4.2 V	Yes	SN74LVC1T45	<1 µA
		Logic high: 1.8 V				<1 µA
TS3A44159	0 to 1.8 V swing	Logic low: 0 V	4.2 V	No	None	<1 µA
		Logic high: 1.8 V				19 uA
Competitor	0 to 1.8 V swing	Logic low: 0 V	4.2 V	No	None	<0.75 µA
		Logic high: 1.8 V				7.3 µA
TS5A6542	0 to 1.8 V swing	Logic low: 0 V	4.2 V	No	None	<0.75 µA
		Logic high: 1.8 V				<0.75 µA
TS5A12301E	0 to 1.8 V swing	Logic low: 0 V	4.2 V	No	None	3 µA
		Logic high: 1.8 V				5 µA

The TS5A3159A analog switch operates normally if V_{OH} of the control input is greater than or equal to V_+, up to 5.5 V max. However, if V_{OH} of the control signal is less than V_+, it leads to excessive current consumption as shown in the summary table. The excess current consumption problem can be solved by adding an external voltage level translator such as the SN74LVC1T45, but this solution increases board space and BOM cost.

An alternate solution is to use a device with a low control input threshold such as the TS3A44159. The current consumption is only 19uA (typical) when the control input is at 1.8 V. However, for this solution, the input threshold voltage decreases as the supply voltage decreases. The competitor solution shown is also susceptible to this exact same drawback that the control input threshold is dependent on V_+. The TS5A6542 fixes this issue by providing a separate supply pin for the control input voltage. This solution solves the problem of excess power consumption and also maintains the control input threshold at a fixed level. However, the system designer has to supply the analog switch with two separate supply voltages.

The TS5A12301E overcomes all shortcomings of the above-mentioned devices. It solves the problem of excess power consumption, provides a fixed threshold independent of the supply voltage, and uses only a single supply voltage pin. The TS5A12301E is an ideal choice for use in audio applications where the supply voltage to the analog switch is greater than V_{OH} of its control signal.

Test Setups

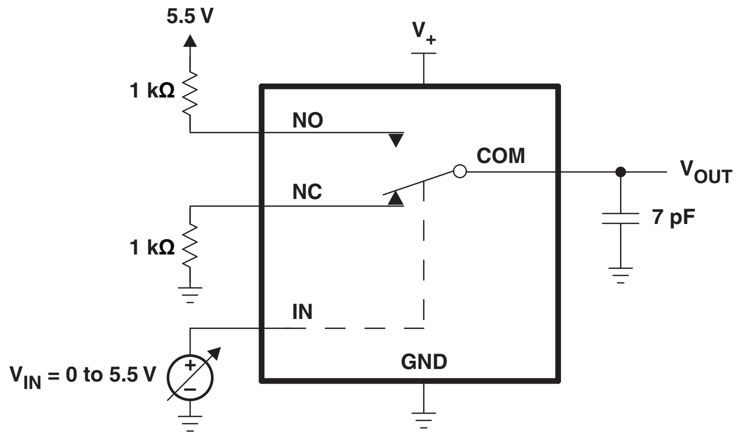

Figure A-1. Test Setup for TS5A12301E (V_{OUT} vs V_{IN})

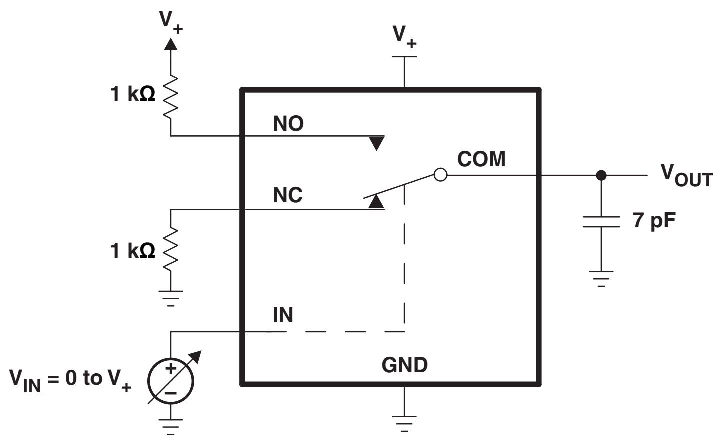

Figure A-2. Test Setup for Competitor Device (V_{OUT} vs V_{IN})

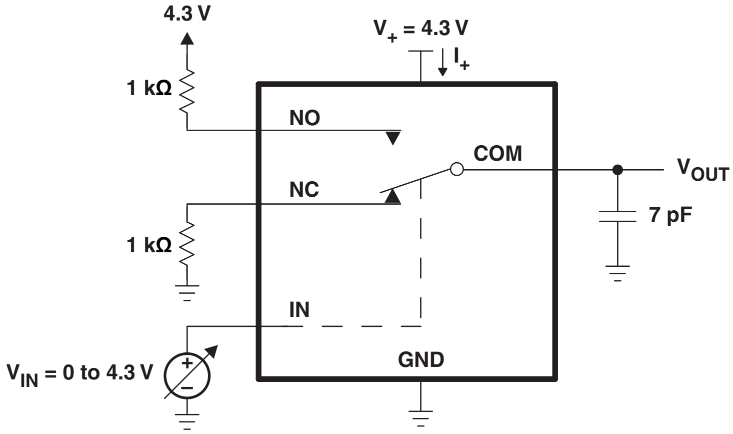

Figure A-3. Test Setup for Supply Currrent vs Control Input Voltage