Application Report
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Interfacing the 3-V MSP430™ MCUs to 5-V Circuits

MSP430 Applications

ABSTRACT

This application report describes the interface of a 3-V MSP430™ microcontroller (MCU) to a circuit with a supply of 5 V or higher. This report explains input, output, and I/O interfaces and provides worst-case design equations where necessary. This report also describes some simple power supplies that generate both voltages.

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1 Introduction

The MSP430 Sensing and Measurement MCUs support a supply voltage range of 1.8 V to 3.6 V. This is due to the manufacturing process used and has the advantage of drawing even less current than with a 5-V supply.

If an interface to a 5-V system or to a system with an even higher voltage is necessary, it can result in difficulties. This application report explains 5-V interfaces for the inputs, outputs, and I/Os of an MSP430 MCU. Figure 1 shows examples of input, output, and I/O interfaces. The shaded boxes in the figure are the topic of this application report.

NOTE: Throughout this document, the term *MSP430 MCU* stands for the members of the different MSP430 families. Refer to the device-specific data sheets for parameter specifications.

The given formulas for the external supply voltage $V_{(sys)}$ also can be used for higher voltages than 5 V. The equation are useful for any external voltage; for example, $V_{(sys)}$ = 12 V.

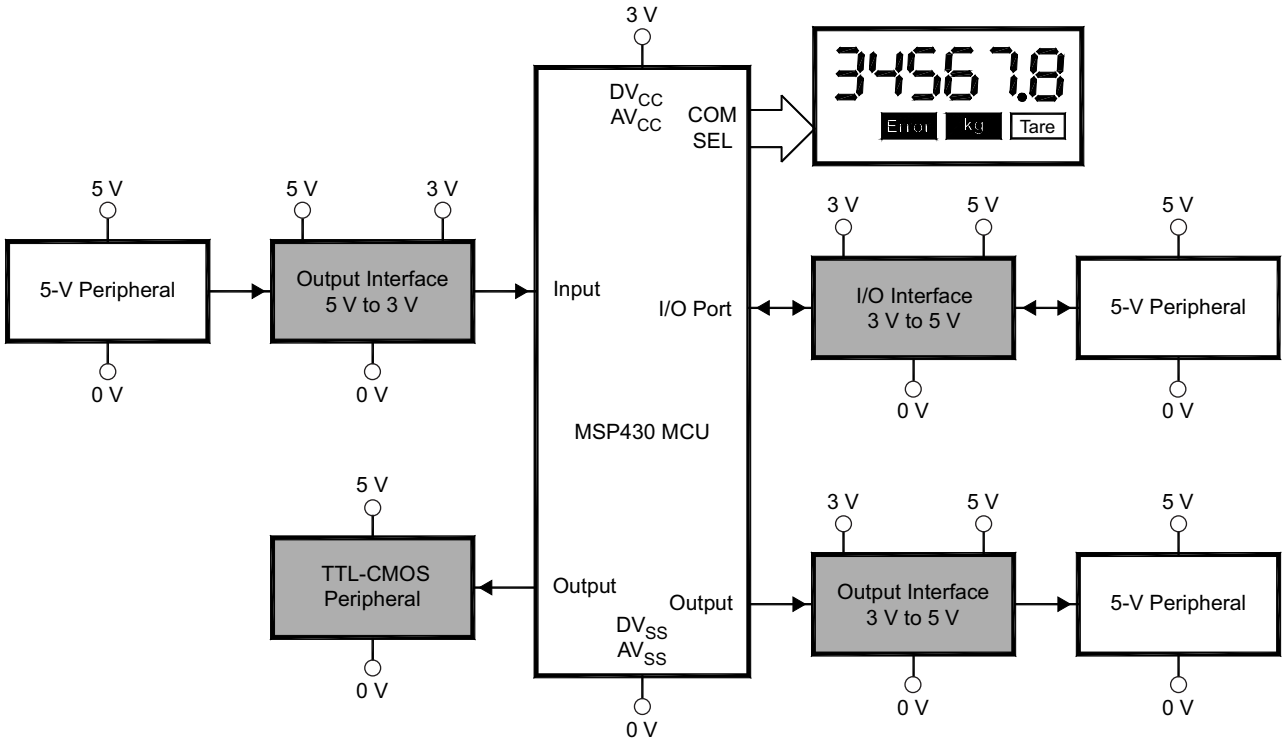

Figure 1. Interfaces Between the 3-V MSP430 MCU and 5-V Systems

With the worst-case equations, the following simplifications are used for the calculation with small values of a_x (like for the tolerance *p*):

$$\frac{1}{1+a_x} \approx (1 - a_x)$$
$$\frac{1}{1-a_x} \approx (1 + a_x)$$
$$\frac{1+a_x}{1-a_x} \approx (1 + 2a_x)$$
$$\frac{1-a_x}{1+a_x} \approx (1 - 2a_x) \quad (1)$$

The resulting errors can be neglected if $| a_x | < 0.1$.

2 Definitions

2.1 Specification Values of MSP430 MCU

The numeric values for the worst-case design equations are taken from MSP430F43x, MSP430F43x1, MSP430F44x Mixed-Signal Microcontrollers. The indicated values are for DV_{CC} = 3 V.

Table 1. Specification Values for MSP430 MCUs

Symbol	Parameter	Value
$DV_{CC(min)}$	Minimum digital supply voltage	1.8 V
$DV_{CC(max)}$	Maximum digital supply voltage	3.6 V
$V_{IT(max)}$	Maximum high input threshold voltage of a port	1.9 V
$V_{IT(min)}$	Minimum low input threshold voltage of a port	0.9 V
$V_{OH(min)}$	Minimum high port output voltage at I_O = –1.5 mA	DV_{CC} – 0.25 V
$V_{OL(max)}$	Maximum low port output voltage at I_O = 1.5 mA	DV_{SS} + 0.25 V
I_{lkg}	Leakage current of an input	±50 nA
	Absolute maximum current through the protection diodes of any terminal (V_I < – 0.3 V or V_I > V_{CC} + 0.3 V)	±2 mA

NOTE: The output impedance $r_{DS(on)}$ of an MSP430 MCU output is not taken into account, due to the choice of high resistor values with the design equations. The output impedance $r_{DS(on)}$ (maximum of 167 Ω) is very small compared to the resistors used.

2.2 External System Definitions

Table 2. External System Definitions

Symbol	Description	Unit
$V_{(sys)}$	Supply voltage of the external system	V
$V_{(sysH)}$	High output voltage from the external system	V
$V_{(sysL)}$	Low output voltage from the external system	V
$V_{(sys+)}$	High input voltage of the external system	V
P	Tolerance of the interface resistors	%
$DV_{CC(min)}$	Minimum supply voltage for the MSP430 with a DV_{CC} = 3.0 V ±10% (3.0 V × 0.9 = 2.7 V)	V

3 Input Interfaces

The input interfaces are primarily intended for an interface between 5-V and 3-V systems. However, they also can be used for external voltages higher than 5 V (for example, the interface of a 12-V signal to the input of the MSP430 MCU).

3.1 Resistor-Divider Input Interfaces

An external digital input voltage ($V_{I(sys)}$) is connected to the MSP430 MCU. The worst case equations for the resistors R1 and R2 in Figure 2 are:

$$\frac{R1}{R2} < \frac{V_{(sysH)}min - V_{IT(max)}}{V_{IT(max)} \times (1 + 2p)}$$
$$\frac{R1}{R2} > \frac{V_{(sysL)}max - V_{IT(min)}}{V_{IT(min)} \times (1 - 2p)}$$
$$R1 \parallel R2 \ll \frac{DV_{CC}}{|I_{lkg}|} \quad (2)$$

The first two equations ensure that the input voltage $V_{I(430)}$ at the input of the MSP430 MCU is above (when $V_{I(sys)}$ is high) or below (when $V_{I(sys)}$ is low) the worst case input threshold voltages. The third equation ensures that the leakage current I_{lkg} of the input does not influence the voltage $V_{I(430)}$.

To avoid current into the input protection diodes of the MSP430 MCU, Equation 3 must be true.

$$V_{sysH(max)} \times \frac{R2max}{R1min + R2max} < DV_{CC(min)} + 0.3$$
$$V_{sysL(min)} \times \frac{R2min}{R1max + R2min} > -0.3 \quad (3)$$

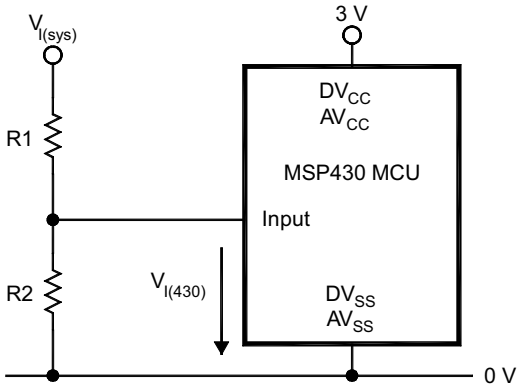

Figure 2. Resistor Input Interface From 5 V to the MSP430

Example: The two input voltages from the system are $V_{(sysH)}$ = 5.0 V ±10% and $V_{(sysL)}$ = 0.5 V ±0.5 V. The resistor tolerance is p = ±5%. The minimum supply voltage of the MSP430 MCU in this example is $DV_{CC(min)}$ = 2.7 V (3.0 V – 10%).

The specifications for the threshold voltages $V_{IT(max)}$ and $V_{IT(min)}$ lead to the following condition for the input voltage $V_{(sysH)min}$:

$$\frac{R1}{R2} < \frac{V_{(sysH)}min - V_{IT(max)}}{V_{IT(max)} \times (1 + 2p)} = \frac{4.5V - 1.9V}{1.9V \times (1 + 0.1)} \rightarrow \frac{R1}{R2} < 1.244 \quad (4)$$

The condition for the low input voltage $V_{(sysL)max}$ is:

$$\frac{R1}{R2} > \frac{V_{(sysL)}max - V_{IT(min)}}{V_{IT(min)} \times (1 - 2p)} = \frac{1.0V - 0.9V}{0.9V \times (1 - 0.1)} \rightarrow \frac{R1}{R2} > 0.1234 \quad (5)$$

To ensure negligible influence of the leakage current I_{lkg}:

$$R1 \parallel R2 \ll \frac{DV_{CC}}{|I_{lkg}|} = \frac{3V}{|\pm 50nA|} \rightarrow R1 \parallel R2 \ll 60M\Omega \quad (6)$$

The previous three design equations allow a wide range for R1 and R2. If R1/R2 is chosen to be 1.0 and R1||R2 is chosen to be 600 kΩ, then R1 = 1.2 MΩ and R2 = 1.2 MΩ.

To avoid current into the input protection diodes of the MSP430 MCU:

$$V_{(sysH)}max \times \frac{R2max}{R1min + R2max} < DV_{CC(min)} + 0.3$$
$$V_{(sysL)}min \times \frac{R2min}{R1max + R2min} > -0.3$$
$$5.5V \times \frac{1.26M\Omega}{1.14M\Omega + 1.26M\Omega} < 2.7V + 0.3 \rightarrow 2.8875V < 3.0V \rightarrow \text{the condition is true}$$
$$0.0V \times \frac{1.14M\Omega}{1.26M\Omega + 1.14M\Omega} > -0.3 \rightarrow 0.0V > -0.3 \rightarrow \text{the condition is also true} \quad (7)$$

The last two equations are not important if the current into the input of the MSP430 MCU is far below ±2 mA (the absolute maximum rating value for an input current). This is the case for R1||R2 = 600 kΩ.

The design equations are valid for the following terminals of the MSP430 MCU, if set to the input direction:

- All I/O ports (ports P1 to P6)
- Crystal inputs XIN and XT2IN: $V_{IL(X)max}$ = 0.2 × DV_{CC}, $V_{IH(X)min}$ = 0.8 × DV_{CC}
- $\overline{RST}$/NMI input: V_{ILmax} = DV_{SS} +0.6 V, V_{IHmin} = 0.8 × DV_{CC}
- Comparator_A inputs CA0 and CA1
- UART and SPI inputs URXDx, SOMIx, SIMOx, UCLK
- Timer_A inputs TACLK and TA0 to TA2
- Timer_B inputs TBCLK and TB0 to TB6
- ADC12 inputs: the sample time $t_{(sample)}$ must be adapted to the impedance R1||R2 of the resistor divider. For more information, see the ADC12 chapter of the MSP430x4xx Family User's Guide or the MSP430x1xx Family User's Guide.

3.2 Transistor Input Interface

The transistor-input interface is a very simple interface that can adapt many external systems to the MSP430 family. Figure 3 shows an example for an inverting input buffer. The resistor R_C can be switched off by an output to save current during low-power mode 3.

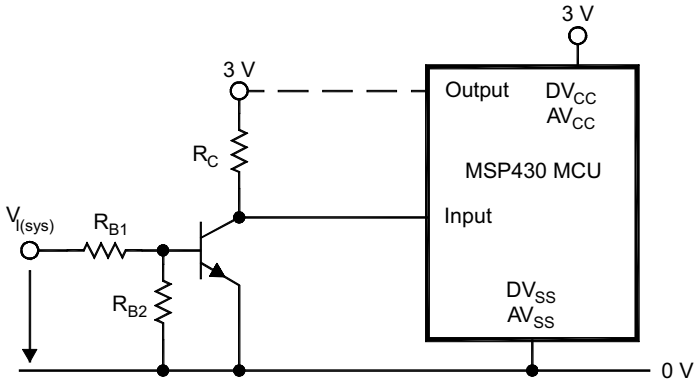

Figure 3. Transistor Input Interface From a 5-V Environment

The design equations for the resistors R_C, R_{B1}, and R_{B2} follow.

Equation 8 ensures high potential at the MSP430 with leakage currents.

$$R_C < \frac{DV_{CC(min)} - V_{IT(max)}}{(1 + p) \times (I_{lkg} + I_{lkg(Tr)})} \quad (8)$$

Equation 9 ensures turn off of the transistor for input voltage $V_{(sysL)}$max.

$$\frac{R_{B1}}{R_{B2}} > \left(\frac{V_{(sysL)}max}{V_{BE(off)}} - 1\right) \times (1 + 2p) \quad (9)$$

Equation 10 ensures the turn on of the transistor for the input voltage $V_{(sysH)}$min.

$$R_{B1} < \frac{V_{(sysH)}\text{min} - V_{BE(on)} \times \left(1 + \frac{R_{B1}}{R_{B2}} \times (1 + 2p)\right)}{DV_{CC(max)}} \times \beta\text{min} \times R_C\text{min}$$

- $V_{BE(off)}$ = Transistor base-emitter voltage for secure turnoff (V)
- $V_{BE(on)}$ = Transistor base-emitter voltage for secure turnon (V)
- β = Current amplification of the transistor
- $I_{lkg(Tr)}$ = Leakage current of the transistor (A)

(10)

Example: Input voltage $V_{I(sys)}$ is connected to an input of the MSP430 MCU with I_{lkg} = ±50 nA. The minimum high-input level $V_{(sysH)min}$ = 4.5 V, the maximum low-input level $V_{(sysL)max}$ = 0.7 V. The resistor tolerance of all resistors is p = ±5%. The supply voltage is DV_{CC} = 3 V ±10%. The transistor properties are $V_{BE(on)}$ = 0.75 V, $V_{BE(off)}$ = 0.2 V, βmin = 100, $I_{lkg(Tr)}$ = 10 nA.

Equation 11 shows the maximum nominal value for R_C.

$$R_C < \frac{DV_{CC(min)} - V_{IT(max)}}{(1 + p) \times (I_{lkg} + I_{lkg(Tr)})} = \frac{2.7\ V - 1.9\ V}{(1 + 0.05) \times (50\ nA + 10\ nA)} = 12.7\ M\Omega$$

$$R_C = 2\ M\Omega \text{ is chosen}$$

(11)

Equation 12 shows the minimum ratio for the nominal values of R_{B1} and R_{B2}.

$$\frac{R_{B1}}{R_{B2}} > \left(\frac{V_{(sysL)}\text{max}}{V_{BE(off)}} - 1\right) \times (1 + 2p) = \left(\frac{0.7\ V}{0.2\ V} - 1\right) \times (1 + 0.1) = 2.75$$

(12)

Equation 13 shows the maximum nominal value for R_{B1}.

$$R_{B1} < \frac{V_{(sysH)}\text{min} - V_{BE(on)} \times \left(1 + \frac{R_{B1}}{R_{B2}} \times (1 + 2p)\right)}{DV_{CC(max)}} \times \beta\text{min} \times R_C\text{min}$$

$$R_{B1} < \frac{4.5\ V - 0.75\ V \times 1 + 2.75 \times (1 + 0.1)}{3.3\ V} \times 100 \times 2\ M\Omega \times \left(1 - 0.05\right) = 85.3 M\Omega$$

$$R_{B1} = 39\ M\Omega \text{ is chosen}$$

(13)

With the value 39 MΩ for R_{B1}, Equation 14 shows the resistor R_{B2}.

$$R_{B2} < \frac{R_{B1}}{2.75} = \frac{39\ M\Omega}{2.75} = 14.18 M\Omega$$

$$R_{B2} = 10\ M\Omega \text{ is chosen}$$

(14)

3.3 Op-Amp Input Interface

Op amps for the input interface are the best choice, if they are needed for the system (for example, as an integrator, comparator, amplifier, or DAC). For the TLC27L4, it is necessary to limit the input voltages to a maximum of V_{DD} + 0.3 V. The minimum supply voltage ($V_{CC(min)}$) of the TLC27L4 is 3 V.

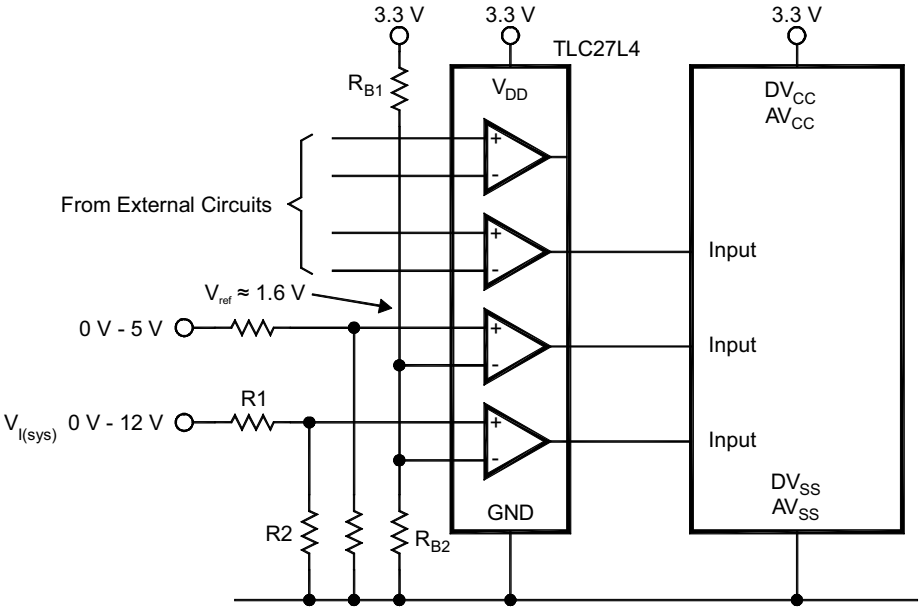

Figure 4. Input Interfaces With Op Amps

Equation 15 shows the worst case equations for the resistors R1 and R2 in Figure 4.

$$\frac{R1}{R2} < \frac{V_{(sysH)}\,min - V_{ref(max)}}{V_{ref(max)} \times (1 + 2p)}$$

$$\frac{R1}{R2} > \frac{V_{(sysL)}\,max - V_{ref(min)}}{V_{ref(min)} \times (1 - 2p)}$$

$$R1 \parallel R2 \ll \frac{DV_{CC}}{|I_{lkg}|}$$

Where

$$V_{ref(max)} = DV_{CC(max)} \times \frac{R_{B2}max}{R_{B1}min + R_{B2}max}$$

$$V_{ref(min)} = DV_{CC(min)} \times \frac{R_{B2}min}{R_{B1}max + R_{B2}min} \quad (15)$$

Section 3.1 includes a calculation example.

3.4 TPL7407LA Input Interface

On the left side of Figure 7, three TPL7407LA buffers are used for the input interfacing to 5-V and 12-V systems. The series resistor R_V (p = ±5%) for the 12-V input signal ($V_{(sysH)min}$ = 11 V) is:

$$R_V < \frac{V_{(sysH)}min - V_{I(on)}min}{(1 + p) \times I_{I(on)}max} = \frac{11\ V - 2.4\ V}{1.05 \times 1.35\ mA} \rightarrow R_V max < 6.06\ k\Omega$$

$$R_V = 6.0\ k\Omega \text{ is chosen} \quad (16)$$

The pullup resistor R_p at the input of the MSP430 MCU is:

$$R_p < \frac{V_{CC} - V_{IT(max)}}{(1 + p) \times I_{CE}max} = \frac{3\ V - 1.9\ V}{1.05 \times 50\ \mu A} \rightarrow R_p max < 20.9\ k\Omega$$

$$R_p = 20\ k\Omega \text{ is chosen} \quad (17)$$

To avoid current consumption, the resistors R_p are switched to DV_{CC} only when necessary.

3.5 Integrated-Circuit Input Interface

For a 5-V to 3.3-V input interface, any CMOS circuit that fulfills the following two conditions can be used:

- It is built for a supply voltage of 3.3 V or lower.
- It is explicitly allowed to use input voltages higher than 3.3 V.

The AHC and LVC families fulfill both conditions. They share the 3.3-V supply of the MSP430 MCU.

Refer to the absolute maximum ratings in the device-specific data sheet to determine if an input voltage V_I higher than the 3.3-V supply is allowed. If a higher voltage is allowed, the following entry appears:

Input voltage range VB_I = 0.5 V to 7 V

This is different from other CMOS circuits, which typically have an entry similar to the following:

Input voltage range V_I = 0.5 V to V_{CC} + 0.5 V

or

Input clamp current I_{IK} (V_I < 0 or V_I > V_{CC}) = ±20 mA

3.6 Analog Input Interface

The same resistor divider solution described for the digital interfaces in Section 3.1 can be used for the analog ADC12 inputs. Figure 5 shows the connection of a 5-V Hall-sensor current interface to the ADC12 input Ax. Section 3.1 describes the worst case equations for the resistor divider.

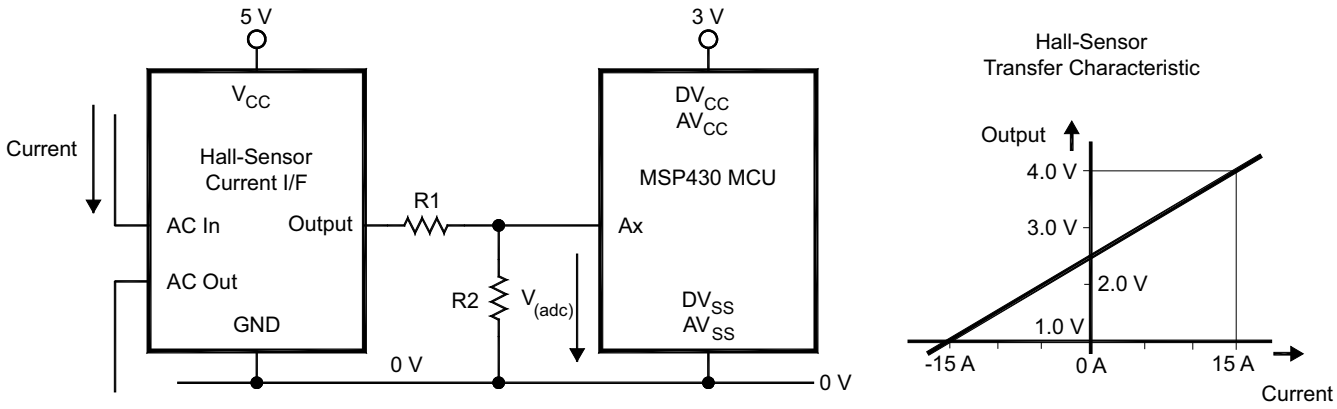

Figure 5. Analog ADC12 Input Interface From 5 V to 3 V

If the external peripheral cannot deliver the current for the resistor divider, a unity-gain op amp can be placed between the peripheral output and resistor R1.

The ADC12 sample time $t_{(sample)}$ must be adapted to the impedance R1||R2 of the resistor divider. For more information, see the ADC12 chapter of the MSP430x4xx Family User's Guide or the MSP430x1xx Family User's Guide.

4 Output Interfaces

No interface is needed for LCDs and for passive sensors. They are directly connected to the MSP430 MCU in the usual way (see the MSP430x4xx Family User's Guide).

4.1 Transistor Output Interface

Figure 6 shows a simple interface to systems with supplies higher than 3 V. The transistor load R_L can be nearly any component (for example, resistors, fans, heating coils, or relays). The base resistor R_{BB} can be calculated with the equation:

$$R_B = \frac{R_L\text{min} \times \beta\text{min} \times (V_{OH(\text{min})} - V_{BE(on)})}{(1 + p) \times V_{(sys)}\text{max}}$$

- $R_L$min = Minimum load resistor (Ω)
- βmin = Minimum current amplification of the transistor
- $V_{(sys)}$max = Maximum supply voltage of the external system (V)
- $V_{BE(on)}$ Transistor base-emitter voltage for turnon (V) (18)

Due to the low output voltage of the port on the MSP430 MCU, no resistor from the transistor base to 0 V is necessary.

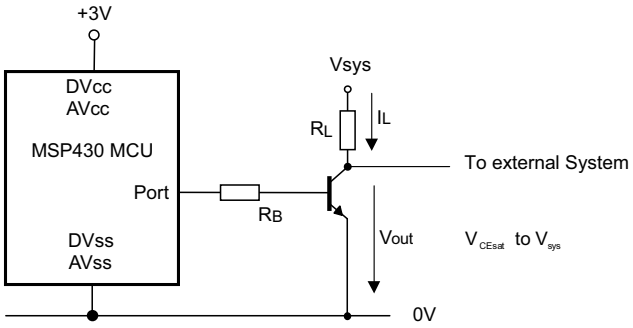

Figure 6. Transistor Output Interface to a 5-V Environment

Example: A load R_L = 100 Ω ±3% is connected to $V_{(sys)}$ = 5 V ±10%. The resistor tolerance of R_{BB} is p = ±10%. The minimum supply voltage in this example is $D_{VCC(min)}$ = 2.7 V (3.0 V – 10%). The transistor properties are $V_{BE(on)}$ = 0.7 V and βmin = 100.

$$R_B < \frac{100\Omega \times (1 - 0.03) \times 100 \times (2.7\text{V} - 0.25\text{V} - 0.7\text{V})}{(1 + 0.1) \times 5\text{V} \times (1 + 0.1)} \rightarrow R_B < 2805.8\Omega$$

$$R_B = 2.7\Omega \text{ is chosen} \quad (19)$$

4.2 Interface to CMOS-TTL Inputs

All integrated circuits with TTL-CMOS inputs can be used as output circuits for the MSP430 MCU. Table 3 lists the input voltages of these ICs.

Table 3. Specifications for CMOS-TTL Inputs

Symbol	Parameter	Value
V_{IHmin}	Minimum high-level input voltage	2.0 V
V_{ILmax}	Maximum low-level input voltage	0.8 V

Both voltages are within the output voltage range of an output of the MSP430 MCU: DV_{CC} – 0.25 V and DV_{SS} + 0.25 V for DV_{CC} = 2.7 V to 3.6 V. No interface circuit is necessary; the TTL-CMOS ICs contain the 3-V-to-5-V interface on-chip.

4.3 Interface to TPL7407LA Inputs

For high output currents or to drive up to seven 5-V output ports, the TPL7407LA output buffer can be used. Table 4 lists the properties of the TPL7407LA.

Table 4. Specifications for TPL7407LA Inputs

Symbol	Parameter	Value
I_{Lmax}	Maximum output current	500 mA
V_{Lmax}	Maximum output voltage	50 V
$V_{I(on)max}$	Maximum input voltage (I_L = 200 mA)	2.4 V
$I_{I(on)max}$	Maximum input current (V_I = 3.85 V)	1.35 mA
I_{CEmax}	Maximum output leakage current (V_{CE} = 50 V)	50 µA

On the right side of Figure 7, the TPL7407LA is used for the output buffering to 5-V and 12-V peripherals. The common free-wheeling diodes of the TPL7407LA that are used for the 12-V peripherals do not influence the 5-V signals.

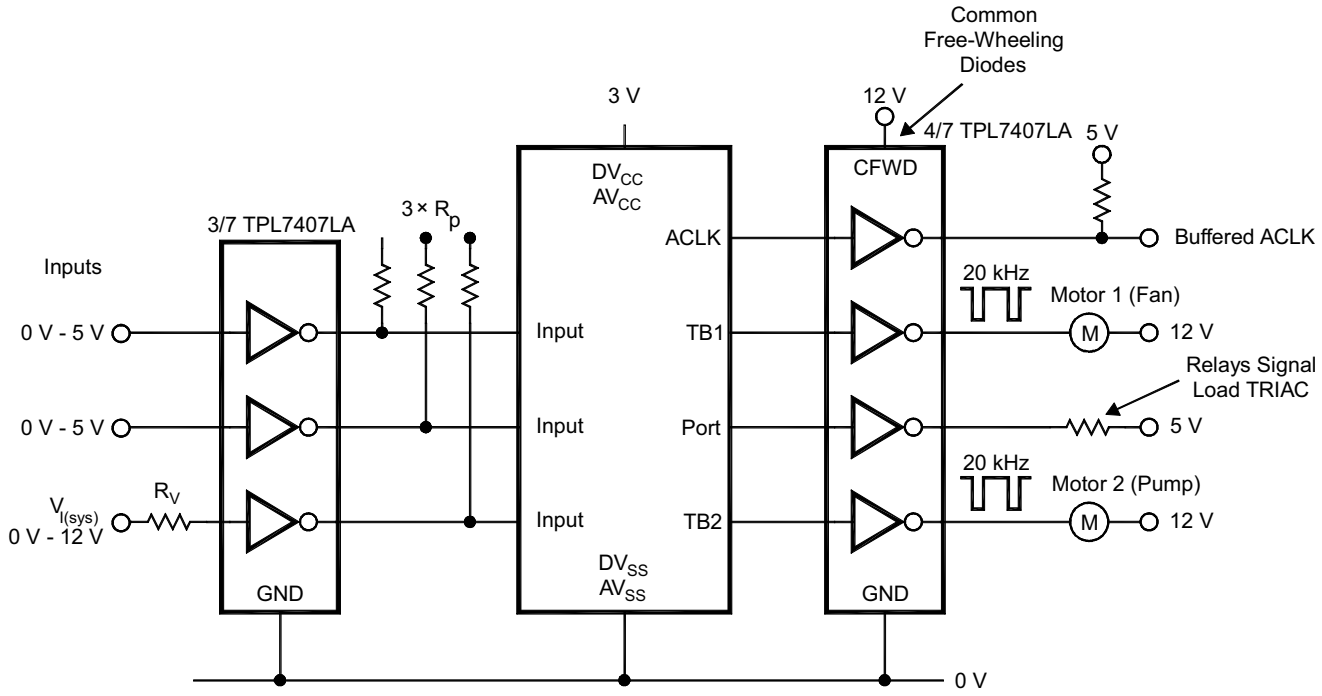

Figure 7. Interfaces With High-Current Output Buffers TPL7407LA

The input interface on the left side of Figure 7 is described in Section 3.4.

4.4 Op-Amp Output Interface

With the quad op amp TLC27L4, an interface to system voltages $V_{(sys)}$ of up to 16 V can be realized. The resistor divider at the inverting inputs of the TLC27L4 generates a voltage of approximately 1.5 V. The values for R_{B1} and R_{B2} must fulfill the equation:

$$R_{B1} \parallel R_{B2} \ll \frac{DV_{CC}}{\sum I_{lkg(Op)}} = \frac{3V}{4 \times 0.7nA} = 1.07G\Omega \quad (20)$$

This allows resistors with 10-MΩ resistance.

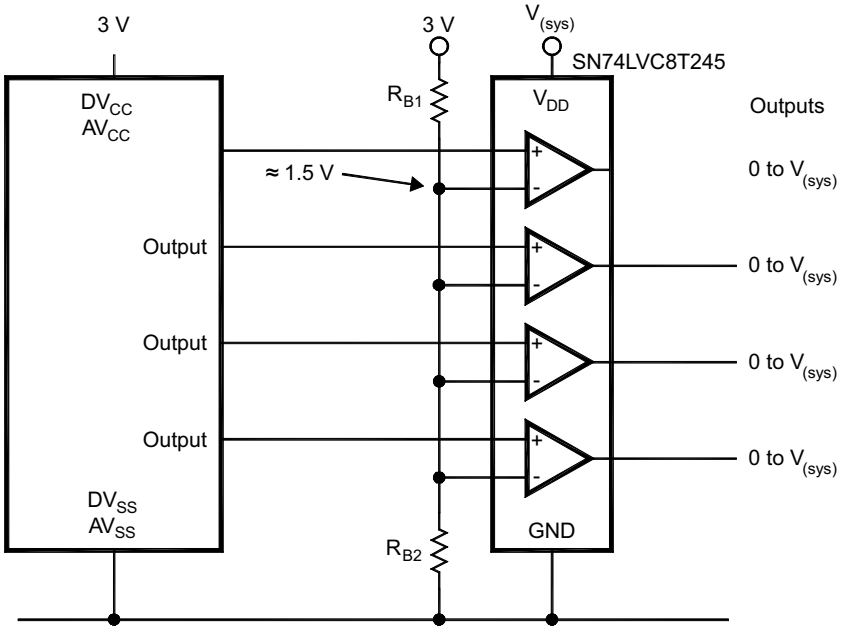

Figure 8. Output Interfaces With Op Amps

4.5 Integrated-Circuit Output Interface

Nearly all TTL-compatible ICs, such as the HCT and AHCT families, can be used for 3-V to 5-V output interfaces. The same is true for all bipolar circuits.

If the 5-V supply is switched off during the time when the 3-V supply is still on (for example, during a power down of the 5-V supply as shown in Figure 11), then only circuits that do not have built-in ESD protection diodes can be used for the input to the V_{CC} connection. Otherwise, a current flows from the 3-V supply to ground through this protection diode. This means that only AHCT and bipolar circuits can be used in this case.

5 Bidirectional Interfaces

5.1 Simple Bidirectional Op-Amp Interface

If true I/O performance is needed between the MSP430 MCU and a 5-V system, then the interface circuit in Figure 9 can be used. The op amp works as a flip-flop: the I/O pin currently working as an output controls the state of this flip-flop. The other I/O pin must be an input.

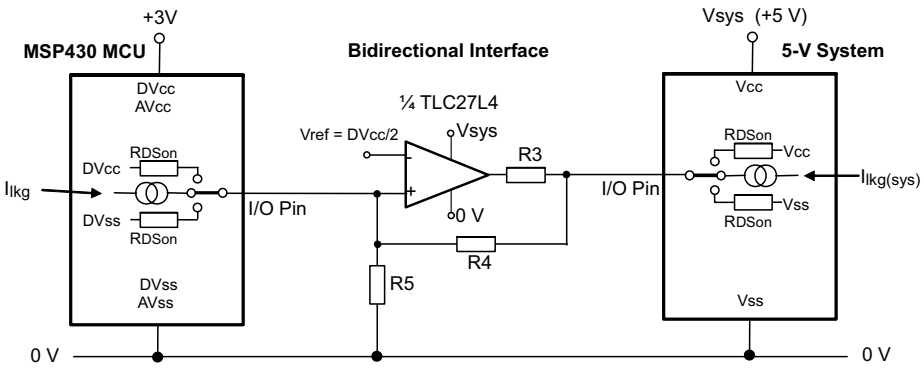

Figure 9. Bidirectional Interface Between 3-V and 5-V Systems

The worst-case design equations for the resistors R3, R,4 and R5 follow. Equation 21 ensures a high level at the MSP430 input.

$$\frac{R4}{R5} < (1 - 2p) \times \left(\frac{V_{(sysH)}min}{V_{ref(max)}} - 1\right) \quad (21)$$

Equation 22 prevents voltages higher than DVCC at the MSP430 input.

$$\frac{R4}{R5} > (1 + 2p) \times \left(\frac{V_{(sysH)}max}{DV_{CC(min)}} - 1\right) \quad (22)$$

Equation 23 ensures high level at the input of the MSP430 MCU with the MSP430 and op amp leakage currents I_{lkg} and $I_{lkg(Op)}$.

$$R4 < \frac{V_{(sysH)}min - V_{ref(max)} \times \left(1 + \frac{R4}{R5} \times (1 + 2p)\right)}{\left(I_{lkg} + I_{lkg(Op)}\right) \times (1 + p)} \quad (23)$$

Equation 24 ensures a high level at the external system input with its leakage current $I_{lkg(sys)}$.

$$R3 < \frac{V_{(sys)}min - V_{(sys+)}min}{(1 + p) \times \left(I_{lkg(sys)} + \frac{V_{(sys+)}^{min} - V_{ref(min)}}{R4 \times (1 + p)}\right)} \quad (24)$$

- V_{ref} = Reference voltage for the input level decision (V)
- I_{lkg} = Input leakage current of an MSP430 input (A)
- $I_{lkg(Op)}$ = Input leakage current of the opamp input (A)
- $I_{lkg(sys)}$ = Input leakage current of the system input (A)

Example: Bidirectional interface for the following data: $V_{(sys)}$ = 5 V ±10%, $V_{(sysH)min}$ = 4 V, $V_{(sys+)max}$ = 3.5 V, $I_{lkg(sys)}$ = ±1 µA, $I_{lkg(Op)}$ = ±700 pA, I_{lkg} = ±50 nA, V_{ref} = 1.5 V ±5%. The resistor tolerance is p = ±5%. The minimum supply voltage of this example is $DV_{CC(min)}$ = 2.7 V (3.0 V – 10%).

$$\frac{R4}{R5} < (1 - 2p) \times \left(\frac{V_{(sysH)}min}{V_{ref(max)}} - 1\right) = (1 - 2 \times 0.05) \times \left(\frac{4V}{1.575V} - 1\right) = 1.386 \quad (25)$$

$$\frac{R4}{R5} > (1 + 2p) \times \left(\frac{V_{(sysH)}max}{DV_{CC(min)}} - 1\right) = (1 + 2 \times 0.05) \times \left(\frac{5.5V}{2.7V} - 1\right) = 1.14 \quad (26)$$

The median value of the R4 and R5 limits is Equation 27.

$$\frac{R4}{R5} = \frac{1.38 + 1.14}{2} = 1.26 \quad (27)$$

$$R4 < \frac{V_{(sysH)}min - V_{ref(max)} \times \left(1 + \frac{R4}{R5} \times (1 + 2p)\right)}{\left(I_{lkg} + I_{lkg(Op)}\right) \times (1 + p)} = \frac{4.0V - 1.575V \times (1 + 1.26 \times (1 + 2 \times 0.05))}{(50nA + 700pA) \times (1 + 0.05)} = 4.55M\Omega \quad (28)$$

R4 is chosen to be 2 MΩ.

Resistor R5 is calculated as Equation 29.

$$R5 = \frac{R4}{1.26} = \frac{2M\Omega}{1.26} = 1.59M\Omega \quad (29)$$

$$R3 < \frac{V_{(sys)}min - V_{(sys+)}min}{(1 + p) \times \left(I_{lkg(sys)} + \frac{V_{(sys+)}^{min} - V_{ref(min)}}{R4 \times (1 + p)}\right)} = \frac{4.5V - 3.5V}{(1 + 0.05) \times \left(1\mu A + \frac{3.5V - 1.425V}{2M\Omega \times (1 + 0.05)}\right)} = 479k\Omega \quad (30)$$

The three chosen resistors are: R3 = 330 kΩ, R4 = 2 MΩ, R5 = 1.6 MΩ

5.2 Integrated-Circuit I/O Interface

Dedicated level converters like the SN74LVC8T245 can be used for a bidirectional I/O interface. This level converter is 8 bits wide and can convert the I/O levels to 5 V for a complete port on the MSP430 MCU. Figure 10 shows an application with this IC.

The MSP430 MCU determines the data direction of the interface with the DIR terminal. If needed, bus A can be isolated from bus B with the $\overline{OE}$ terminal.

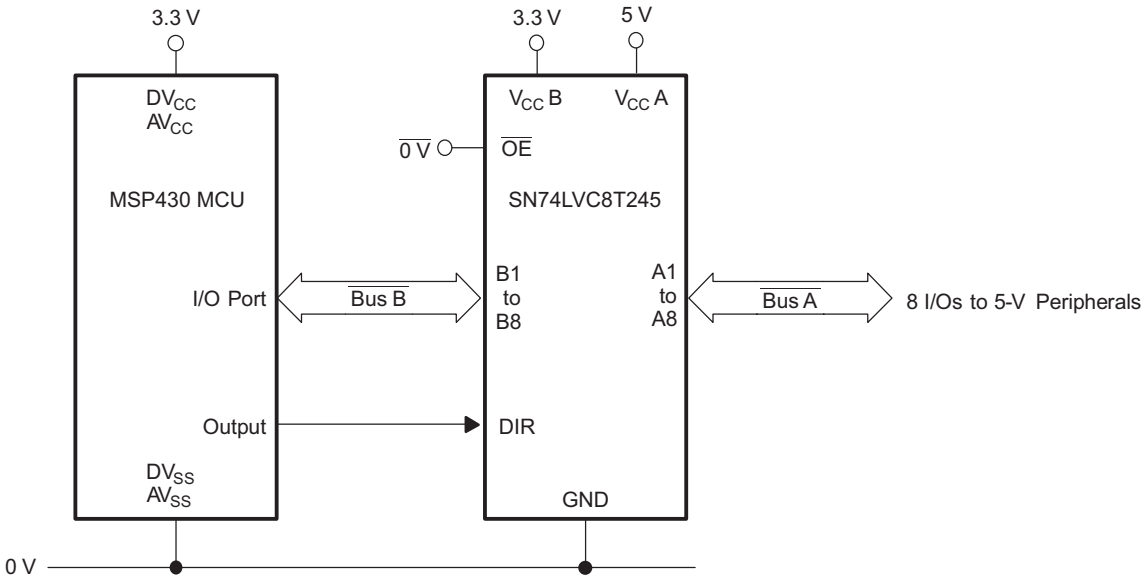

Figure 10. Integrated-Circuit I/O Interface

6 Power Supplies

Figure 11 shows a capacitor power supply for two output voltages, V_{CC1} = 3 V and V_{CC2} = 5 V. If the output current of the TLC27L4s is not sufficient, an NPN output buffer can be used (see Figure 12).

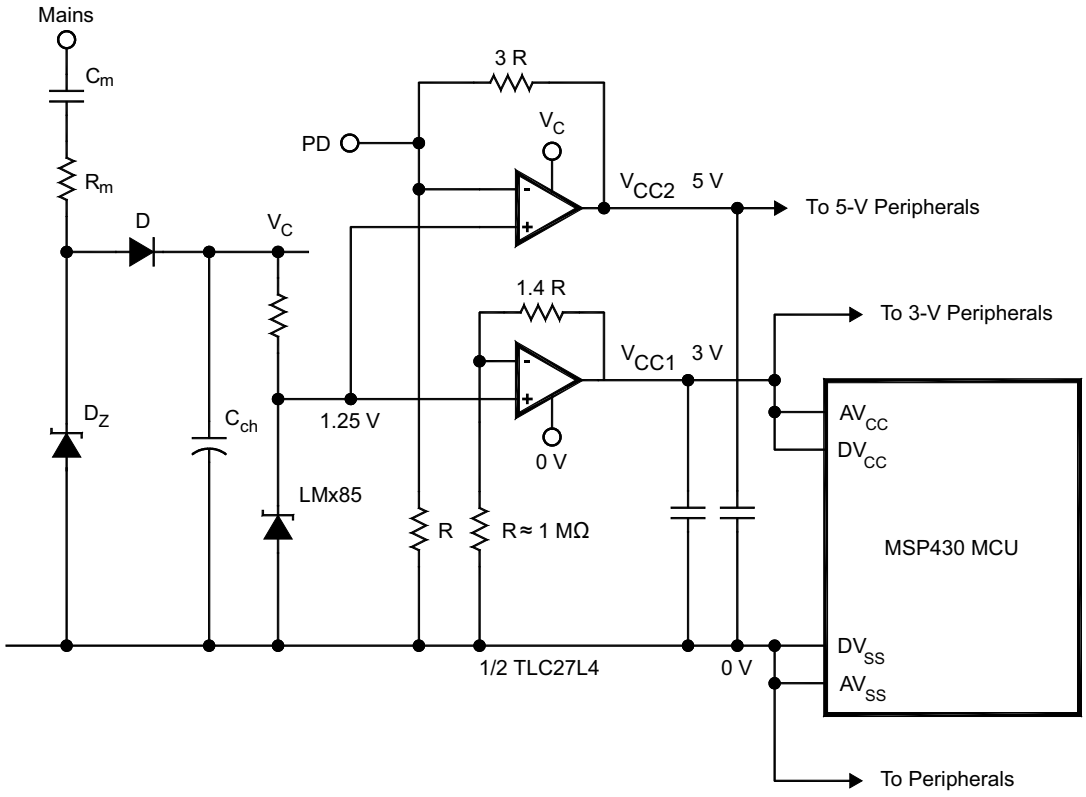

Figure 11. Capacitor Power Supply for Two Output Voltages

Using the power-down output, PD, the MSP430 MCU can switch off the 5-V supply during low power periods (LPM3).

- Active mode: The PD output of the MSP430 MCU is switched to the high-impedance mode.
- LPM3: The PD output of the MSP430 MCU is switched to DVCC. The 5-V regulator outputs a voltage near 0 V.

Figure 12 shows a power supply for two output voltages V_{CC1} = 3 V and V_{CC2} = 5 V. The 3-V supply is buffered with an NPN transistor to allow a higher current.

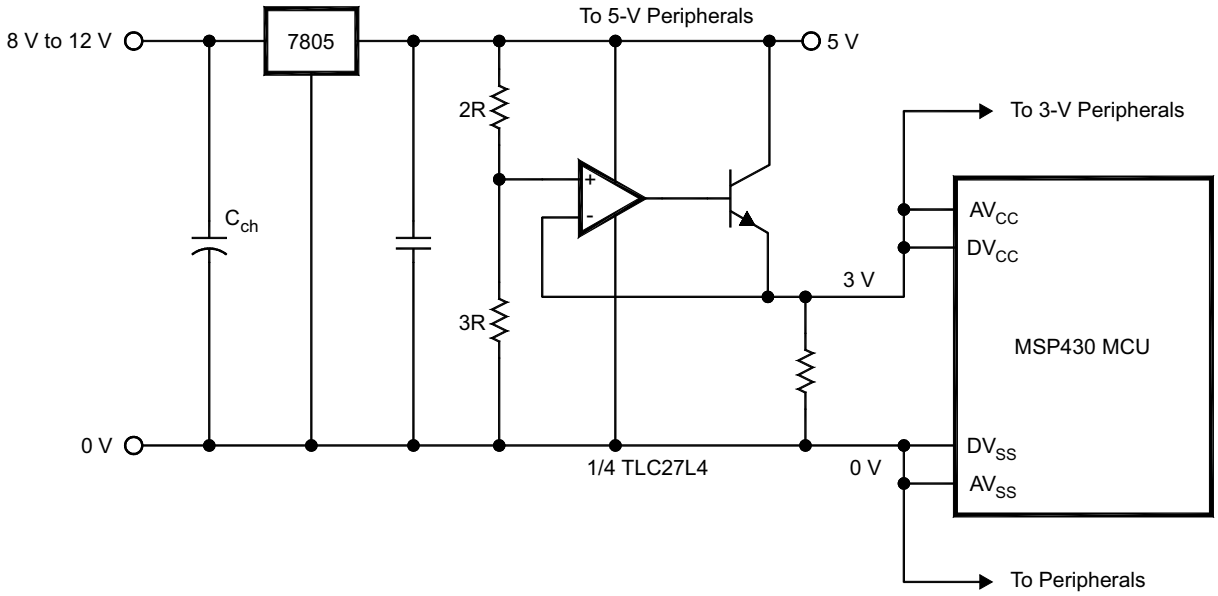

Figure 12. Power Supply for Two Output Voltages

7 Summary

As this application report shows, it is possible to build cost-effective interfaces for the connection of the 3-V MSP430 families to a 5-V environment. In some cases, the external 5-V peripherals already contain the necessary interface.

8 References

1. MSP430 ultra-low-power sensing and measurement MCUs
2. MSP430x4xx Family User's Guide
3. MSP430x1xx Family User's Guide
4. MSP430F43x, MSP430F43x1, MSP430F44x Mixed-Signal Microcontrollers
5. TLC27L4, TLC27L4A, TLC27L4B,TLC27L4Y, TLC27L9 LinCMOS™ Precision Quad Operational Amplifiers
6. SN74LVC8T245 8-Bit Dual-Supply Bus Transceiver With Configurable Voltage Translation and 3-State Outputs
7. SN74LVCC4245A Octal Dual-Supply Bus Transceiver With Configurable Output Voltage and 3-State Outputs
8. Selecting the Right Level-Translation Solutions

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from October 1, 2002 to October 3, 2018	Page
• Formatting and editorial changes throughout document, including removing references to documents that are no longer available	1
• Changed all instances of ULN2003A to TPL7407LA	7

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