Application Note

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5V to 3V Design Considerations

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Contents

Introduction

Hand-held and mobile communication products continue to require longer battery life and/or smaller product sizes. Both features are made possible by low voltage microcontrollers (MCUs) that help to reduce system power consumption, which then decreases system costs.

While moving to more energy efficient products, designers may need to use a mixture of both 5V and 3V components due the to lack of availability of all the necessary 3V components[1]. The move from 5V to 3V technology creates a challenging scenario for system designers. This application note will address the benefits that such a change brings and the design considerations that make the transition as smooth as possible.

Low Voltage Microcontrollers

The market demand for low-voltage systems is gradually increasing due to the requirements for lower power consumption. The technology itself is also a strong driving force towards this change, with semiconductor companies reducing the geometry of the internal circuitry of the new generation of components in order to remain competitive. With smaller geometries, it is possible to integrate more circuits closer together and offer increasing functionality in the same area of silicon.

The new generation of MCUs is now moving below 0.25 µm processes. As transistor oxide thickness and channel lengths decrease, lower operating voltages are essential to avoid over stressing the transistor and causing reliability concerns such as gate oxide breakdown, punch-through and hot-electron effects.

Semiconductor manufacturers continually make steps in designing more and more products capable of operating at 3V (or less). This will soon eliminate the necessity of having additional interfacing devices that increase the power dissipation, complexity, size and cost of an application.

1. *In the following discussion we will assume interfacing between 5V systems with V_{DD5} = 5V ±10% (4.5 – 5.5V) to 3.3V systems with V_{DD3} = 3.3V ±10% (3.0 – 3.6V) and vice-versa. The reader will notice that 3.3V and 3V are used in different parts of the analysis, dependent on the supply voltage tolerance of the logic family in question. The main points of the analysis remain unaffected.*

Mixed Voltage Systems

In a mixed voltage application, parts must be able to translate from one voltage to another. A typical scenario is shown in **Figure 1**, where an MCU uses a 3V supply, the EEPROM memory and the various I/O parts are powered at 5V, and a voltage converter provides the interfacing between the two sub-systems.

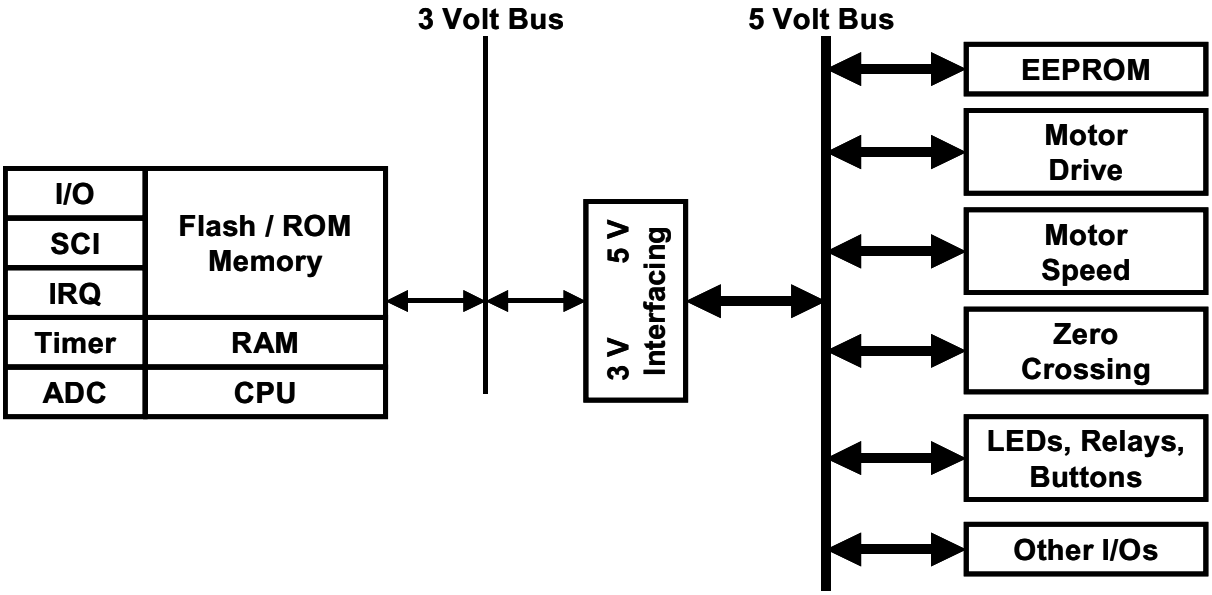

Figure 1. 3V and 5V parts in a dual voltage design

The disadvantages of mixed voltage systems are mainly due to the increased number of components required for interfacing parts operating at different voltages. Possibly, also, the need for multiple voltage power supplies, which in turn produces additional current consumption.

The additional parts required in a mixed voltage system increase the overall system power dissipation, mainly due to the power absorbed by the interfacing components. Also, the output high level (V_{OH}) of the driving device influences the current consumption of the driven part.

For example when using ACT or HCT logic for 3V to 5V translation, if a TTL-compatible 5V CMOS device is driven by voltages lower than $V_{DD} - 2.1V$ there is an additional current consumption that needs to be taken into account: the leakage current from V_{DD} to V_{SS} (Ground) of the receiving device, ΔI_{DD}. ΔI_{DD} is negligible if the applied input voltage approaches V_{DD} or V_{SS}. But if the voltage applied moves away from the full power rail values, the p-channel and the n-channel transistors that form the typical CMOS input stage of a device will

both be slightly on. Indeed, they will be in their respective saturation regions and their resistance to ground will be much lower than compared to their off states, see **Figure 2**, thus ΔI_{DD} will reach quite a high value; the maximum could be as high as 4 mA. Typically ΔI_{DD} is around 100 – 200 µA per input pin. This added current consumption will only occur when a logic high is applied to the pin and, normally, not all the inputs will be at '1' at the same time. Nevertheless, even with these allowances, the extra current consumption is a major disadvantage in a mixed voltage system.

Furthermore, a mixed voltage application requires several voltage supplies. Single chip solutions providing 3V, 5V, plus a third variable supply voltage (± 12V required, for example, for RS-232 communications) are already available from some power supply manufacturers. This helps in reducing the surplus of components required by a mixed voltage system.

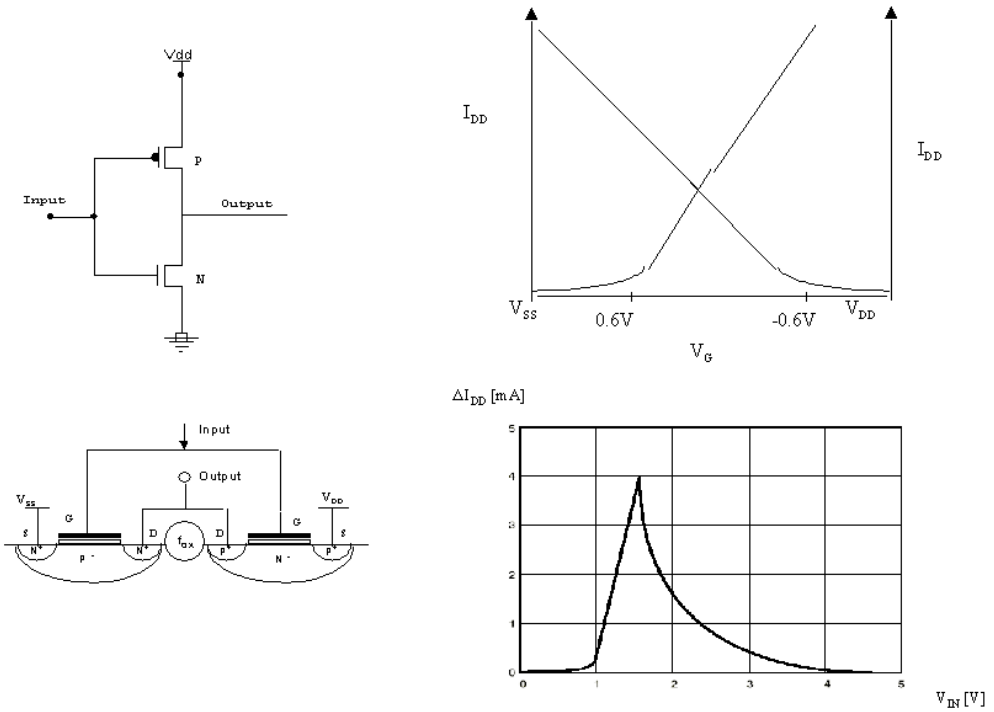

Figure 2. Typical CMOS input structure and ΔI_{DD} current example

While the penalties of a hybrid system in comparison to a 'pure' 3V system emerge quite clearly, this does not mean that a system will be better off running at 5V. In fact a 5V/3V mixed system still requires less power than a 5V version; therefore it is advantageous to replace 5V parts with 3V ones wherever possible, especially in portable applications where long battery life is important.

Microcontrollers with 3V supplies require care when interfacing to the external control circuitry. There is a wide range of 3V compatible components and ICs in the market so replacing 5V digital control circuitry by 3V control circuitry represents no significant complication in interfacing. The easiest way of interfacing 3V and 5V devices happens when 3V devices have 5V tolerant inputs and 5V devices have TTL compatible input levels. In such cases, simple direct connections without any level translators and current limit resistors are possible.

Microcontroller Inputs

Input Levels to Port Pins

All Motorola MCUs contain some form of ESD protection circuitry between the physical input pin and the active circuit. There are two basic types of input pins: input-only and input / output pins.

All the pins have an internal diode clamp to V_{SS}, but some of the pins include a diode clamp to V_{DD}. Input pins like IRQ are designed to take higher voltages than V_{DD}, so the maximum voltage is not limited by V_{DD}. IRQ pins have a normal n-channel transistor acting as a protection device whose gate terminal is hard wired to V_{SS}, i.e. only negative V_{IN} is clamped to V_{SS} – 0.6V and not V_{IN} higher than V_{DD}.

First, let us examine in more detail the CMOS circuitry of an MCU pin capable of operating as an input-only pin, see **Figure 3**.

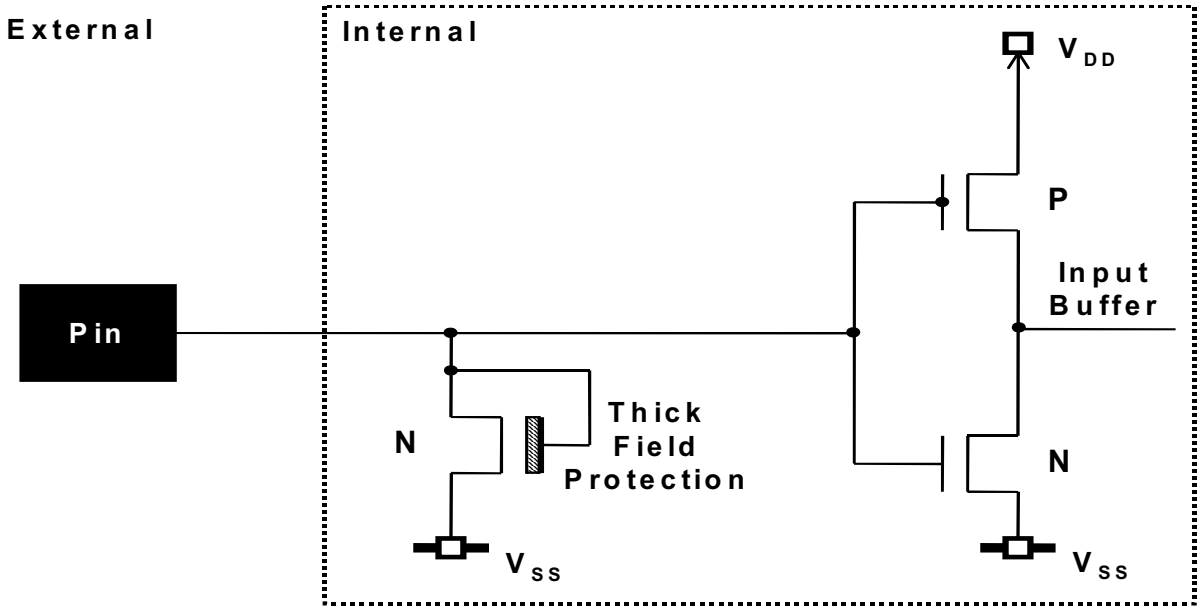

Figure 3. Digital Input-Only Pin

In some microcontroller families, instead of a thick-field protection device there is a normal n-channel transistor, but the following discussion is still valid, the only difference being the clamping voltage levels for V_{IN} higher than V_{DD}.

The thick-field protection device forms an inherent diode junction to V_{SS}. Therefore if the voltage applied becomes lower than V_{SS}, this inherent diode will start to conduct when the pin voltage gets more than a diode drop below V_{SS}. As the negative voltage applied to the pin increases, more current will be injected, but the input will be clamped to a value which corresponds to a diode drop below V_{SS} (therefore –0.6V), irrespective of the V_{DD} supply.

If the voltage at the input pin is taken above V_{DD}, the voltage at the input buffer rises as well. The gates of the input buffers have very high impedance and could be sufficient to provide protection when V_{IN} has overtaken V_{DD}. If V_{IN} keeps rising, the thick-field protection device will turn on and clamp this input voltage to protect the input buffer. The level of the clamping voltage may vary over the operating temperature and is typically, at room temperature, up to 10–11V (5V V_{DD}) and 7–8V (3V V_{DD}).

Let us now examine the CMOS circuitry of an input-output pin, see **Figure 4**.

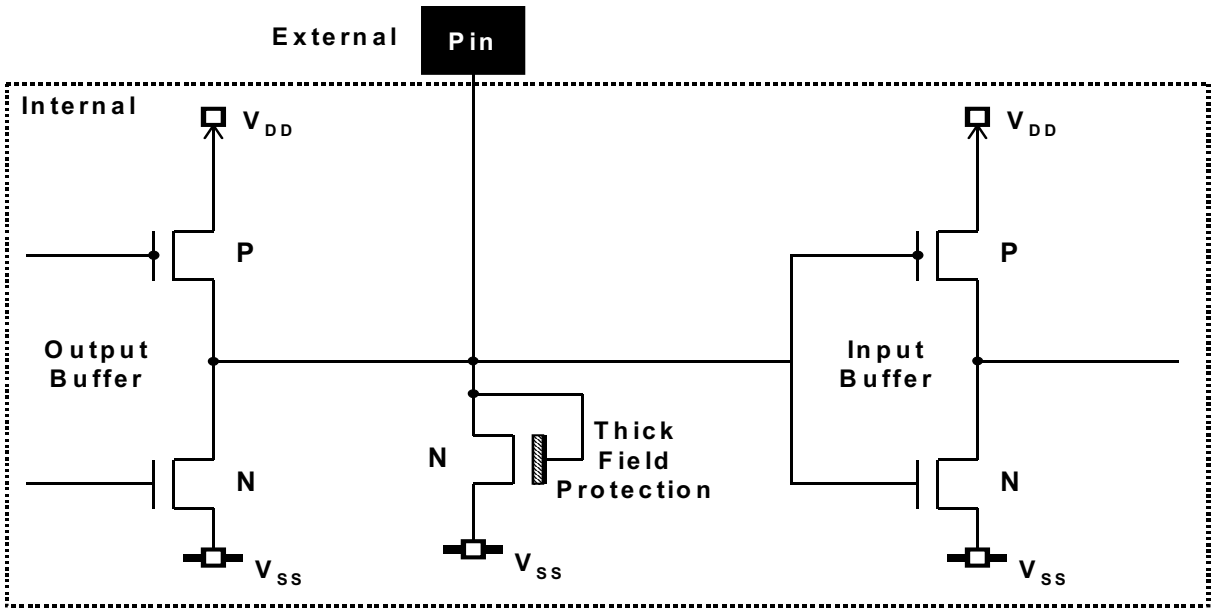

Figure 4. Digital I/O Pin

When the pin is configured as an input, the output driver circuitry is disabled, but its MOS transistors still affect the way the input pin reacts to illegal voltage levels.

The p-channel transistor of the output driver forms an inherent diode to V_{DD} and the n-channel device forms an inherent diode to V_{SS}, which is in parallel to the inherent diode of the thick-field protection device.

Because the protections are now both to V_{DD} and V_{SS}, input signals are clamped to within a diode drop of the power supply rails, i.e. V_{DD} + 0.6V and V_{SS} – 0.6V respectively. The main difference for an I/O pin compared to an input-only pin is that the n-channel output device starts to conduct before the thick-field protection device, thus the clamp level for voltages above V_{DD} will typically be lower than for a digital input-only pin.

Therefore, in the 5V V_{DD} case, if the input voltage rises above 5V, the voltage to the input buffer will increase, until it reaches 5.6V. At this level of voltage, the protection diode to V_{DD} will switch on and current will flow to V_{DD} but there will be no current entering the input buffer because of the very high impedance of its gate. The same scenario will happen in the 3V V_{DD} case, except that the clamping value will be approximately 3.6V.

As the technology moves from 5V to 3V, input level protection will still be available, although the level of current injection will be reduced. In extreme situations, series resistors or some other form of protection will be required to limit the currents to safe levels.

Interfacing to Microcontroller Inputs

The main objective for interfacing circuits is to avoid over voltages on 3V inputs (and outputs for bi-directional pins), which are connected to 5V outputs and limit the current flowing from 5V parts.

Input pin structures usually contain ESD protection diodes, which clamp input voltages when they go below V_{SS} (GND) or beyond V_{DD} levels.

For a 5V output being applied to a 3V input, when the maximum input voltage is exceeded on the 3V input, the ESD protection diode on the input of the device can be forward biased and current will flow into the 3V V_{DD}. This could take the voltage level of the 3V power supply up to the input voltage minus the voltage drop across the protection diode. Therefore, this difference in voltage will cause a high current to be drawn (almost a short-circuit), which will lead to heat and possible long-term reliability problems.

To avoid such problems, the voltage on inputs should not exceed V_{DD3} + 0.5V in order not to conduct the clamping diode. This means that for 3V minimum (V_{DD3min}) voltage the maximum input voltage should be V_{Imax} = 3.5V. In many cases the easiest work around is to use simple series resistors that limit currents flowing into 3V inputs, but usually these can add delays and board space.

5V TTL Output to 3V MCU Inputs

A typical bipolar output has an active high output voltage level limitation of $V_{DD5} – 2*V_{BE}$ because of internal TTL gate structure, see **Figure 5** where V_{BE} is both the base-emitter and the diode voltage drops, which are both approximately 0.6V.

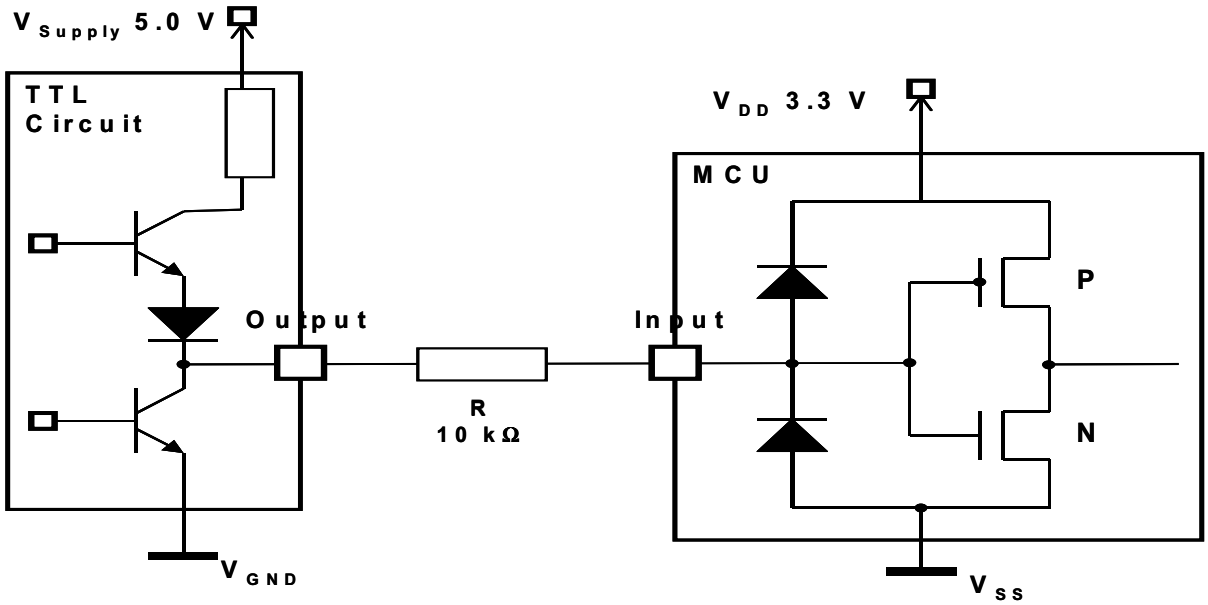

Figure 5. 5V TTL output to 3.3V MCU input

The maximum high output voltage value for the TTL (V_{OH}) is for maximum V_{DD}, which is 5.5V. In this case, the V_{OH} voltage level is typically 4.3V ($5.5–2*V_{BE}$) at no-load. The maximum voltage on a 3V MCU input should not exceed V_{Imax}= 3.5V (for V_{DD3min} = 3V), as stated in the previous paragraph. Thus the maximum differential voltage between TTL output logic high and the MCU maximum input voltage V_{Imax} is 0.8V (4.3V – 3.5V). Just placing a resistor between the TTL output and the MCU input will limit the current flowing to the input and thus its voltage will drop to a safe level. In the example above, the 10 kΩ resistor will limit the current to a maximum of 80 μA (0.8V/10kΩ).

The current flowing to the MCU input should be limited to a level which is well below the maximum specification in order to avoid latch-up as excessive input current can damage the internal silicon structures.

Care should be taken in choosing the correct resistor value, as too high a value can cause significant signal propagation delay because of the RC constant created by the resistor and the input capacitance, which is typically about 5–10 pF plus the PCB capacitance.

Also, excessive current increases the power consumption because the current flows into the MCU input when the driving component is outputting a logic high.

5V CMOS Output to 3V MCU Inputs

The typical CMOS output swings fully between GND and V_{DD} (within tens of millivolts) at no-load or slight-load condition. So the maximum V_{OH} level of a CMOS output can be 5.5V for V_{DD5max} = 5.5V at no-load. The maximum differential voltage for logic high in the worst-case, which is for V_{DD5max} and with V_{Imax} (which is 3.5V – see previous paragraphs) is 2V.

It is possible to use a series resistor with a larger value, but this may lead to higher propagation delay. A better solution is to use a resistor divider network between the CMOS output and the MCU input such that a signal voltage level of logic high appears at the input at approximately 3.0V, see **Figure 6**.

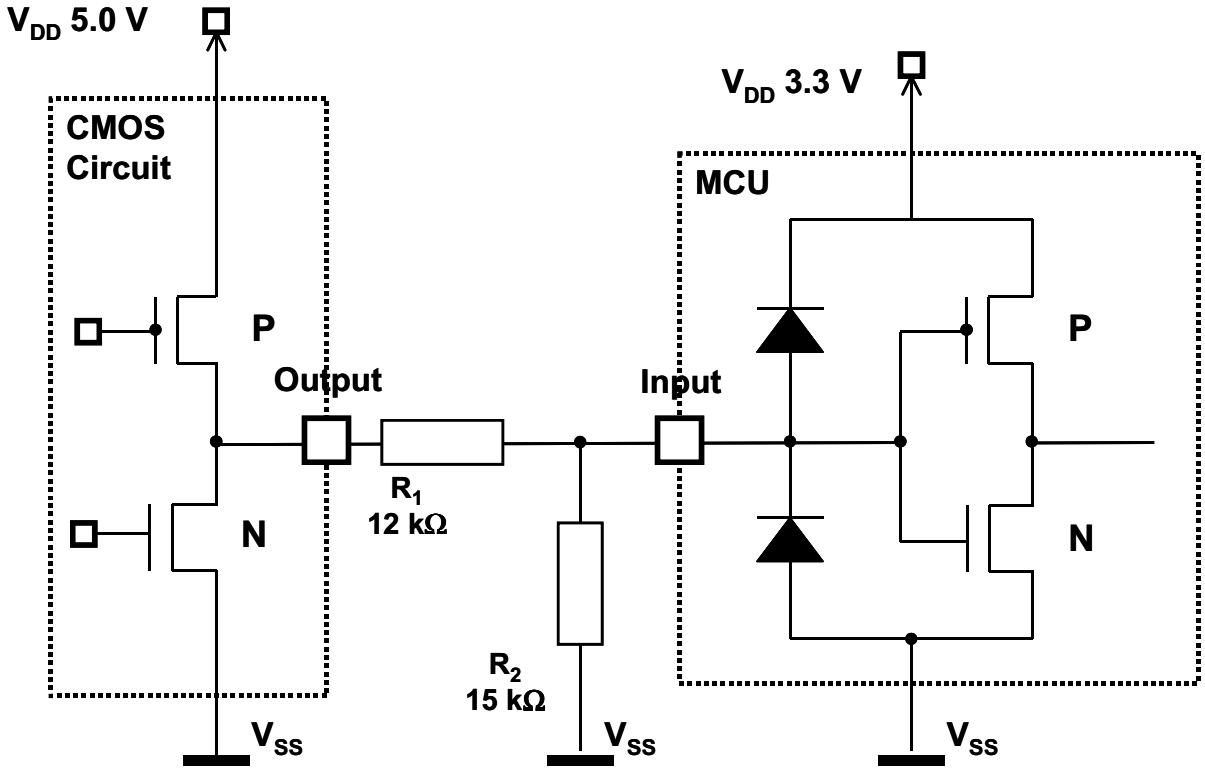

Figure 6. 5V CMOS output to 3.3V MCU input

Another level conversion from a 5V output (TTL or CMOS) to a 3.3V MCU input circuit can employ a device from the LCX logic family powered at 3.3V, which has 5V tolerant inputs (V_{Imax}=5.5V), or one from the LVX family, which has V_{Imax}=7V. **Figure 7** shows such a solution with the MC74LCX244 buffer.

For example, such a circuit is suitable for connecting a JTAG interface to a PC printer port that has a 5V level. Also, by using a MC74LCX244 logic device instead of a simple resistor circuit, the MCU inputs are more protected against

over-voltages because this kind of device has a larger latch-up current rating than most MCUs.

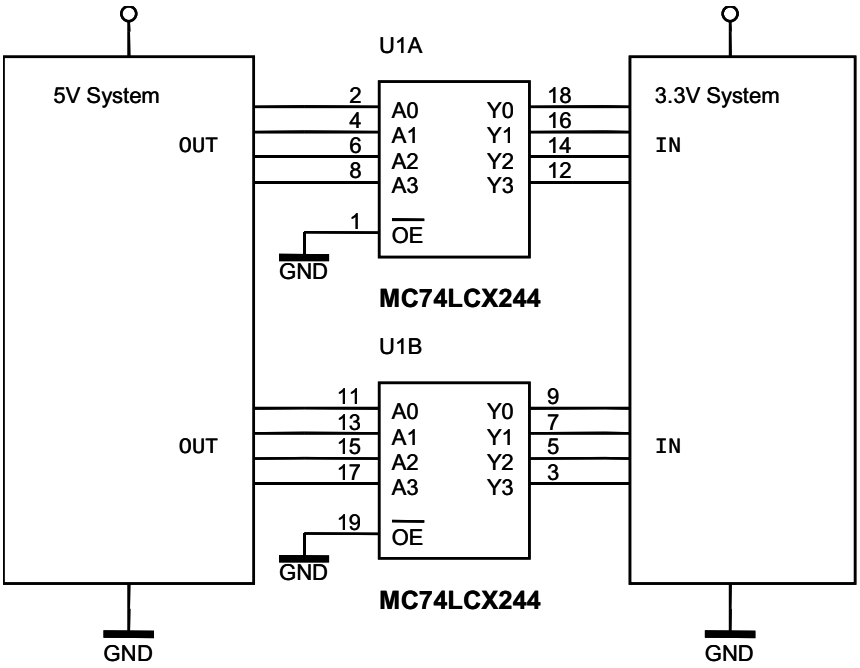

Figure 7. 5V CMOS or TTL output to 3.3V MCU input using an LCX device

Microcontroller Outputs

Ports current drive capabilities

The output structure of a digital circuit determines the output voltage swing and the current capability. The MOS circuitry for an MCU pin capable of operating as an output is shown in **Figure 8**.

To guarantee reliable output high voltage and low voltage the load current should be limited within the specified values given on the data sheets.

If the pin current is increased to very high levels, which is typically over the specified limit of 25 mA, the die substrate in the area around the protection device will be influenced thus affecting the electrical characteristics of the devices in the vicinity as well. This will cause physical damage to the pins.

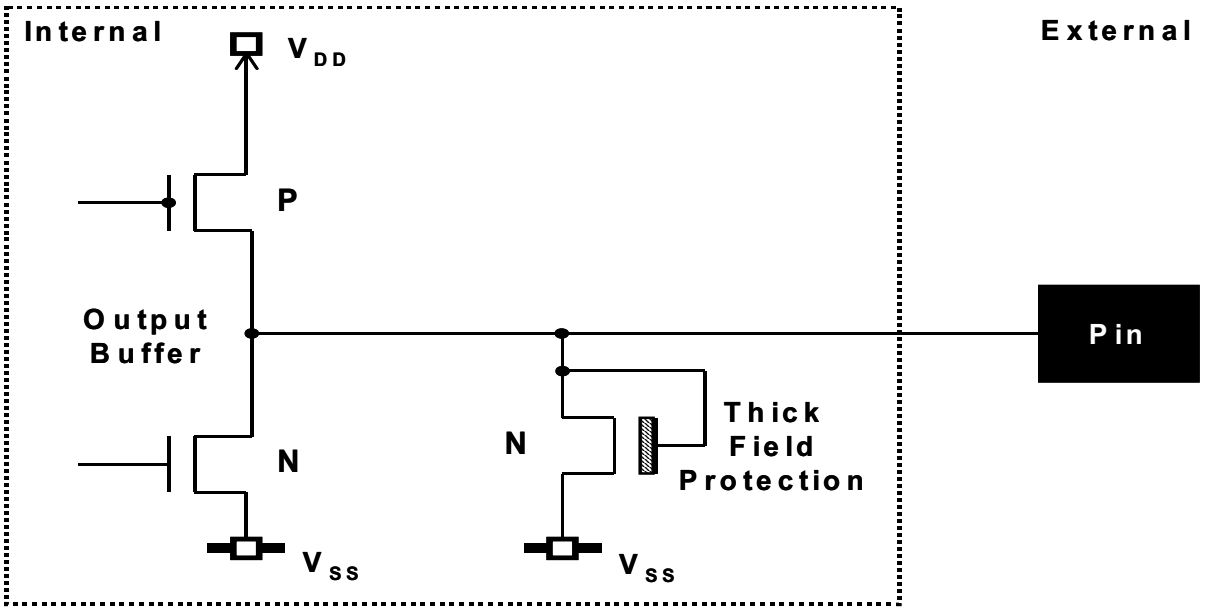

Figure 8. Output-Only Pin

A characterization analysis was performed using five units of QFP MC68HC908GP32 (0.5 micron microcontroller with 32Kbytes Embedded Flash) in three different temperatures –40°C, 25°C and 85°C. This device was chosen as a reference example because it is a general purpose microcontroller and it works both at 5V and 3V. The results found can be extrapolated for other 5V and 3V microcontrollers.

V_{OH}/I_{OH} and V_{OL}/I_{OL} measurements with varied loading in terms of sink and source currents (I_{LOAD}) were carried out to characterize low-side (V_{OL}) and high-side driver (V_{OH}) at 2.7V and 5.5V.

Generally, the sinking capability is higher than the sourcing one due to the higher mobility of n-channel devices over p-channel ones. This consideration explains the bigger current values, when the port is outputting a logic '0', which will be highlighted in the data below.

Typically, for the normal current I/O Ports, the current sink and source specifications are as follows:

@ V_{DD} = 5.5V, $V_{OH} > (V_{DD} – 1.5V)$ at source current of 10mA

$V_{OL} < 1.5V$ at sink current of 10mA

@ V_{DD} = 2.7V, $V_{OH} > (V_{DD} – 1.0V)$ at source current of 4mA

$V_{OL} < 1.0V$ at sink current of 6mA

And typically, for the high current I/O Ports, the sink current capability is as follows:

@ V_{DD} = 5.5V, V_{OL} < 1.0V at sink current of 15mA

@ V_{DD} = 2.7V, V_{OL} < 0.8V at sink current of 10mA

For the 3V only MC68HC9S08GB60 MCU the current sink and source specifications, at full drive, are as follows:

V_{OH} > (V_{DD} – 0.8V) at source current of 10mA

V_{OL} < 0.4V at sink current of 10mA

Therefore, it can be concluded that moving from 5V to 3V technology will not jeopardise the output high voltage and low voltage provided by the microcontrollers. For some applications the sourcing and sinking capability required might be quite demanding, therefore, as lower V_{DDS} will have the effect of reducing the current sourcing and sinking capability of the devices, some signal amplification could provide assistance. Some examples will be illustrated in the following paragraphs.

Interfacing to Microcontroller Outputs

Interfacing 3V CMOS devices to 5V TTL devices causes no problems because the 3V device outputs have enough margin to drive 5V TTL-device inputs. For other technologies or voltage levels, such as 3V CMOS to 5V CMOS, some level shifting may be necessary.

3V CMOS Output to 5V TTL Input

The maximum input voltage level permissible for TTL technology for a logical "0", V_{IL}, must be ≤ 0.8V, and the minimum input voltage level for logical "1", V_{IH}, must be ≥ 2.0V. Since MCU outputs are TTL compatible, no special circuitry is required for interfacing.

3V CMOS to 5V CMOS

Interfacing a 3V MCU output to a 5V CMOS input requires extra drive to prevent current leakage.

For CMOS technology the input switching levels are defined as:
$V_{IL} \leq (0.3 * V_{DD})$, and $V_{IH} \geq (0.7 * V_{DD})$.

Therefore for 5V V_{DD} the maximum input level for logical "0" must be ≤ 1.5V and the minimum input level for logical "1" must be ≥ 3.5V.

A simple resistor and diode are sufficient to provide a 0.6V upward level shift of the MCU's output voltage, see **Figure 9**. The only disadvantage is that when the 3V device is outputting a logic zero level, there will be an inherent current drawn via R and D.

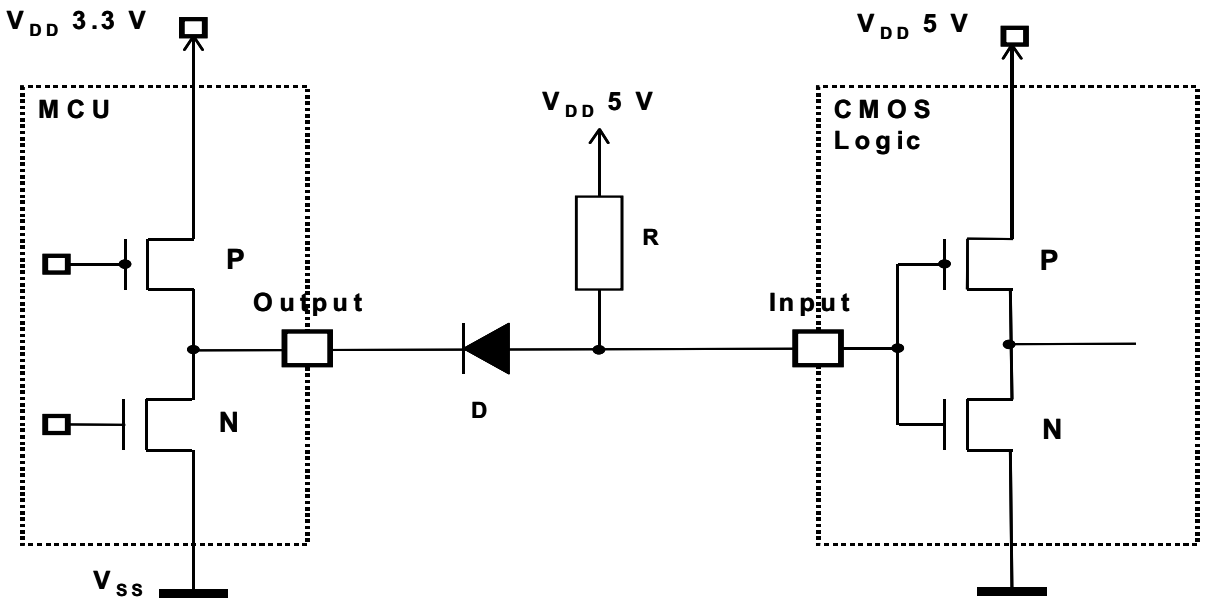

Figure 9. 3.3V MCU Output to 5V CMOS Input

Another possible solution for interfacing a 3.3V MCU output to a 5V CMOS input is to use ACT, HCT, VHCT or VHC1GT (1 gate VHCT) logic families. By using these parts, a 3.3V MCU output can be connected directly to a CMOS input, see **Figure 10**.

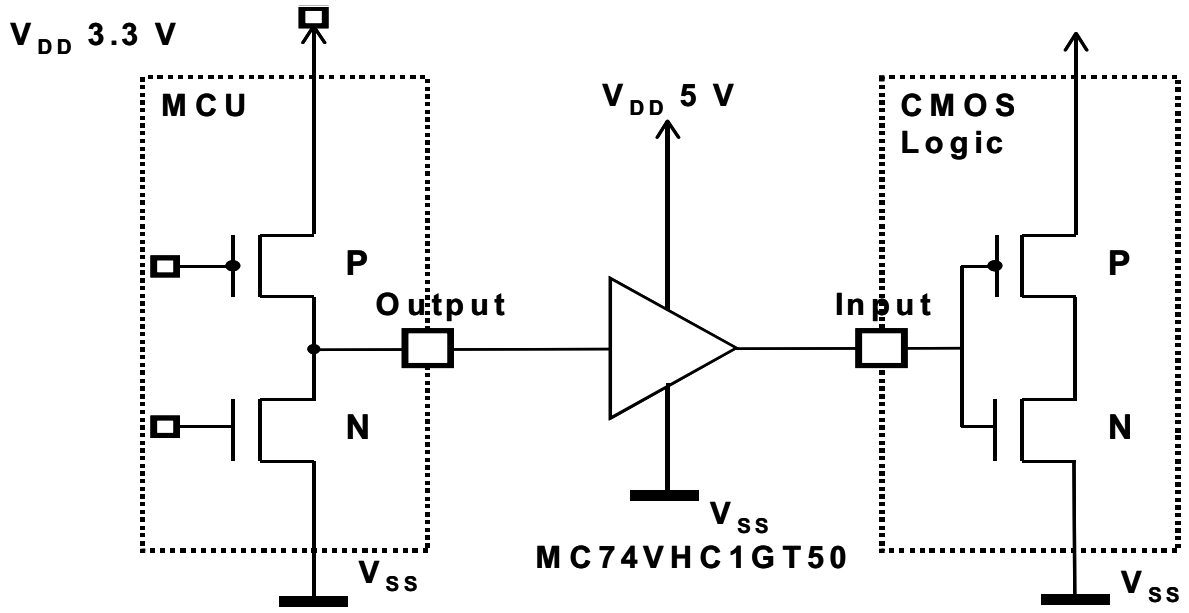

Figure 10. 3.3V MCU Output to 5V CMOS Input with level shifter

Similar TTL compatible product inputs offer additional protection when the V_{DD5} supply is powered down and the V_{DD3} supply is applied; they can withstand up to 7V input voltage regardless of the V_{DD5} value provided. This feature simplifies power-up and power-down sequences of 5V and 3V parts of the system because 5V parts can be powered down while 3V parts are running without excessive currents on the 5V inputs.

Bi-directional Translation

When bi-directional connections of 3.3V and 5V devices are required, special level shifters are normally used, see **Figure 11**. The disadvantage of this kind of transceiver is that the direction of the data flow (DIR pin) needs to be controlled and requires an additional port pin from the master MCU.

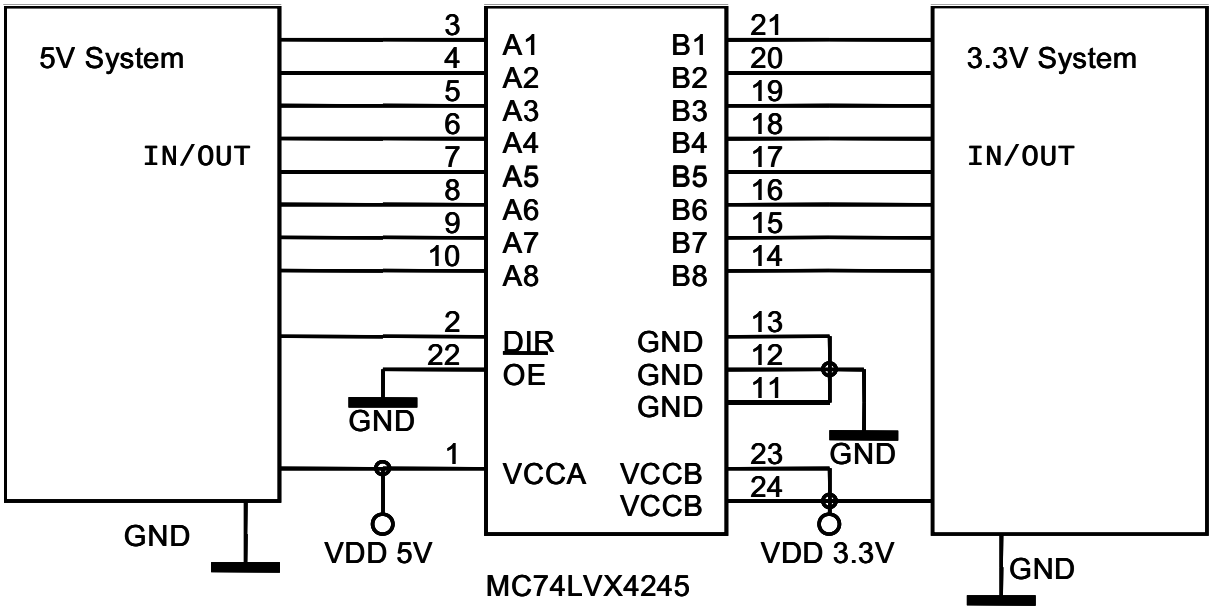

Figure 11. Interfacing of the 3.3V and 5V system bus

Another alternative for interfacing 5V and 3V systems is to use a Bus Switch such as the QS3384. The main advantages of such a device are very low propagation delay (0.25 ns) and the fact that the control of the data direction is not necessary. The disadvantage of this solution is that the 5V system must have TTL compatible levels because that Bus Switch only limits voltage to 3V levels, in the same way as limiting resistors do. Therefore, contrary to the MC74LVX4245 and other similar transceivers, it does not provide additional drive capability.

By supplying 4.3V to the V_{CC} pin of the Bus Switch, the driven output will be limited to 3.3V maximum, even under light loading. A 4.3V V_{CC} can be created by adding a diode with a voltage drop of approximately 0.7V between the 5V supply and the device. The QS3384 device has an internal 10 kΩ resistor between the diode's cathode and ground to provide a current path for the diode. In other types of bus switches, like the QS3861, the diode D1 and the resistor R1 are not available inside the chip, therefore those components are required externally, see **Figure 12**.

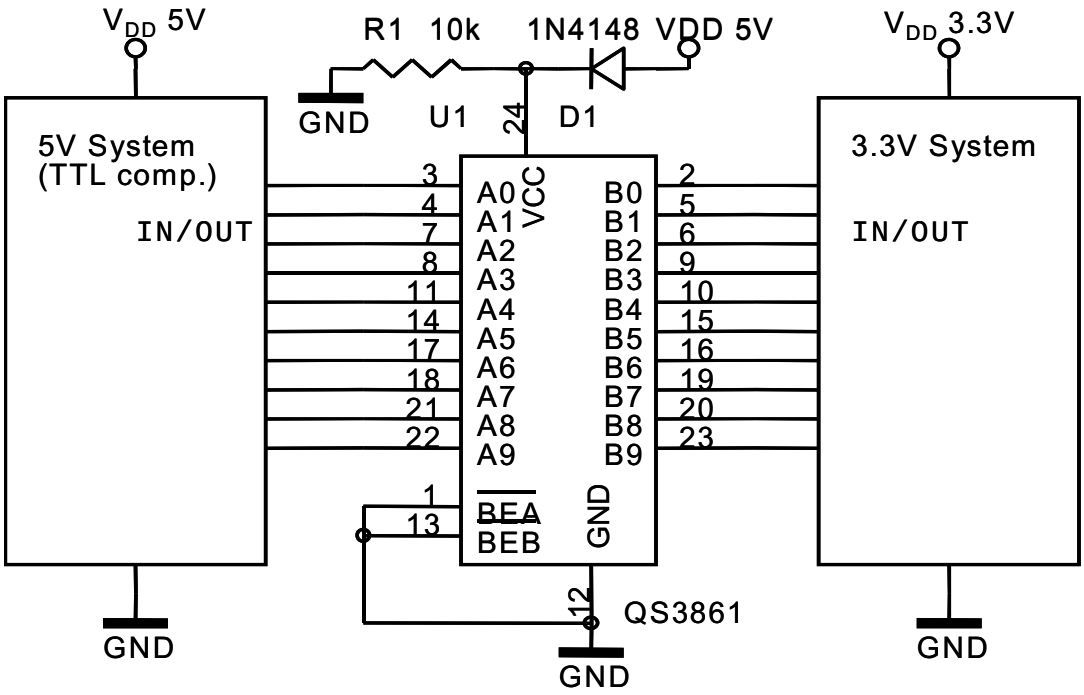

Figure 12. Interfacing of 3V and 5V system with bus switch

When there is not the option of controlling the data flow direction in the bi-directional interfacing between 5V and 3.3V systems, special level translators like the MAX3370/1 shown in **Figure 13** can be used. The MAX3370/MAX3371 are available in space-saving 5-pin and 6-pin SC70 packages respectively.

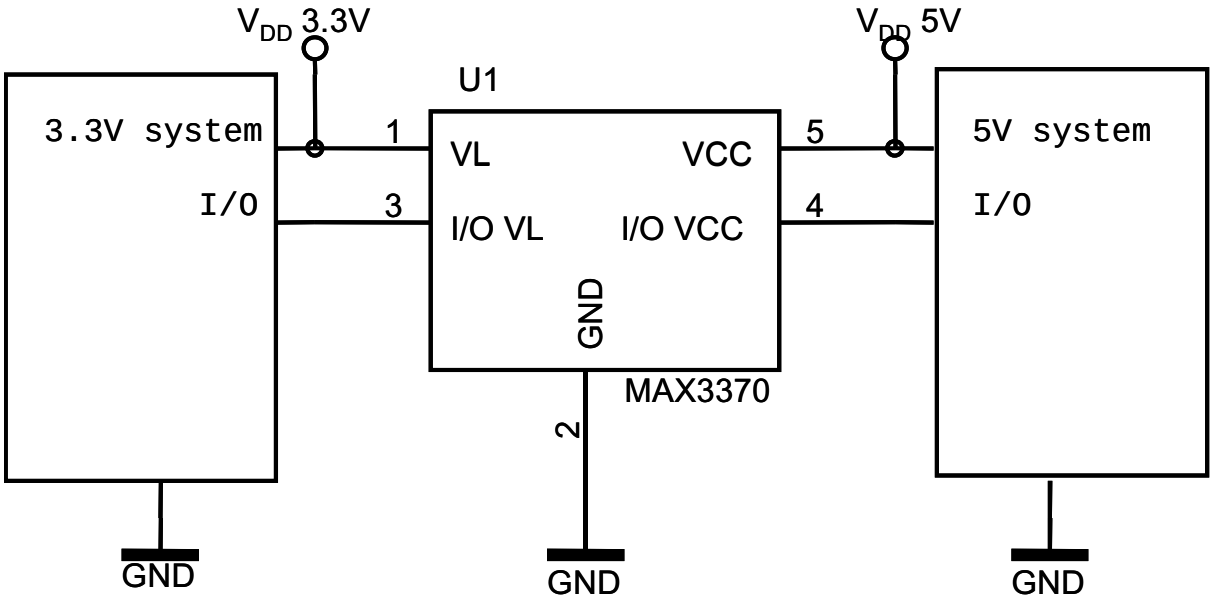

Figure 13. 3.3V MCU to 5V system bi-directional interface

The NCN6010/1 level translators (respectively with and without charge pump) allow the interfacing of more than one signal. Those devices are originally targeted for interfacing 5V SIM cards to 3.3V microprocessors or GSM controllers, see **Figure 14**. These level translators have 1 bi-directional line and 2 unidirectional lines. The NCN6010 also contains a charge pump to facilitate 3V / 5V conversion.

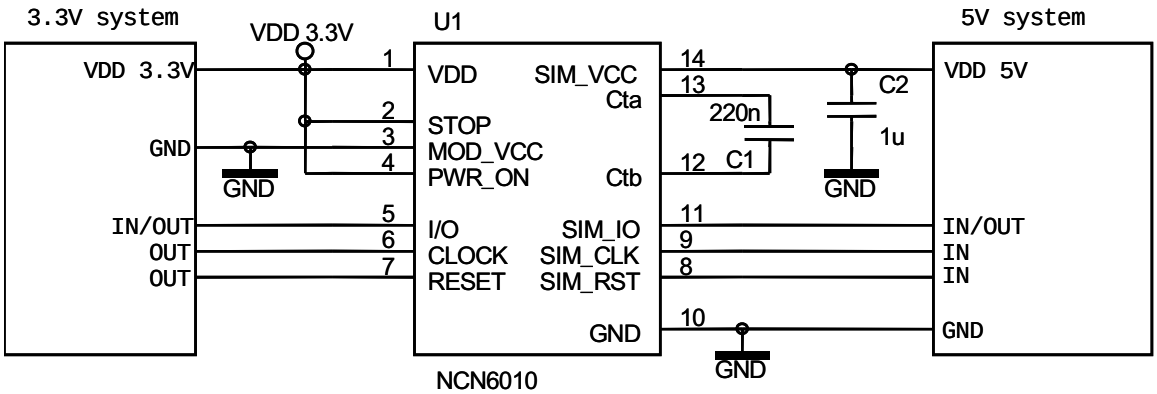

Figure 14. MCU to 5V system interfacing without 5V supply

Interfacing to Motor Control Parts

A motor drive system, controlled by an MCU, includes the power supply stage, the power transistors and their gate drivers, and the motor.

The AC input line is rectified in the input power supply stage and it provides the DC voltage for switching the power transistors that deliver the power to the motor.

The transition from 5V to 3.3V for motor control applications needs to be considered both for the analogue and digital signals.

Analogue Signals

In motor control applications, the feedback signals are typically analogue in nature. Most motor control applications utilize voltage and current feedback for control algorithms and safe operation. The auxiliary feedback signals, like temperature sensing, depend on the requirements of the actual application.

A voltage measurement (e.g. back EMF) is commonly used as an indication of motor speed. This signal is digitised by the MCU's on-board A/D converter. Resistor dividers are used to ensure that the voltage at the input of the A/D converter (MCU pins) does not exceed the maximum rated voltage (**Figure 15**). The two (and sometimes three) resistors R1 and R2 are normally used for high motor voltage. It is necessitated because of the maximum voltage rating of the resistors. For lower voltage motor control applications, even a single resistor is usually sufficient. Moving to a lower MCU operating voltage will not have any impact on 3.3 V MCU applications.

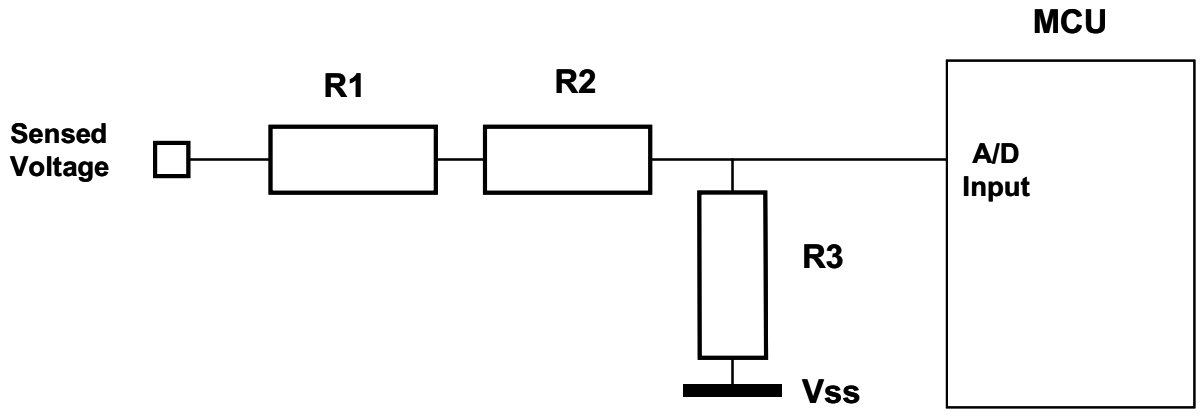

Figure 15. Voltage Sensor

Current sensing is used for motor over-current protection as well as determination of accurate back emf voltage. A current sensing resistor is often used in low-cost applications (**Figure 16**). This resistor is placed in the ground return path of the DC-Bus lines for DC-Bus current measurement, or in the individual legs of the inverter bridge for phase current measurements. The voltage drop created on the current sense resistor is amplified using an operational amplifier. The gain of the operational amplifier is set to get the output signal in the MCU voltage range reference, i.e. 0V – 5V, 0V – 3.3V.

The output voltage for zero input current is set to the middle of the ADC range by the Voltage GND level, which is usually derived from a reference voltage generator.

Compared to 5V systems there is no change except that the chosen operational amplifiers must operate on 3.3V single supply with rail-to-rail output. Among suitable amplifiers are the On Semiconductor MC3320x and the MC3350x rail-to-rail types.

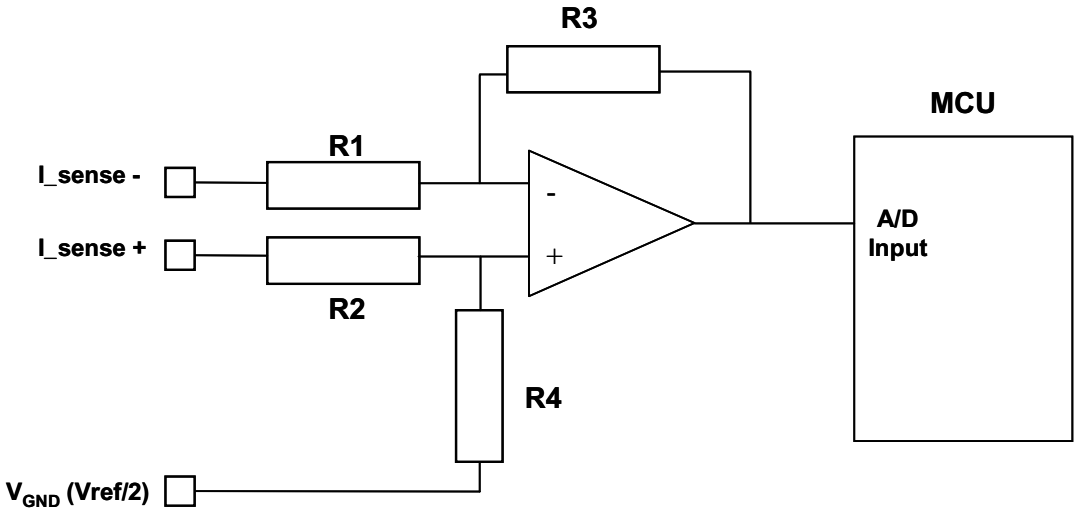

Figure 16. Current Sensor

Digital Signals

In motor control applications, the MCU input signals serve as a user interface (i.e. switches, push buttons) and as a means of communication and detection of the state of control/feedback signals (i.e. zero crossing detection, enable signal, etc.).

Compared to 5V systems, the input signals need to be adjusted to the 3.3V level and the implementation of this adjustment depends on the actual signal circuitry. Some examples are shown in **Interfacing to Microcontroller Inputs**. No other modifications are needed.

In motor control applications, the MCU output signals serve as user interface (LED, display), communication and control signals (IGBT / MOSFET control, Triac control, etc). The IGBTs / MOSFETs and Triacs are key control parts in motor control applications, so the implication of moving to lower operating voltages will be analysed in the following paragraphs.

Controlling IGBTs & MOSFETs with Drivers

IGBTs and MOSFETs are mostly used in the power stage design. Both types of power switches are controlled in the same way using high side and low side drivers.

The input characteristics of the drivers are very important for the power stage topology and its interface to 3.3V control signals.

The logic level requirement that is the key factor for the selection of the driver type is “1”, because the logic level “0” requirement is near to the ground voltage and it is satisfied by all types of drivers.

For direct interfacing to a 3.3V MCU, the driver logic “1” threshold level, V_{IH}, should be well below 3.3V. This condition is met by drivers that have TTL compatible input levels with $V_{IH} < V_{DD3min}$ (3.0V), such as the IR2181 from International Rectifier, which has V_{IH} = 2.7V.

For other types of drivers with logic “1” input voltage close or even above V_{DD3min}, a level shifter needs to be used in order to prevent the current leakage. An example of this is the MC74VHC1GT50 buffer, as shown in **3V CMOS to 5V CMOS**.

Controlling MOSFETs without Drivers

Small power MOSFETs can sometimes be driven directly without drivers, such as the IR2181 and similar.

In these circumstances, because of the large MOSFET gate capacitance, the transient response is considerably slower than when a driver IC is used. This is due to the fact that an MCU has a lower output current and voltage rating compared to the output of a driver, therefore this solution is appropriate only for slow changing outputs, i.e. controlling lamps, solenoids, etc. Also if the transition from the on to the off state and vice versa is slow, switching losses increase and they have to be taken into account during design.

For direct driving, the MOSFET used should have a gate threshold voltage V_{GTH} well below V_{DD3min} (3.0V). Among suitable MOSFET types are the On Semiconductor MMDF6N03HD dual 6A N channel MOSFET in SO8 package and similar types and the International rectifier IRF7501 dual N channel MOSFET in Micro8 package with $R_{DS(ON)}$=0.135ohm at V_{GS}=2.7V and others marked as "3V drive" types.

Driving TRIACs

Driving of TRIACs does not bring any issues for 5V to 3V transition, except that the value of R1 in **Figure 17** should be lowered compared to that in a 5V system in order to have enough TRIAC gate current.

The number of MCU pins should be chosen according to the driving capability of the MCU outputs to comply with the TRIAC minimum gate current requirement, which is 15mA for MAC4DC type for example. The circuitry on **Figure 17** has a galvanic connection to the power outlets.

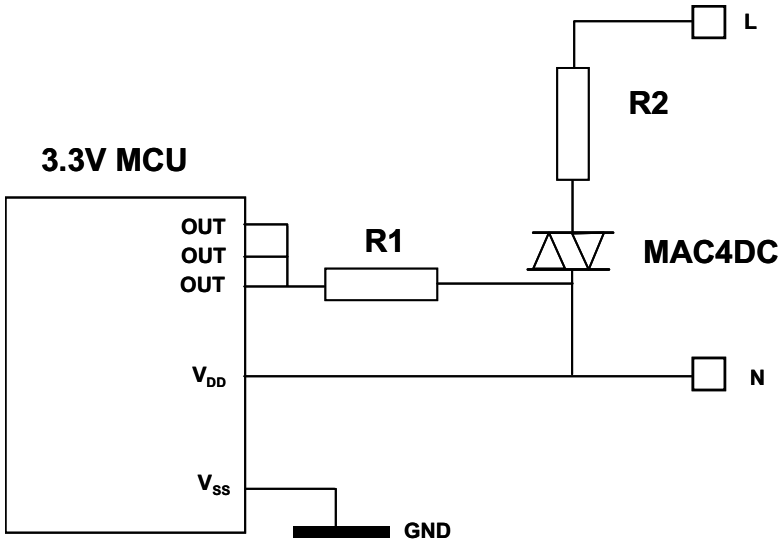

Figure 17. Driving of TRIAC

When galvanic isolation is necessary, the standard opto-triac or opto-coupler can be used for connection to the TRIAC. With a 3.3V MCU the situation is the same as in the 5V system, only the resistor limiting the opto-coupler current should be lowered to get the same driving current as in the 5V system.

The situation is similar for driving LEDs, although considering that the LED forward voltage drop is in the range of 1.6–2V there is a smaller headroom for the MCU output pin voltage drop compared to 5V system.

Therefore, the output characteristic of the MCU must be taken into consideration in these circumstances.

Power Supplies for Low Voltage Systems

The challenge is to provide a power supply that will satisfy the new technology operating at 3.3 V and also provide power for legacy 5 V devices. The 3.3 V power supply may be either a switching or a linear design. For most applications, a linear regulated power supply minimizes the number of additional components.

Linear Voltage Regulators

Linear voltage regulators are the simplest to design, as they do not require any magnetic components and are much more forgiving from a standpoint of printed circuit layout and grounding requirements. Linear voltage regulators are not as efficient as switching voltage regulators. The linear voltage regulator operates by reducing a higher input voltage to a lower output voltage by linearly controlling the conduction of a series pass power device in response to changes in the output load. This results in a voltage being dropped across the series pass device with the load current passing through it. Because of the voltage drop across the series pass device, the linear voltage regulator may be only 30 to 50 percent efficient. Linear voltage regulators become somewhat uneconomical above 10 W due to a significant increase in the heat sink requirements.

For a hybrid 5 V–3 V system it is reasonable to use a 5 V regulator, which supplies 5 V logic, and derive the 3.3 V for the rest of the system from it. As there are only 1.7V of drop between the 5 V power supply and the 3.3 V power supply, a low dropout regulator is a necessity. Typically low current linear voltage regulators supplying less than 500 mA use PNP pass transistors. A PNP pass transistor linear voltage regulator usually requires about 500 mV of dropout. Modern designed low dropout voltage regulators utilize FET transistors as the pass transistor, yielding dropout voltages of less than 100 mV. Higher current output linear voltage regulators typically use an NPN pass transistor and their dropout voltage is typically greater than 1 V. An advantage of deriving the 3.3 V necessary for the system from the 5 V regulated power supply is the increased ripple rejection from the 5 V pre-regulation device.

A number of semiconductor suppliers manufacture both adjustable and fixed linear voltage regulators. The following table is a partial list of 3.3 V linear regulators:

Manufacturer	Part Number	Output Current	Dropout Voltage	Tolerance
ON Semiconductor	MC78PC33NTR	150mA	300mV	+-2%
ON Semiconductor	CS5201-3L	1.0A	1.2 V	+-1.5%
ON Semiconductor	CS52015-3L	1.5A	1.4V	+-1.5%
ON Semiconductor	CS5203-3L	3A	1.15V	+-1.5%
ON Semiconductor	CS5206-1GT3	6A	1.3V	+-2%
ON Semiconductor	CS5207-3GDP3	7A	1.4V	+-2%
National Semiconductor	LM2936DT-3.3	50mA	200mV	+-3%
National Semiconductor	LM3940IT-3.3	1A	500mV	+-3%
Linear Technology	LT1121N8-3.3	150mA	400mV	+-3%
Linear Technology	LT1086CT-3.3	1.5A	1.5V	+-2%
Linear Technology	LT1085CT-3.3	3A	1.5V	+-2%
Linear Technology	LT1083CK-3.3	7.5A	1.5V	+-2%

Typically, in a linear voltage regulator design, the input bypass (bulk) capacitor is placed close to the input terminal of the regulator. The input bypass capacitor provides a low impedance source into the voltage regulator. Typical input bypass capacitors are in the 5 μF to 100 μF range. Connected to the output side of the voltage regulator will be another bulk capacitor (output bypass), in the range from 1 μF to 100 μF. This capacitor helps stabilize the regulator during current transients until its internal control loop can take over. It is also standard practice to bypass the logic elements, connected to the 3.3 V voltage regulator, with small bypass capacitors located close to their power leads. These small bypass capacitors help provide a low impedance power source during very fast transient current demands. Depending on the frequency of the transients, the value of these capacitors will range from 100 pF to 1000 pF. **Figure 18** shows a schematic for a typical linear voltage regulator.

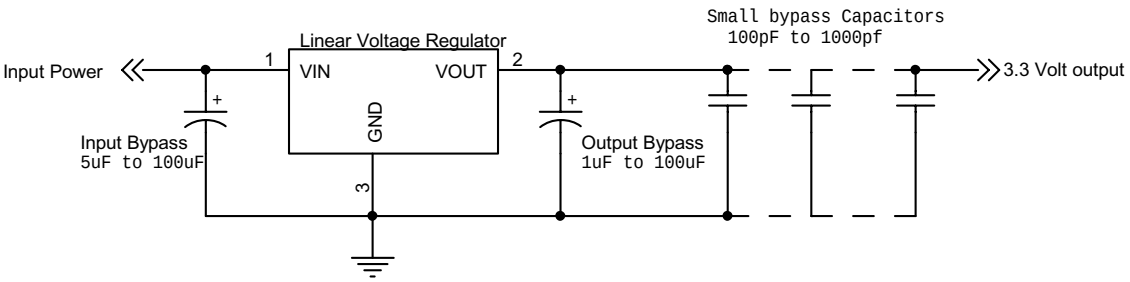

Figure 18. Typical Linear Regulator Schematic

Switching Voltage Regulators

Switching regulation is accomplished by the control of the on-time and off-time ratio of the pass transistor in a fast switching technique. Therefore, the switching voltage regulator operates the power device in a full-on or full-off mode. This control technique is known as pulse width modulation (PWM) and is commonly working at switching frequency above 20 kHz.

Switching voltage regulators have a distinct advantage over linear ones in that their efficiencies can exceed 90%. This operation mode results in much lower power being dissipated across the power device. Switching power supply regulators become very cost effective when used for output powers greater then 10 W. The disadvantage of a switching voltage regulator is that it requires more components, including magnetics, than a linear design and is less forgiving from a printed circuit board layout and grounding prospective (most switching regulators do not provide isolation between the input and output circuits). Similar to linear regulators, a switching regulator in a typical system is powered by an input voltage that is higher than what is required to be regulated (output voltage). In a typical 3.3 V only system, its power supply will use some voltage source greater than 3.3 V and then regulate it down to 3.3 V. A step-down or buck converter will be used in the application. Input bulk capacitors and output bypass capacitors used in switching design follow the same configuration as those in linear voltage regulators.

The following table is a partial list of switching voltage regulators appropriate for use with 3.3 V circuits from a few manufacturers:

Manufacturer	Part Number	Output Current	Ext. MOSFET Rqd.
ON Semiconductor	LM2575D2T-3.3	1A	No
ON Semiconductor	LM2576D2T-3.3	3A	No
ON Semiconductor	MC33163P	3.6A	No
National Semiconductor	LM2574-3.3	500mA	No
National Semiconductor	LM1575-3.3	1A	No
National Semiconductor	LM2655-3.3	2.5A	Yes
National Semiconductor	LM2576-3.3	3A	No
Linear Technology	LTC1701	500mA	No
Linear Technology	LTC1878	600mA	No
Linear Technology	LTC1772	2.5A	Yes

Figure 19 shows a basic schematic for a switching voltage regulator containing an internal MOSFET power device.

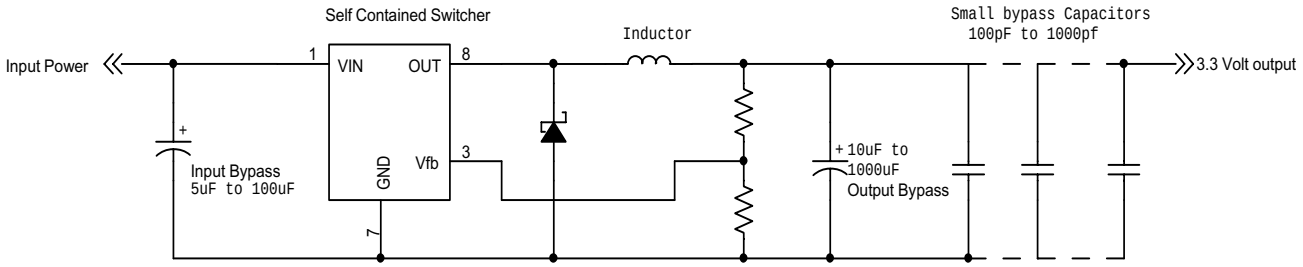

Figure 19. Typical Step-down Switching Voltage Regulator Schematic With Internal MOSFET

Figure 20 shows a basic schematic for a switching voltage regulator using an external MOSFET power device.

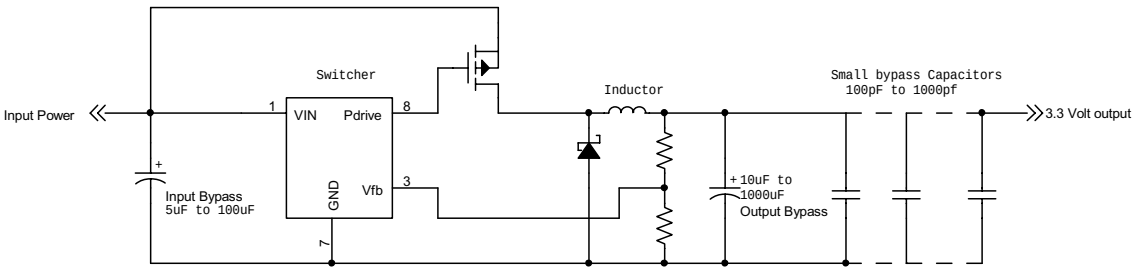

Figure 20. Typical Step-down Switching Voltage Regulator Schematic With External MOSFET

In summary, designing a power supply for 3.3 V microcontroller systems requires looking at the system as a whole. Power requirements of the system will dictate if a linear or switching voltage regulator will satisfy the system's power requirements. Most systems will have 3.3 and 5 V logic mixed in them. Deriving small amounts of current for the 3.3 V portion of the system from the 5 V regulated power supply with a linear voltage regulator is a simple choice. In the case where higher amounts of power are necessary for the 3.3 V portion of the system, a close look at a switching voltage regulator will be prudent. If the system only has the requirement for a 3.3 V power supply, the components in this document will suffice for those needs as well.

Conclusions

This application note discusses the design considerations which should be taken into account when moving a microcontroller application from today's 5V technology to tomorrow's 3V technology.

The growing popularity for lower voltage systems forces components to be designed and manufactured only for 3V operation, and this trend has also reached the microcontroller market. The new generations of MCUs are now moving to sub 0.25 micron processes and supply voltages of 3V or less.

The advantages of low voltage MCUs include:

- Ability to reduce power consumption
- Smaller on board power sources
- Increase in operational lives of battery powered applications
- Decrease in battery weight of portable applications
- Lower costs for the overall system

Designers now moving from 5V to 3V technology will be required to create systems in an interim period using a mixture of both 5V and 3V components. During this transition time, components allowing the translation from 3V to 5V and vice versa will be needed. Thus the migration to 3V technology brings also challenges which need to be considered:

Interfacing 5V outputs peripherals to 3V MCU inputs via a level shifter typically causes no issues, as the output voltage swing of 5V devices is sufficient to reliably drive 3V inputs.

Interfacing 3V MCU outputs to 5V TTL peripheral inputs does not constitute a problematic task, as 3V CMOS outputs have enough margin to drive 5V TTL inputs (voltage-translation devices come into place to facilitate interfacing).

Interfacing 3V MCU outputs to 5V CMOS peripheral inputs is more demanding, but careful design of level shifters using discrete or specially designed interface devices will address these situations.

The 5V to 3V technology move opens a challenging scenario for systems designers. This report shows the benefits that will accrue from such a change and also identifies topics that require further investigation in order to make this transition as smooth as possible.

Bibliography

- "M68HC11 Reference Manual", Motorola.
- "Analog-to-digital converter Reference Manual", Motorola.
- "Interfacing 3V and 5V applications", Application Note AN240, Philips Semiconductors.
- "Supply-Voltage Migration 5V to 3.3V", Application note XAPP 080, Xilinx.
- "Understanding True CMOS Outputs", Application note XAPP329, Xilinx.
- "Low Power Tips for Cool Runner Design", Application note XAPP346, Xilinx.
- “Bus Switches Provide 5V and 3V Logic Conversion with Zero Delay, Application Note AN- 11A, Quality Semiconductor.
- "Low Power Level Shifter", On Semiconductor.
- "MC74LVX4245 Dual Supply Octal Translating Transceiver", On Semiconductor.
- "MC74VHC1GT50 Non-inverting Buffer/ CMOS Logic Level Shifter", On Semiconductor.
- "MAX3370/3371 Low Voltage Level Translator", Maxim Semiconductor.
- "Low Cost, Low-Power Level Shifting in Mixed-Voltage Systems", Application Note SCBA002, Texas Instruments.
- "Low Voltage Embedded Design", Application Note AP-477, Intel.

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