

# APPLICATION NOTE

## **ABSTRACT**

To be able to offer the LPC900 family of microcontrollers with so many on-chip features at low prices, they are made in a process, which allows only 3V operation. This application note describes how these microcontrollers can be adapted to 5V-systems.

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### Philips LPC900 family in 5 V environments

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## INTRODUCTION

Philips LPC900 family of microcontrollers<sup>1</sup> is made in an advanced CMOS process, which allows the cost-effective implementation of a broad variety of on-chip features. Like in many other highly integrated ICs, the small structures of such technologies limit the maximum supply voltages to values below 5V. The LPC900 family is specified to work from 2.4V to 3.6V.

Although the supply voltage is lower, the I/O-pins are 5V-tolerant. I.e., the I/O stages cannot actively drive the outputs higher than the supply voltage, but they may be pulled to 5V externally.

Several aspects have to be taken into account, when an LPC900 is to be used in a 5V-system:

- 3.3V power supply from a 5V source
- Interfacing inputs and outputs to 5V logic levels.
- Driving external loads requiring higher currents and voltages above V<sub>DD</sub>.

## POWER SUPPLY CONSIDERATIONS

The LPC900 can be supplied with voltages between 2.4V and 3.6V. If the internal brownout detection circuit is used to detect power-failures, its trip-voltage lies between 2.4V and 2.7V. In this case the nominal supply voltage should be above 2.7V. This allows the use in 3.0V- and 3.3V-systems with appropriate tolerances.

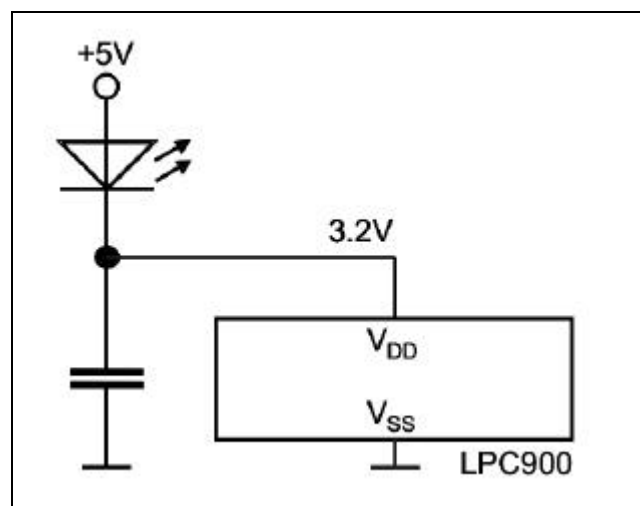


Figure 1

<sup>1</sup> Please check Philips Semiconductors' microcontrollers web site for product data [1].

In 5V-systems power for the 3V-microcontroller can either be derived directly from the unregulated supply or from the 5V supply.

The LPC932 e.g. consumes 25 mA maximum from the 3V supply. The I/Os each can source or sink currents up to -3.2mA or +20mA respectively. The power supply needs to be able to additionally handle the total of these currents, particularly when this is drawn from the 3V supply as well.

Smaller systems can use an LED with a typical voltage drop of 1.8V to generate the 3V from a 5V supply (see Figure 1), while bigger systems will require an LDO (Low Drop-Out regulator) like the Philips TDA3663. The LED solution has the advantage of not drawing any additional current, which is particularly important, when the microcontroller is in power-down mode. To achieve the same with a voltage regulator, a type with an enable input (e.g. TDA3673) has to be chosen<sup>2</sup>.

Because the outputs of the LPC900 are 5V-tolerant, driving loads from the 5V-supply directly can reduce the current drawn from the 3V-supply (see below).

## I/O PORT CHARACTERISTICS

An outstanding feature of the LPC900 family is that it can be run without external components and all but the power supply pins can be used as I/O. I.e., the 28-pin LPC932 has up to 26 I/Os. The I/O-pins are (individually) configurable via SFR and can be grouped as follows:

- 23 general-purpose I/O ports. These are bi-directional I/Os. They are 5V tolerant with the exception of two pins, which alternatively can be used to build a crystal oscillator
- 1 Reset input, which can also be used as a general-purpose input, when the internal reset function is used. It is not 5V tolerant.
- 2 I<sup>2</sup>C serial clock and data I/O. They are 5V tolerant and can alternatively be used as input or open-drain output.

An I/O configured as **bi-directional** performs like a standard 80C51-I/O: Writing a "0" to the port switches on a very strong pull-down transistor, which is capa-

<sup>2</sup> Please check Philips Semiconductors' standard analog web site for LDO product data [2].

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Table 1

Port	5V tolerant	Input	Quasi Bi-Directional	Push-Pull	Open-Drain
P0.0 - P0.7	X	X	X	X	X
P1.0, P1.1, P1.4, P1.6, P1.7	X	X	X	X	X
P2.0 - P2.7	X	X	X	X	X
P1.2, P1.3	X	X	-	-	X
P3.0 - P3.1	-	X	X	X	X
P1.5	-	X	-	-	-

ble of sinking up to 20mA in case of the LPC900-family.

Writing a "1" to the port switches the pull-down transistor off and activates a strong pull-up transistor momentarily. This rapidly charges external load capacitances and allows a fast output transition. Two weak pull-up devices sustain the high output level capable of sourcing up to 20µA.

In this configuration the port also serves as an input. Pulling down the input, the driving circuitry has to sink the current supplied by the two pull-up devices.

Once the input level is below about 1.5V, one of the pull-up devices is switched off and only the current of the remaining pull-up needs to be drawn. This static current is lower than 50µA, while the transitional current at 1.5V may be as high as 250µA. By this means a hysteresis is achieved, which is dependent on the impedance of the driving circuitry.

In **push-pull** mode a "0" switches on the strong pull-down transistor like in bi-directional mode. For the high-level output, however, the strong pull-up is switched on as long as a "1" is output; the weak pull-up devices are not used. The output can source up to 3.2mA in this configuration.

In **open-drain** mode only the strong pull-down transistor is available, no pull-up devices are involved at all.

The I<sup>2</sup>C-bus requires special open-drain drivers. An un-powered microcontroller must not disturb the communication of other devices on the I<sup>2</sup>C-bus. With no power, V<sub>dd</sub> would be 0V and any structure like a pull-up or ESD protection device connected to V<sub>dd</sub> would clamp the voltage level on the I<sup>2</sup>C-bus to about 1V and thus prevent the I<sup>2</sup>C-bus lines from going

high. Therefore no such devices<sup>3</sup> are present in P1.2 and P1.3, which can be used as SCL and SDA in an I<sup>2</sup>C bus system.

All ports can be configured as **input** by putting the outputs into tri-state, no pull-up or pull-down are activated. The high-impedance inputs (leakage currents below 10µA) are equipped with Schmitt-Trigger circuitry to suppress input noise. All but three inputs are 5V tolerant in this configuration (see Table 1).

## INTERFACING INPUTS TO 5V LOGIC

5V logic families have different trip points for their logic levels. TTL-type levels, which were adopted by some CMOS logic families, are rather asymmetrical, while pure CMOS logic has symmetrical levels. Special care must be taken when driving CMOS devices with TTL logic.

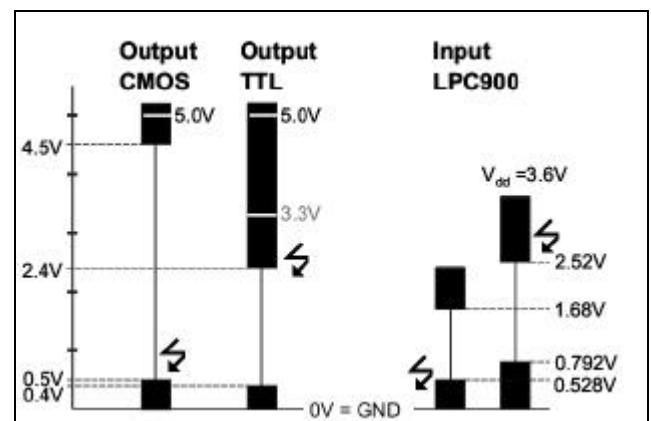


Figure 2

The inputs of the LPC900 can be driven directly from outputs of 5V logic families, when they are configured

<sup>3</sup> Of course, a different kind of ESD protection is implemented on these pins.

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as inputs<sup>4</sup>. The (worst-case) switching levels of the Schmitt-Trigger inputs are specified as follows:

$$\begin{aligned} V_{IL}: & 0.528V @ V_{dd}=2.4V \\ V_{IH}: & 2.520V @ V_{dd}=3.6V \end{aligned}$$

When driven from 5V CMOS logic families, the resulting noise immunity is worst at the low level, where the CMOS output may be as high as 0.5V. This improves from 25mV at  $V_{dd}=2.4V$  to about 0.7V in typical applications with supply voltages of 3.0V or 3.3V. The output high level of the CMOS logic is close to 5V, thus not critical.

The low level output of 5V (and 3.3V) TTL-logic is <0.4V, resulting in a worst case noise immunity of 125mV. More critical is its >2.4V output high level. With the LPC900 it virtually gives no noise margin (see Figure 2). Some measures have to be taken to improve this.

When no current is drawn from a TTL output, the high level voltage is significantly higher than 2.4V and should work well with the (high-impedance) input of the LPC900. To be sure a pull-up resistor of some k $\Omega$  (pull-up to either 5V or the microcontrollers  $V_{dd}$ ) should be added<sup>5</sup>

Although the noise margin of TTL seems to be worse than that of CMOS, it should be noted, that the output impedance of TTL is much lower than that of CMOS. This makes it less susceptible to capacitively coupled noise.

Also the use of the internal pull-ups of the LPC900 can be considered. To achieve this, the port has to be configured as bi-directional I/O with a "1" written to it. However, the following obstacles have to be taken into account:

- the current flowing into the pull-up device above  $V_{dd}$  is typically higher than the leakage currents (and is not specified),
- this current adds to the power supply of the microcontroller. Care must be taken, that the sum of currents flowing into the pins does not pull the supply voltage higher than specified i.e., the power supply must be able to sink current (particularly in power-down)!

<sup>4</sup> This is the default mode after power-up.

<sup>5</sup> For 3.3V TTL a pull-up resistor to 3.3V will also improve the noise margin.

## INTERFACING OUTPUTS TO 5V LOGIC

Driving a low-level the LPC900 can sink up to 20mA at a voltage not higher than 0.3V. This gives an excellent noise margin of > 500mV for TTL and >1.2V for CMOS.

Because the LPC900 can drive a high-level close to the supply voltage, an output can drive a TTL-input (which are rather high impedance at high level) directly; the noise margin still is >0.2V. The outputs should be configured as bi-directional; the weak internal pull-up devices pull the levels up to  $V_{dd}$ .

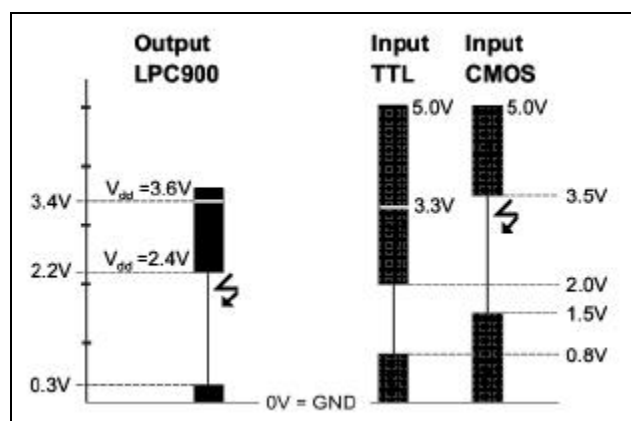


Figure 3

The input high level of 5V CMOS-logic cannot be reached by any 3V part without external components. Either a level-shifter<sup>6</sup> or external pull-up resistors to 5V with the LPC900's output in open-drain configuration can be used. The value of the pull-up resistor depends on the load characteristics (capacitance, current, speed) and the drive capability of the LPC900; a resistor of some k $\Omega$  should do in most cases.

## DRIVING OTHER LOADS

The rather strong outputs of the LPC900 can sink 20mA or source 3.2mA. This combined with the option to individually configure the outputs to bi-directional, push-pull or open drain gives a high degree of flexibility to drive any load.

The push-pull configuration cannot be used to drive loads above  $V_{dd}$ ; this would result in excessive currents flowing into the port.

<sup>6</sup> Please check Philips Semiconductors' logic web site for product selection [5].

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The internal pull-up devices of the bi-directional mode can be used to support an external pull-up resistor by actively pulling the output up to  $V_{dd}$ . However, an unspecified current will flow into the output above  $V_{dd}$  as described above.

The best solution to handle higher voltages than  $V_{dd}$  is the use of the open-drain configuration. An external resistor can pull the level up to 5.5V maximum with only leakage currents flowing into the LPC900 output.

Like in most CMOS devices the LPC900 outputs' drive capability is unsymmetrical; they can sink much higher currents than they can source. Higher current loads up to 20mA can preferably be switched to GND or  $V_{ss}$ . Tying the loads directly to the 5V supply also reduces the load on the (regulated) 3V power supply.

LED e.g. should advantageously be connected to 5V via a current limiting resistor. For higher currents than 20mA several outputs of one port can be used in parallel; it only has to be made sure that all are driven high or low at the same time and that the sum of all currents does not exceed 80mA.

If a higher-current load connected to ground needs to be driven, some external components are required.

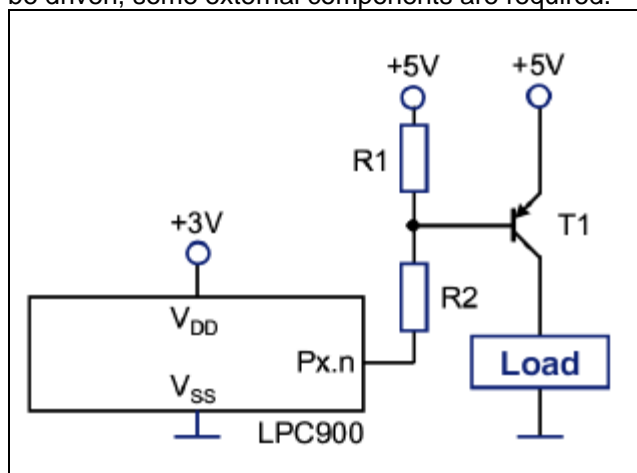


Figure 4

Either a p-channel logic-FET or a bipolar pnp-transistor will do the job (see Figure 4). R1 is required to make sure T1 switches off when the microcontroller's (open-drain) output is also off. R2 is needed to limit the current driving the transistor; its value is determined by the transistor parameters and the load-current. It is not necessary when a p-channel FET is used.

## ANALOG INPUTS

The analog comparators of the LPC900 can be used in different configurations. Their input voltage range is specified from  $V_{ss}$  to  $V_{dd} - 0.3V$ . To monitor voltages above this limit they need to be scaled down by any kind of voltage divider. Because of the high impedance of the inputs - the maximum leakage current is less than  $10\mu A$  - a resistive divider can be applied in many cases.

## REFERENCES

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**Revision history:****2003-05-21****Revision 01****Definitions**

**Short-form specification** – The data in a short-form specification is extracted from a full data sheet with the same type number and title. For detailed information, see the relevant datasheet or data handbook.

**Limiting values definition** – Limiting values given are in accordance with the Absolute Maximum Rating System (IEC134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.

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