White Paper

Interfacing Microcontrollers to the Industrial World

Utilizing embedded microcontrollers for industrial applications requires special attention given the harsh and noisy environment. Going from a supply voltage as low as +1.5V or +3.3V to the +24V industrial world requires careful design decisions and dedicated solutions to achieve safe and reliable operation.

The following white paper describes the different challenges and design considerations to be made, as well as potential solutions to maximize functional safety and ease of serviceability.

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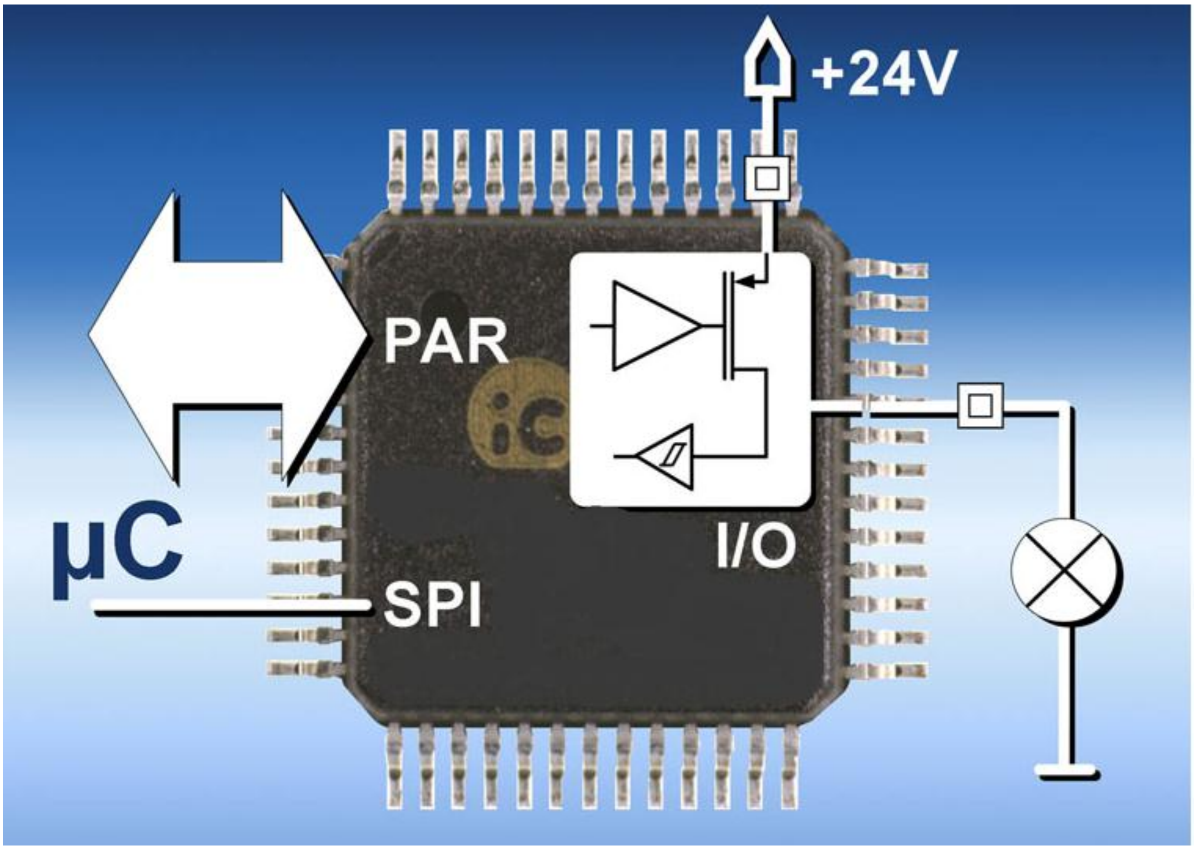

1) Industrial – a different world?

Since its invention in the 1970's, microcontrollers are on the trend toward more application specific derivatives and higher complexity, at smaller technology nodes. This enables the integration of more functionality, larger memory, and lower power consumption per function.
Everybody is looking for the "sweet spot" to minimize cost, space, and power consumption for a given application segment with a volume high enough to justify the development cost for a new microcontroller. As a result, microcontrollers supply voltages have continuously decreased over the last decade, reaching in some cases +0,8V for the core and +1,5V for the I/O-interface.

In industrial applications however, the majority of the supply and logic levels are still at +24V. There are very good reasons for this including noisy and harsh operating environments. For this reason, high electrical noise immunity is required for the interface to tolerate high current spikes, magnetic interference, static discharge, etc. In most cases it is a factor of 10 in terms of current or voltage between the microcontroller and the industrial world. Thus we are talking about ampere and volt, rather than milliampere or millivolt. This provides a challenge for the hardware designer to isolate and translate the signal level between the two worlds. That means shifting the logic levels from the microcontroller from as low as +1,5V to a +24V swing on the outputs or in the other direction for inputs.

Using a microcontroller in embedded applications, like machine control, robotics, automation equipment, etc. means designing the interfaces carefully in a way that is reliable and allows for safe operation. There are also many standards in place for functional safety, like IEC 61508[1] and EN 60204-1.

2) What are the design challenges?

It is the nature for the industrial environment to challenge everybody's design expertise to deal with the following requirements:

- High voltage swings with fast dV/dt or dI/dt transitions causing cross talk on input and output signals
- Ground loops shifting ground levels in distributed parts of the system
- System or software failure could cause damage on the actuator side (e.g., power outputs stages)

As a result of this, the following points need to be considered during the design of the interface between the microcontroller and the +24V world:

- What level shifting is needed for the microcontroller to outputs?
- What level adaption is needed for the microcontroller inputs?
- How to protect outputs against malfunction of the hardware or software?
- What filtering is required for digital and/or analog connections?
- Is isolation mandatory between the industrial I/O and the microcontroller?
- What power-up/down behavior should be considered?
- Which failures should be monitored and how?
- Where is high power consumption causing hot spots (e.g. high current or frequencies)?

3) Shifting and driving output signals safely

The initial consideration is to look at the logic levels on the microcontroller I/O-ports and then define the output requirements in terms of current and voltage. For example, driving high current resistive loads, like heaters or actuators, demands a shifting of the logic level and also pre-driving of the power transistors or FETs. Figure 1 shows an example of translating from the +1,8V microcontroller supply logic level, through the pre-driver, to control a high current +24V FET. From the microcontroller logic level, this low level FET allows switching loads at >10 Amps. Also shown is another option to connect a high side switch, like the iC-DP, for loads up to 200mA with +36V supply.

Since the microcontroller I/O-ports are switched to inputs on power-up, special precaution is needed here. To avoid floating input levels on the level shifter during this time, additional pull-down resistors are required if they are not already integrated into the device like with the iC-MFL.

Other areas to be considered for fail-safe operation are the detection of shorts on the outputs, monitoring the VCC supply, as well as ground and chip temperature. In applications where a failure on the output would cause harm or damage to the user, or valuable equipment, an FMEA analysis would be needed to meet safety standards (e.g. IEC 61508[1]). This can be done either at the complete system level, board level, or chip level. In the case of the level shifter and pre-driver iC-MFL, it has already been integrated at the chip-level, and as a result, includes a second ground connection and a special ground monitor.

For the iC-MFL, if one ground connection is lost (first order failure level), the monitor clears all outputs to a defined low level turning off all connected power output stages. The same applies if inputs are open, outputs are shorted, or the microcontroller disables the level shifter through a low level on the EN-input.

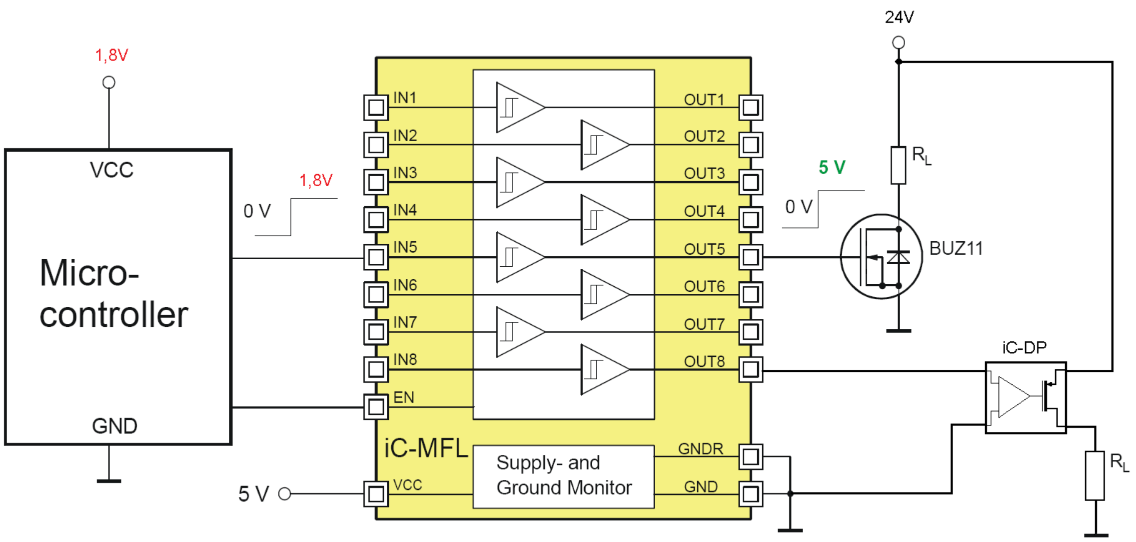

Figure 1: Shifting voltage level and driving power outputs

The iC-MFL outputs are designed for a maximum output voltage of +18V. Other types of drivers, like the iC-MFN, are useful for different output levels and can handle a direct supply from +24V, up to +40V. In many embedded systems the number of inputs and outputs can vary for different machine configurations and do require some modularity on the I/O-ports.

4) Discrete or ASSP-I/O?

I/O modularity can be addressed in different ways. One solution would be at the board-level with a choice of different I/O-modules or PCBs, or at the IC-level on the embedded circuit board. Here either an FPGA with discrete input or output stages, or dedicated ASSP's can be used. These are specifically designed for flexible and programmable I/O configurations.

In embedded machine or robotic applications, the sensors and actuators are sometimes only a few meters away. If they are connected with shielded twisted pair cable and centrally grounded, then ground loops are normally not a problem for the I/O-system. Thus in most cases an electrical isolation (e.g. galvanic isolation via optocoupler) is not needed. This reduces the cost for the I/O ports and increases flexibility for the system designer.

In other cases, digital I/O with +24V logic levels are used to connect switches, digital sensors and low speed serial communication on the input side over longer cable runs. The +24V outputs are also used to drive actuators like relays, coils, motors or indicators, such as lamps or LEDs. For high speed serial transmission (e.g. for SSI/BiSS encoder [2]) in a noisy environment, RS422 is also often used to bridge distances of more the 100 Meters [3]. To achieve reliable operation with failure monitoring, specific design considerations on the inputs are:

- I/O ports may not be connected
- Detection of open, shorted, or broken connections
- Provide filtering to suppress noise, crosstalk, spikes or bouncing of mechanical switches
- Detection of defined signal transitions to generate interrupts for the microcontroller

The design considerations on the outputs are equally important, such as:

- Tolerate and detect shorts, as well as over temperature
- Limit inrush current on lamps and suppress the turn-off voltage spikes on coils
- Providing pulsed outputs for blinking or power reduction

Switching loads with high-side outputs is the most the preferred method of operation. A broken or grounded connection to the load would then not impact the +24V system supply. Monitoring different critical failures, such as a +24V undersupply, missing ground connections, and driver over-temperature are mission critical in some applications [4]. Having the option to read back outputs, or to measure the analog levels on the I/O-port for a more detailed diagnosis, are very helpful to achieve functional safety. In the latter case the digital I/O-ports may also be used as +24V analog inputs.

Most of the digital functionality required in modular I/O-ports can be implemented in an FPGA, while the analog function, +24V I/O, and error monitoring requires discrete implementations. An example of a dedicated, programmable, and modular +24V I/O-solution is shown in Figure 2. This example is based upon an ASSP which can be connected to the microcontroller via a parallel bus or serially through an SPI interface, available on nearly every microcontroller.

In applications where supply and ground isolation is needed, the iC-JX can be connected via an isolated (e.g. optocoupler) SPI-interface. This has a clear cost advantage due to the fewer isolation lines needed. In this case the logic supply voltage for the iC-JX can be generated from the +24V through a voltage regulator providing +3,3V and +5V for digital and analog circuits.

With the iC-JX, there is also available full read back of all I/O ports. Additionally, internally the 16-channel, 10-bit A/D-converter allows the ports to be viewed as +24V analog inputs for diagnostic purposes.

This implementation provides functional safety, improved online serviceability, and failure detection. This reduces service cost significantly when a remote diagnostic is utilized.

For voltage regulation, the iC-WD or iC-DC voltage regulator can generate the two output voltages for a small I/O subsystem by combining a switched mode DC/DC converter with an internal linear regulator. This minimizes ripple for analog circuits and keeps power consumption low at the same time.

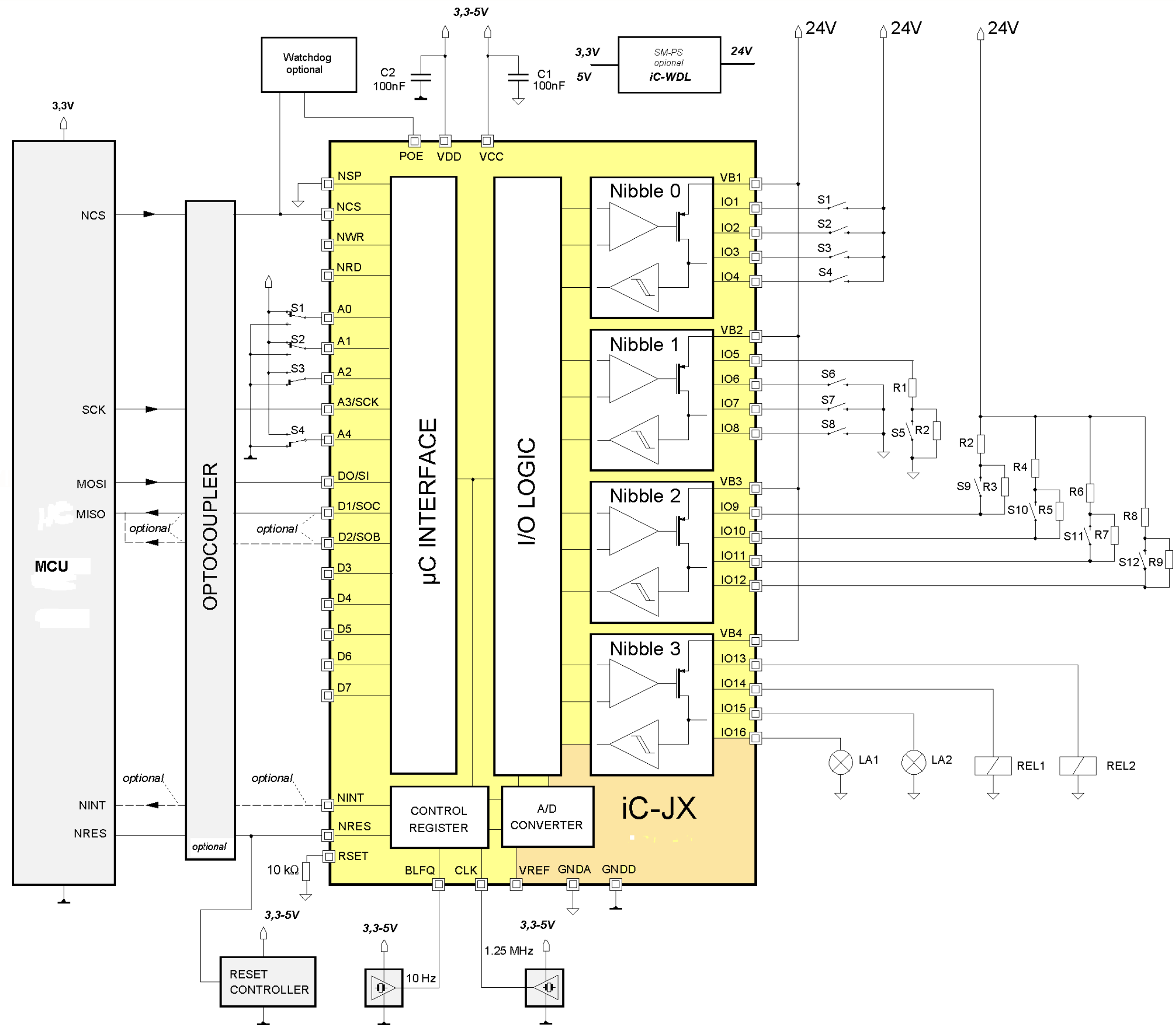

Figure 2: Compact universal I/O with optional isolation

For additional safety in this circuit, an external watchdog circuit can also monitor the activity of the microcontroller and disable all of the 16 I/O ports if an error state occurs internal to the microcontroller.

5) Dealing with noisy +24V Input Signals

In the case of noisy input signals, digital or analog filters are needed to avoid faulty readings by the microcontroller. For digital signals, the iC-JX inputs have hysteresis built in and the option of digital filtering. Analog input signals can be filtered via discrete filters or a comparator with built-in filter function, such as hold, hysteresis, or RC. Figure 3 shows the effect of the HOLD function on noisy analog inputs of the iC-HC.

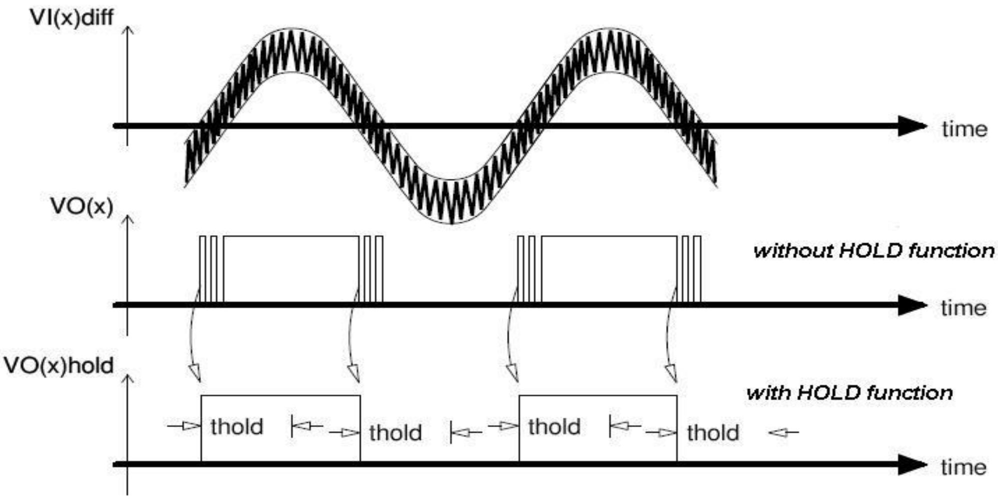

Figure 3: Integrated solution to filter noisy input signals

This solution is typically used for fast measurement of input levels and contains built-in level shifting for microcontroller inputs. The supply voltage and the differential input voltage can be up to +36V. For power saving, the iC-HC comparator can be switched to “zero power” consumption through an enable input.

6) Driving laser diodes and LEDs

To drive laser diodes [5] from a microcontroller requires constant current sources and spike-free switching to avoid damage to expensive laser diode. Depending on the current and switching frequency different standard drivers allow average current control (ACC) and/or average power control (APC). Figure 4 shows the integrated solution of the iC-HG driving three laser diodes (or LED arrays) with an adjustable constant current.

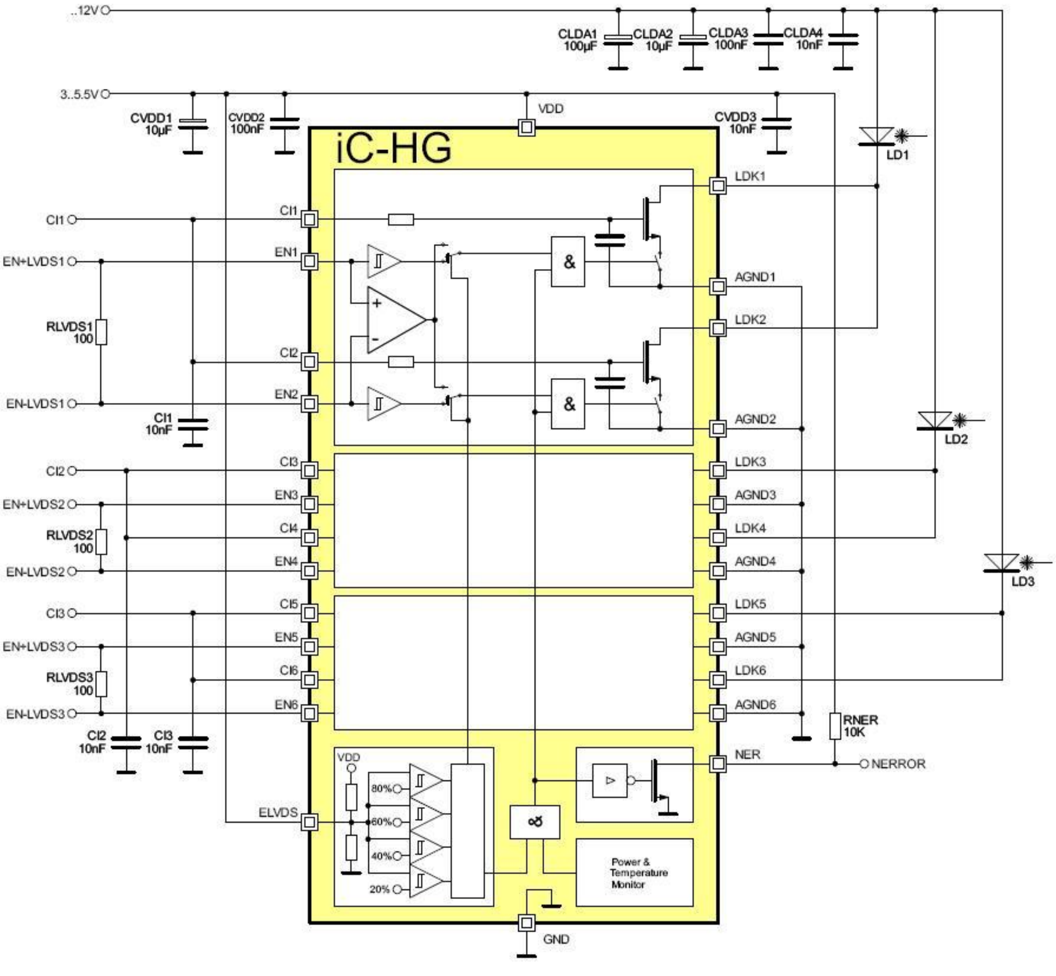

Figure 4: Driving RGB Laser Diodes/LEDs up to 1Amp

Typically the configuration in Figure 4 provides RGB light sources for different industrial application, such as projector or laser modules. On the design and test of fast laser driver circuit an additional White Paper is available.

7) Save power – but where?

Due to the high voltage swings of industrial signals, power consumption can become a significant issue. For output stages, excessive heat-up will occur when the switching frequency is increased. A typical example is a 24V line driver for serial communication to subsystems.

One option to deal with this problem is to store the reflected signal energy of the unterminated transmission line in capacitors and using this energy for the line driver [6]. This could save up to 50%, or 3 watts, of power consumption at switching frequencies of >250 kHz. Thus increasing reliability and decreasing cooling requirements. The iC-HX is a 24V line driver allowing this option just by adding a capacitor to the IC. Tests have shown that the package temperature of an iC-HX can be reduced from about 100°C to approximately 70°C at a transfer clock rate of 200 kHz.

Reducing line driver power is one example of power reduction. Thus, all parts of the system running at a high frequency and high current (e.g. power outputs) should be looked at carefully and evaluated for their potential to reduce power consumption (e.g., using low R_{DSON} FET's).

Driving relays and valves is also a special case due to special characteristics during activation and deactivation. Given this, it is important to look at driving relays and valves carefully at the circuit level. The activation current needed can be twice as much as the operating current with a turn-on time of 10-100 ms; depending on the relay or valve type. Beyond this activation time, the current can be reduced typically by at least one third. This can be designed-in by using a discrete RC-network or pulse width modulation (PWM) circuit; changing the duty cycle after a fixed activation time, or by changing the frequency. The PWM-unit itself can either be built into a FPGA sequencer, a microcontroller PWM-output, or via an ASSP-device to address this requirement.

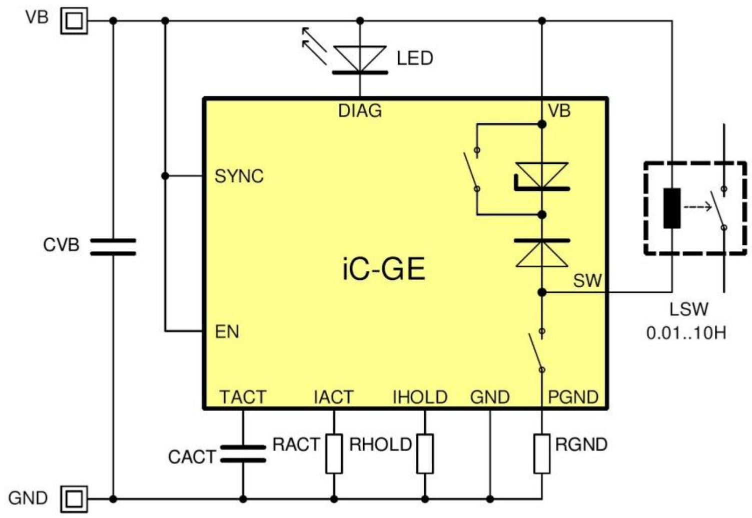

Figure 5: Integrated drive solution to save power consumption in relays or valves

If functional monitoring of relays or values is also needed, a dedicated ASSP may be mandatory. Figure 4 shows the iC-GE circuit for driving relays or valves direction on supply voltages of up to +36V from a typical TTL-input level. The device requires only external resisters (RHOLD, RACT) to define the required activation and hold current. This integrated solution actually modifies the current to allow that the same relay to be used on different supply voltages [7]. To achieve this with a classical PWM-output, both duty cycle and frequency need to be calibrated to the different supply voltages.

The dedicated ASSP-solution can also integrate the clamping diode and service indicator. It also monitors the coil current, under voltage and over temperature. In case of an error it provides either a flashing LED light or it can be used as an interrupt to the microcontroller. As shown in the above example, reduction of power consumption is possible when driving relays and valves. By taking special consideration, a board level solution can be realized during the design phase of the project.

8) Summary

As show in this white paper, there are many special design considerations to be made when interfacing microcontrollers to the industrial world.

The wide spread use of microcontrollers as embedded solutions in automation, motion, and machine control systems requires the designer to take on special requirements when interfacing with the industrial world. Fortunately, iC-Haus' expertise with dedicated ASSP solutions in the industrial market reduces the burden and solves many issues for the designer at the board level.

9) Literature

[1] More Safety with Functional Safety, Thomas Franken, Automotive 1-2, 2009, page 41-43
[2] BiSS-Webseite: http://www.biss-interface.com/
[3] Flexible Sensor Signal Conditioning and Safe Transmission, Marko Hepp, Sensors Magazine
[4] IO-Error Monitoring in Industrial Machine Control, Dr. David Lin, Application Note
[5] Driving Diode Laser, Uwe Malzahn, Euro Photonics
[6] Using smart Drivers to save Energy, Dr. David Lin, Industrial Control Design Line
[7] One Relay for multiple Supply Voltages, Uwe Malzahn, Power Management Design Line

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iC-Haus GmbH is a leading independent German manufacturer of standard iCs (ASSP) and customized ASiC semiconductor solutions. The company has been active in the design, production, and sales of application-specific iCs for industrial, automotive, and medical technology since more than 25 years and is represented worldwide. The iC-Haus cell libraries in CMOS, bipolar, and BCD technologies are fully equipped to realize the design of sensor, laser/opto, and actuator ASiCs.
The iCs are assembled either in standard plastic packages or using the iC-Haus chip-on-board technology to manufacture complete microsystems, multichip modules and optoBGA™, the latter in conjunction with sensors.

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