Highly Integrated Controller/Driver for Industrial Motion Control of Stepper Motors

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Introduction :

Stepper motors are used more and more in industrial environments. Increasing performance and reduced size make them more and more attractive. Their application is not only limited to accurate positioning anymore.. Applications like dose pumps, valve control, even very dynamic positioning and movements reserved before for linear positioners are becoming more popular.

The drive electronics for such stepper motors are evolving accordingly: In the traditional way, the architecture typically includes a standard micro controller or DSP, custom logic to provide the decoder inputs, a number of analog-to-digital and digital-to-analog converters, and an H-bridge transistor arrangement to drive the currents in the stator coils of the stepper motor.

Developments of driver and control driven by automotive applications have yielded interesting products and building blocks. These increase local intelligence close to the motor and turn it into mechatronic units. Application Specific Standard Products (ASSP) have become available to drive stepper motors directly from high level position commands on a bus. Such single chip solution integrates driver transistors, on chip current regulation, a translation table between exact rotor position and corresponding coil currents, a positioner controlling position, speed and acceleration, and the physical layer and data-link protocol of a communication bus. Furthermore the use of micro-stepping is converting low resolution motors in cheap high resolution actuators.

Such ASSP's are very convenient for multi-axis positioning applications. System builders who want more flexibility on the control of the movement can still chose for dual chip solutions : they embed their knowledge in standard micro cores or DSP's and concentrate on producing a 'next step' signal to the stepper motor. The ASSP takes care of the rest, and replaces the bulk if not all of the traditional motor drive circuitry.

This allows designers to concentrate on their core concern: the programming of the motion, rather than concentrating on driving a current through a coil using complex PWM algorithms. The development time and hence the time to market of new products reduces accordingly. But that is not the end of the fun: the ASSP's come with new features like embedded diagnostics and information on the torque and motion. The sharp-brained designer can use these signals and program the controller to detect rotor blockage, to detect rotor position, and to perform automated adaptation of torque without use of external sensors!

Applications

Dynamic positioning implies that an object is moved from 1 position to another at a speed that is designed specifically for that motion. In most cases this is high speed, but with acceleration and deceleration adapted to the specific design of the motor and the load, as the designer wants to avoid oscillations and resonances occurring in the system including the motor. Applications in which such demanding dynamic positioning is being implemented are found in dynamic headlamp positioning and climate control dynamic flap positioning in the automotive industry. In the industrial world we see the need for smooth dynamic motion in surveillance camera positioning, air-flap and water-valve positioning in climate control installations, valve positioning and dose pumps in process control.
Very high speed dynamic motion is occurring in manufacturing equipment like weaving equipment, pick-and-place equipment, industrial robots, X-Y-Z tables, and in the dynamic stage lighting of the entertainment business.

Motor driver control architectures

The traditional architecture for stepper motor driver electronics is show in Figure 1. The core of the circuit is a microcontroller, usually with the program code embedded in a flash memory. For some applications a DSP is more suited. The micro has the motion programmed, and interacts with feedback from the motion and the motor. The first feedback is provided by a Hall sensor basically providing information on the rotor position. It can be used to keep track of the rotor position, or to monitor the motion and detect a possible stall condition or blocked rotor. In simple cases an end of loop position switch is sufficient. Optical position coding is also an option, or even a resistive potentiometer mounted on the motor shaft can do the job. All these options are however adding to the bill of material, and require space and cash.
A resistor in series with the motor driver collects information on the motor current, and an ADC presents it as a digital input to the controller. Other diagnostics are obviously possible but add very quickly to the required analog circuitry.
The micro or DSP delivers a PWM signal to drive the motor coils. Analog circuitry is amplifying this signal and drives the power stage, which in its turn drives the coils of the motor.

An integrated controller/driver solution drastically simplifies the architecture. A fully integrated solution takes care of everything done in the traditional way and pushes it into a single device. This hence contains the controller, speed, position, current, diagnostics and power stage all in 1 chip. Figure 2 AMIS30624. This solution is by far the simplest construction and is the preferred choice for applications where the required current in the coils is close to the maximum operating current provided by the single chip controller/driver.

There can basically be two reasons to deviate from this ideal single chip solution: Current drive and controller flexibility.

In a fully integrated solution the controller is provided by the chip manufacturer and can be a micro or a programmable state machine. Some users have developed a high level of expertise and associated software that they use with their preferred standard micro or DSP. This firmware can be the core of their business and they want to re-use and improve that further. For such cases an intelligent integrated motor driver chip can still be a strong simplification of the architecture: The intelligent integrated motor driver chip requires as an input just a next micro-step command, and does all what is required to deliver the PWM at the coils of the motor. Hence still the BOM is extremely limited, and the requirements for the microcontroller are very minimum, even to the extend that 1 micro can control more than 1 motor as the PWM generation is done in the intelligent integrated motor driver device. Furthermore such motor driver generates internally, without need for external components, all required information on motor speed, position, coil current, diagnostics on open or shorted coils, overheating, ...you name it, and offers this information to the controller. Figure 3 AMIS30522.

Better functionality through integration

The intelligent integrated stepper motor driver AMIS-30522 is a micro-stepping stepper motor driver for bipolar stepper motors. The IC can be interfaced via I/O pins and the SPI bus to an external microcontroller and/or DSP. This external controller can be very simple
as the AMIS-30522 contains a current translation table and takes the next micro-step on every rising (or falling) edge of the signal on the NXT input pin. The DIR register or input pin defines the direction of rotation. This implies that the PWM signal is generated in the driver chip, uses a proprietary PWM algorithm for reliable current control. The NXT step can be a full step or a micro step down to $1/32^{th}$ of a full step. Micro-stepping operation overcomes the design trade-offs between minimum speed, audible noise and step-loss due to resonance phenomena. It also increases torque at low velocities.
Furthermore via the SPI bus a list of parameters can be controlled: current amplitude (5-bit DAC), step-mode, PWM frequency, EMC slope control, enabling and disabling the driver, sleep mode entry.
The intelligent driver device provides also a long list of information to the external controller through the SPI bus: Thermal warning and shutdown status flags, detection of open coil, detection of shorts and over-current, position of the internal translator table.

The most exciting feature however is the Speed and Load Angle (SLA) output signal. Basically this measures and interprets the Back ElectroMagnetic Force (BEMF) induced in the motor coils by the passing by of the magnetic poles of the rotor. This SLA output signal enables the running of stall detection algorithms on the external microcontroller, which offers silent, yet accurate position-calibrations during the referencing run without external sensor. But there is more!! The micro can be programmed with control loops based on the load-angle information provided by the SLA output, and to adjust torque and speed accordingly to avoid step loss or to boost temporarily the motor current and torque. The way to use this feature is explained further on.

Additionally, the AMIS-30522 has an on-chip voltage regulator able to deliver power to externals, a reset output and a watchdog circuit reset to supply and monitor the external micro.

When added to a simple microcontroller, the intelligent integrated stepper motor driver completes it to a fully integrated stepper motor driver/controller circuit without need for neither external current nor position sensors, and without need for external drivers. The designer can fully concentrate on the driver algorithm on his preferred platform and enjoy the SLA feature to design even better algorithms.

And integration can go a step further. **The intelligent integrated stepper motor Driver/Controller AMIS-30624** is a stepper motor driver similar to AMIS30522 but contains on top an integrated programmable state machine. The state machine translates a target position into the required sequence of (micro) steps to get to the target position with desired acceleration, speed and deceleration. The target position and other high level positioning information is dictated by a remote host, who communicates with the intelligent stepper driver/controller through and I²C bus (AMIS30624) or LIN bus (AMIS30623). The high abstraction level of the products' command set reduces the load of the processor on the master side. Scaling of the application towards number of axes is straight-forward: hardware and software designs are extended in a modular way, without severely affecting the demands on the master microcontroller. The bus structure simplifies PCB track-layout and/or wiring architectures.

The SLA output is in this case connected to the internal state machine, and its use is limited to the generation of stall detection.

The on-chip position controller is configurable with One-Time Programmable (OTP) default settings and RAM to overwrite the defaults through the I²C interface. These parameters have to be set to adapt the circuit for the specific motor type used, for the positioning ranges and for setting the maximum speed, acceleration, deceleration, and stall detection.

The intelligent integrated stepper motor Driver/Controller acts as a slave on an I²C bus (AMIS30624) or LIN bus (AMIS30623) and the master (host) can fetch specific status information like actual position, error flags, etc. from each individual slave node.

The **key advantage of intelligent integrated drivers and driver/controllers** are primarily their ease of use: The designer can choose for the embedded controller, or use a simple low cost controller. He can concentrate on designing the motion algorithm using a proven and reproducible translation of the motion to the driving of the coils. This translation obviously has to be 'designed' as well to the specific mechanics of the designer's application. Though it boils down to the running of a characterization algorithm that returns the required parameter setting.

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For designing the motion algorithm, the designer has a range of features available that are difficult if not impossible to achieve with a discrete solution, or with simple standard products. The most important are micro-stepping for low acoustic noise, and the detection of rotor speed and load angle without external sensors. The latter can be used as a stall detection, and to adapt the motor speed and drive interactively with the feedback from the motion. The communication is limited to a position command for the motor driver/controller, or a next step pulse for the intelligent motor driver. This low speed of communication causes no radiated emission. The high speed PWM signals are limited to the short tracks between driver and motor coils, and those signals are slope controlled to reduce further any radiated emission.

Despite the long list of features, the end solution is small in Bill Off Material and has a specific advantage for small positioning applications and mechatronics, and can even be built inside a small stepper motor or actuator. No sensors are needed, and virtually no externals. Even a current sense resistor is integrated. Picture 1 example of mechatronic solution.

Reduced engineering development time by using the parameterization mode (OTP bits)

A major concern of every system designer using a stepper-motor is how to drive this actuator without losing steps. Many parameters are influencing the correct motion and it is not always easy to find the right combination. [Ref 1]. Varying all kinds of settings to find the optimum can lead to a long development time.

Using highly integrated stepper-motor driver-positioners such as AMIS30624 eases the programming of the key parameters without compiling and re-qualifying the software. In Application Note AN_AMIS-3062x_04 [Ref 2] a step by step guideline is offered to help designers.

In a first step the needed torque is calculated. This is in most cases a system requirement. Knowing the velocity and the required corresponding torque one can determine the needed current. This so called run current can be selected from a table containing 16 values varying from 59 mA up to 800 mA sending a single I^2C command. Also setting the holding torque generated in the motor by supplying a small DC current in the coils, is using the same principle. In a separate table a holding current is selected using a similar 4-bit word.

As a second step the motor dynamics are considered. Every stepper-motor has its own resonance frequency, also called forbidden or Eigen-frequency. During acceleration and deceleration this forbidden frequency zone should be crossed as quickly as possible. Figure 4: Forbidden frequency zone. A solution offered in AMIS30624 is the selection of 2 velocities and 2 corresponding acceleration and deceleration profiles. The first velocity 'minimum velocity Vmin' is chosen above the danger zone. A second velocity 'maximum velocity Vmax' is the nominal speed of the motor. Both velocities can be selected from 2 velocity tables. The motion starts at Vmin, which means that the acceleration to reach Vmin is in theory infinite. A second acceleration determines the time to reach the Vmax value, and can be set. Because

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the deceleration is symmetrical it also sets the time to slow down to complete stop. These timings are in most cases part of the system requirements. Based on those the minimum acceleration can be calculated. The upper limit is as explained in Application Note AN_AMIS-3062x_04 [Ref 2] a function of the Eigen frequency of the motor. Again the acceleration/deceleration can be set by just sending a 4-bit word using a simple I^2C command.

Once all parameters have been calculated, they are sent on the I^2Cbus to the motor driver/positioner. When they are proven to be stable, the system designer has the option to burn this set of values in a non volatile memory embedded in the IC.

Programming a stall detection without sensors

Stepper motors are mostly used in open loop systems. This has the advantage of being a simple and by definition stable concept. The major disadvantage however is the absence of (position) feedback. If the motor blocks the driver/positioner continues driving the coils "thinking" the motor is still moving. This creates noise and more important the link between real and actual position stored in the positioner is lost. AMIS30624 is able to detect when the motor is blocked using the stall detection function.

Every motor is based on the basic principle that a current in a conductor in the presence of a magnetic field creates a force. This causes this conductor to move. At the same time a moving conductor in a magnetic field creates an electro magnetic force in the opposite direction given by $e = -\frac{d\Phi}{dt}$ where Φ is the magnetic flux of the field. If the motion is circular with an angular speed w, this so called Back e.m.f. is given by: $e = E_m \cos \omega t$ where $E_m = -N\omega\Phi_m$

The amplitude E_m is a linear function of the speed. As a result the Back e.m.f. is zero when the motor is blocked.

AMIS motor drivers are able to measure this Back e.m.f. AMIS30522 makes this voltage available on the SLA pin (Speed and Load Angle) which can be fed into an ADC inside an external microcontroller. It is then possible to detect a stalled motor with a small algorithm in this micro.

AMIS30624 has its detection circuit embedded. A simple I^2C command sets the different threshold levels. Again Application Note AN_AMIS-3062x_04 [Ref 2] explains the different steps how to parameterize these levels.

Programming dynamic torque

As explained, the Back-e.m.f. is a function of the velocity of the motion. The phase between this voltage and the current in the coils is influenced by the mechanical load on the motor axis. If this mechanical load increases the phase difference increases as well.

As a result, the sampled voltage level will decrease with increasing mechanical load if we sample the Back-e.m.f. always at the same time. See Figure 5: Load Angle

This phenomenon is called Load Angle and can be used to compensate for overload situations.

Usually system designers parameterize the run current to cope with potential load variations. The torque delivered should be higher than the expected peak load. This leads to over dimensioning of the current and motor.
Load Angle can be observed on the SLA pin of AMIS30522. If for a given velocity the voltage on this pin starts to drop it indicates the mechanical load is increasing. This can be compensated by selecting a higher current increasing the delivered torque of the motor. With this dynamic torque generation it is not longer needed to dimension the system for the expected peak loads. As a result the stepper-motor can be smaller and thus cheaper.
For more information see Application Note AN_AMIS-3052x_01 [Ref 3].

Examples of application diagrams

A **Dual CAN stepper motor driver/controller** reference design adds 1 AMIS30521 and 1 AMIS30522 parts to a microcontroller and CAN transceiver. The solution is a fully integrated solution to drive 2 stepper motors from a CAN bus using a single microcontroller.
Figure 6: Block diagram of CAN dual stepper.

In this **Three-axes stepper motor driver/controller** reference design, three 30624 are used to drive the pan, tilt and zoom functions in a surveillance camera. The 3 parts are connected to the I²C bus that is getting the high level position commands from a remote host.
Picture 2 PICTURE of driving 3 motors over 1 bus.

A reference design of a **Motor driver/controller with standard micro** combines a standard microcontroller with AMIS30522. The ASSP supplies the microcontroller and performs the driving function for the motor.
Picture 3 PICTURE of 522 evaluation board

Picture 4 shows a **stamp with AMIS30624**, and illustrates the possible small size of the PCB of this ASSP and BOM, a total solution to drive a bipolar stepper motor.

Summary

Intelligent stepper motor driver/controller ASSP have become available to control and drive bipolar stepper motors from a single chip. They drive the motor to a target position from a simple command on a bus. Dual chip solutions give designers the full freedom to use their proprietary software on their favorite DSP or microcontroller platform and take full control of the motion. Yet they are saving considerable design time as the intelligent motor driver translates position or 'next step' commands to the PMW power signals to drive the coils of the motor.
The designer can concentrate on the design of the motion itself. The intelligent ASSP provides useful information on faults, rotor speed, coil currents to enable the designer to develop algorithms that result in well-controlled motion and minimum motor size. Methods are offered to calculate the parameter setting for maximum and minimum values of motor speed, current, acceleration, and to program stall detection and dynamic torque.
No need to use position sensors or external currents sensors, a total solution can be built with just a few passives added and is very suited for mechatronics. Several

application diagrams have been presented to illustrate the use of the ASSP for industrial applications.

References

[Ref1] Douglas W. Jones "Stepping Motor Physics"
www.cs.uiowa.edu/~jones/step/
[Ref2] Application Note AN_AMIS-3062x_04
www.amis.com/products/motor_controllers
[Ref3] Application Note AN_AMIS-3052x_01
www.amis.com/products/motor_controllers

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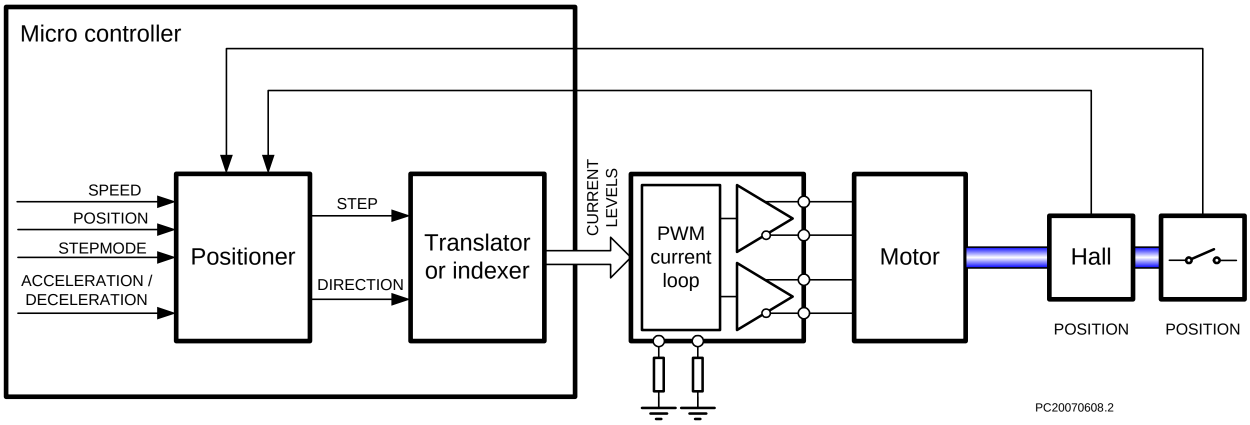

Figure 1: traditional architecture

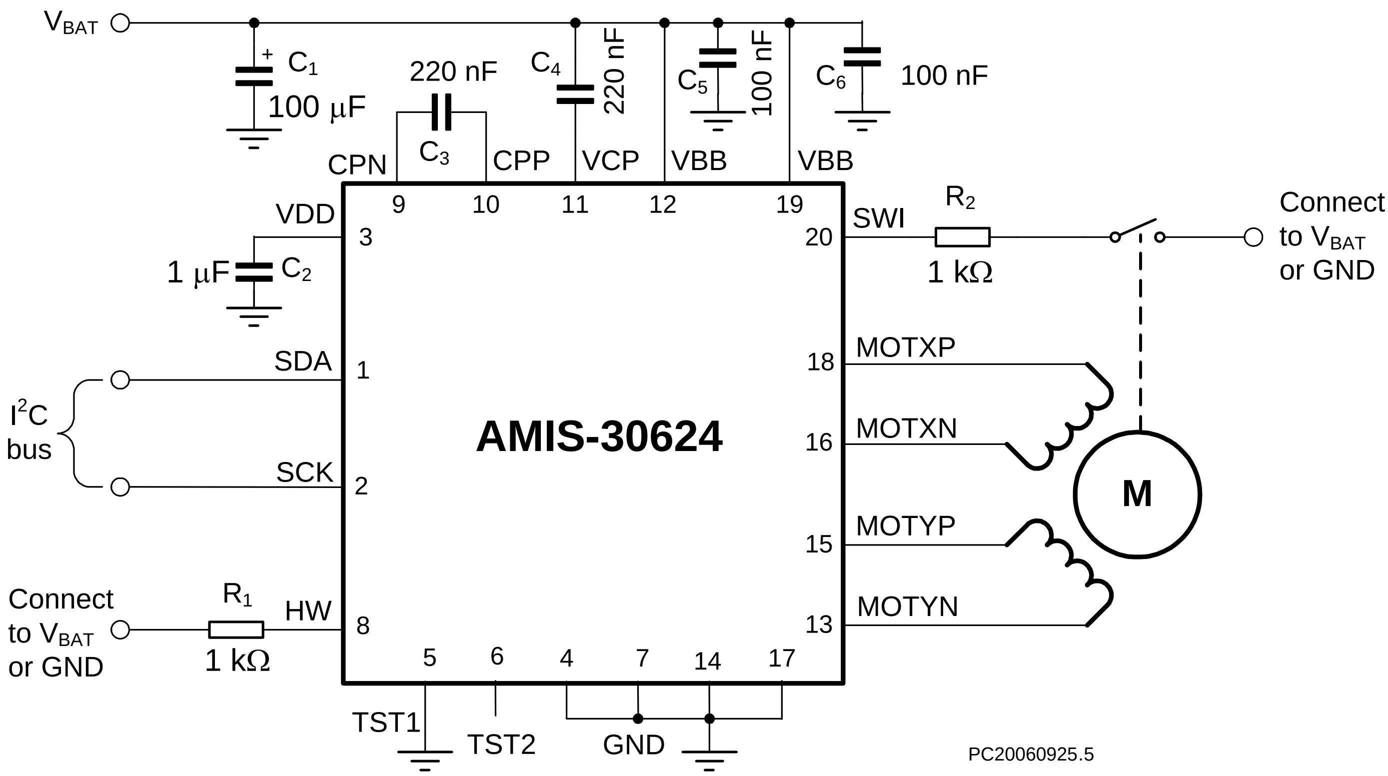

Figure 2: application diagram AMIS30624

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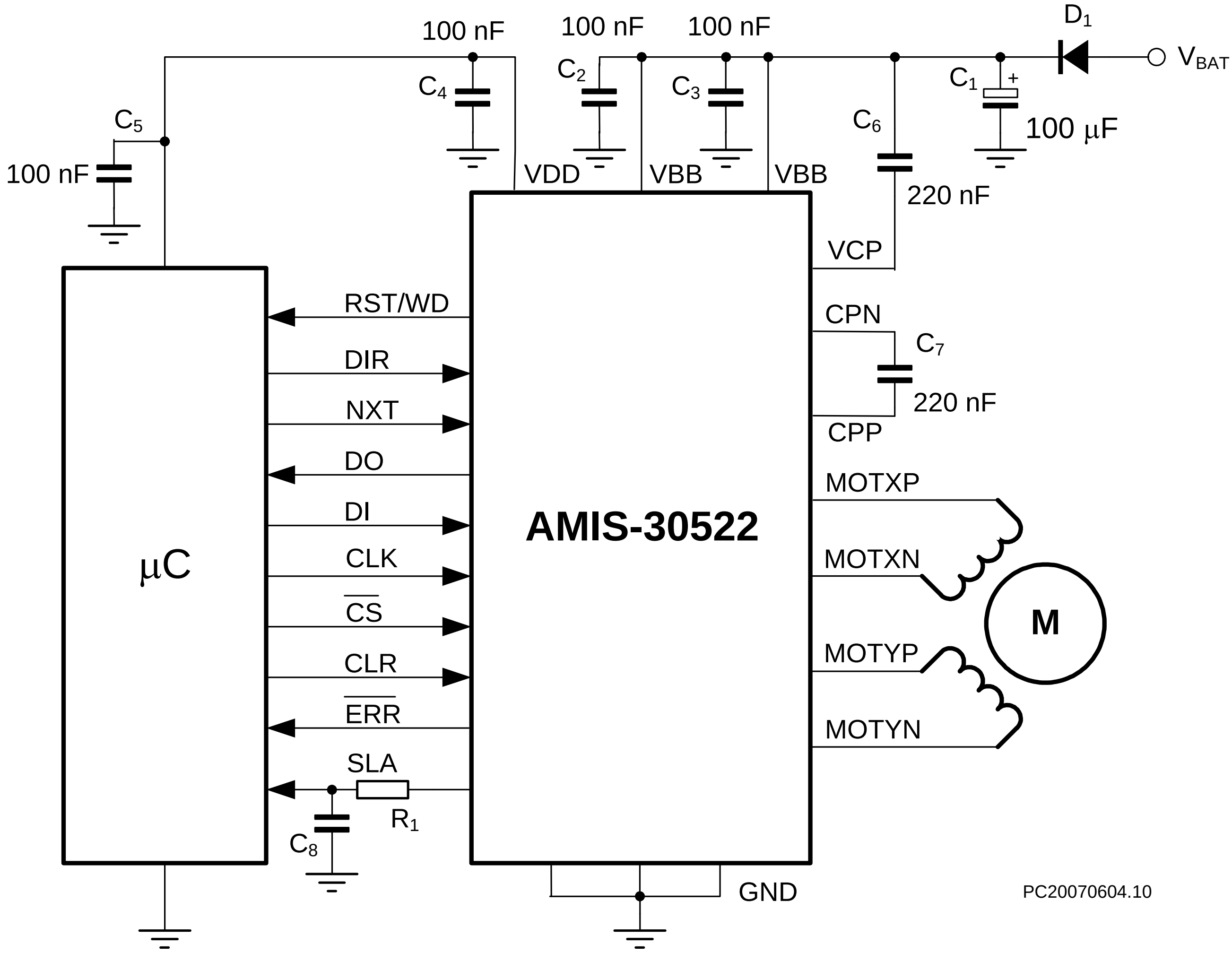

Figure 3: application diagram AMIS30522

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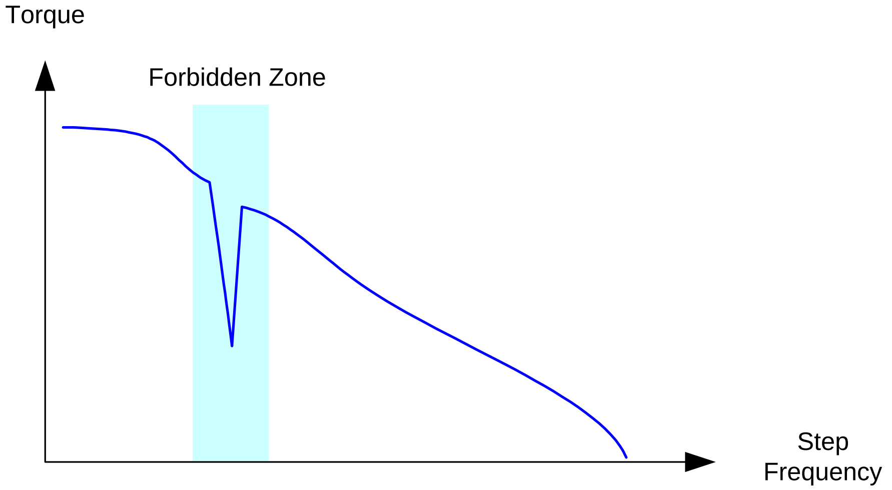

Figure 4: Forbidden frequency zone

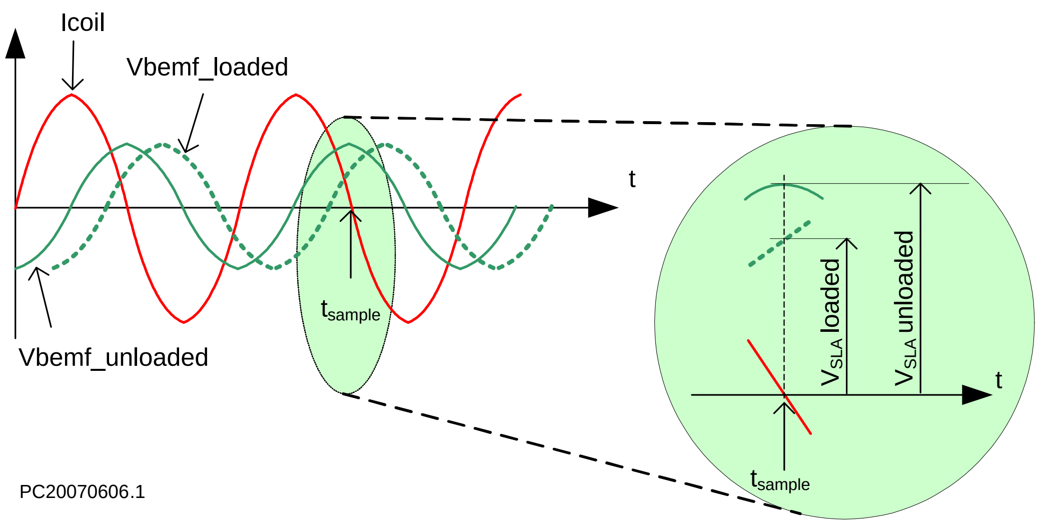

Figure 5: Load Angle

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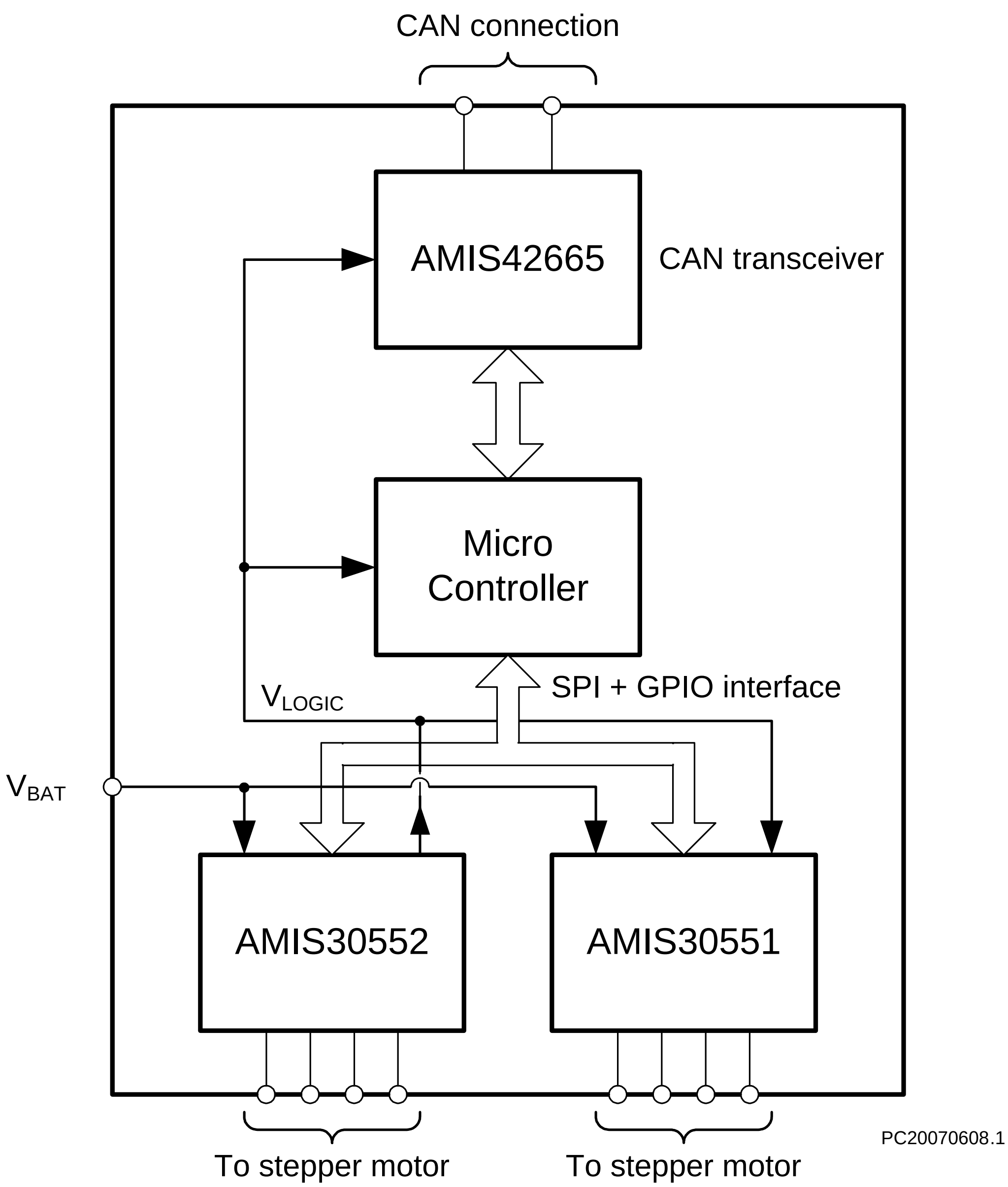

Figure 6: Application diagram CAN dual stepper.

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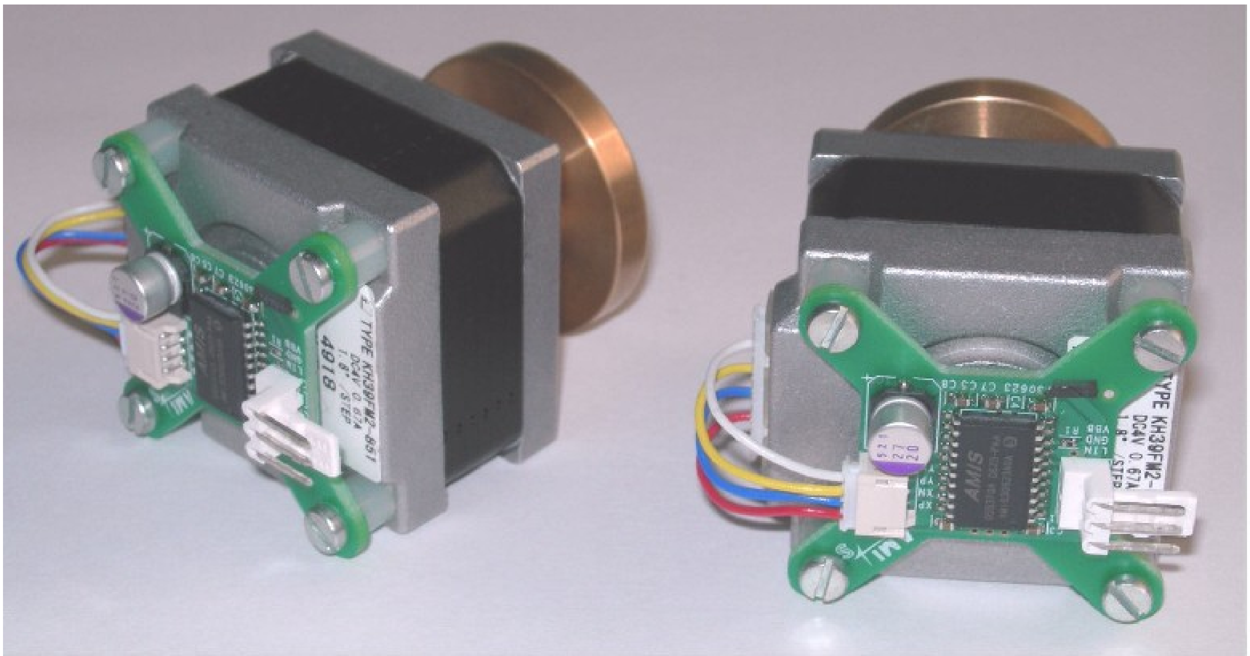
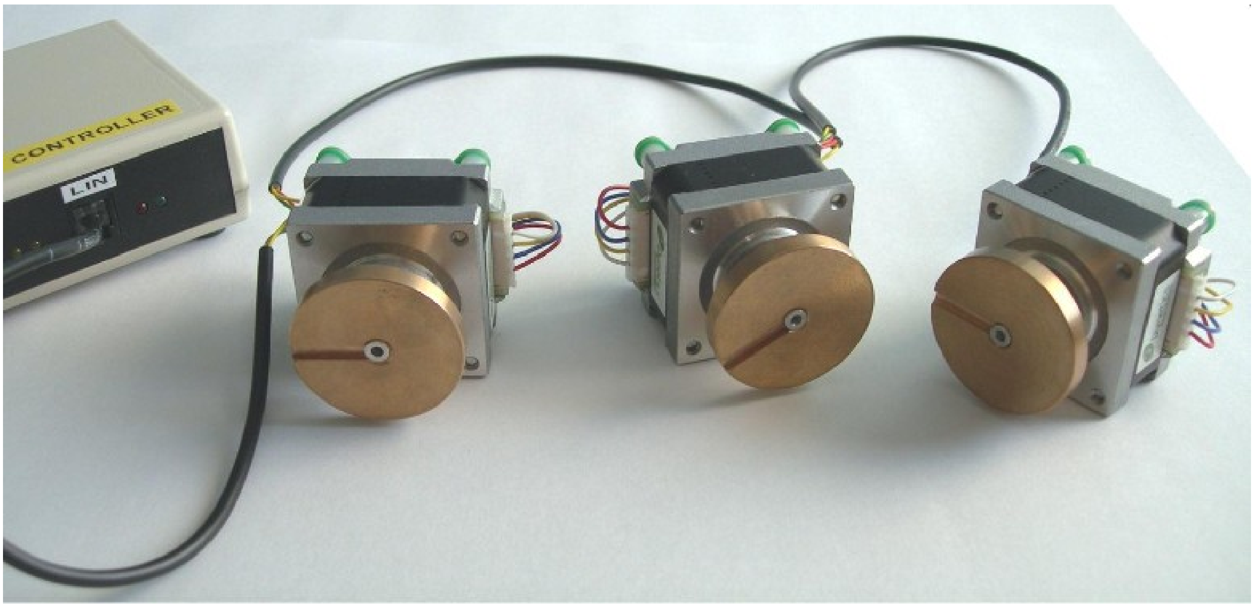


Picture 1: Example of Mechatronic solution



Picture 2: Driving 3 axes on one bus

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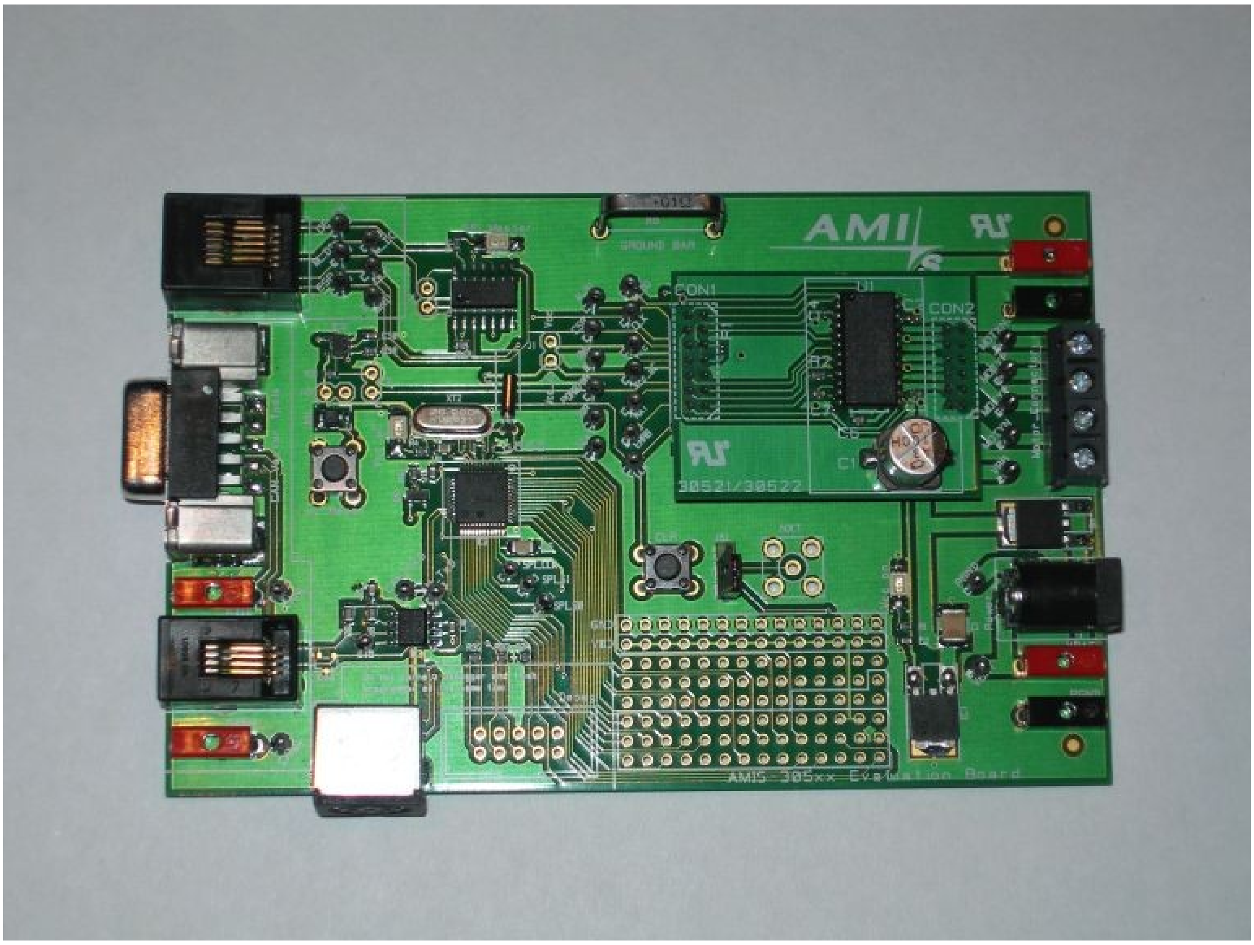

Picture 3 AMIS30521 and AMIS30522 evaluation board

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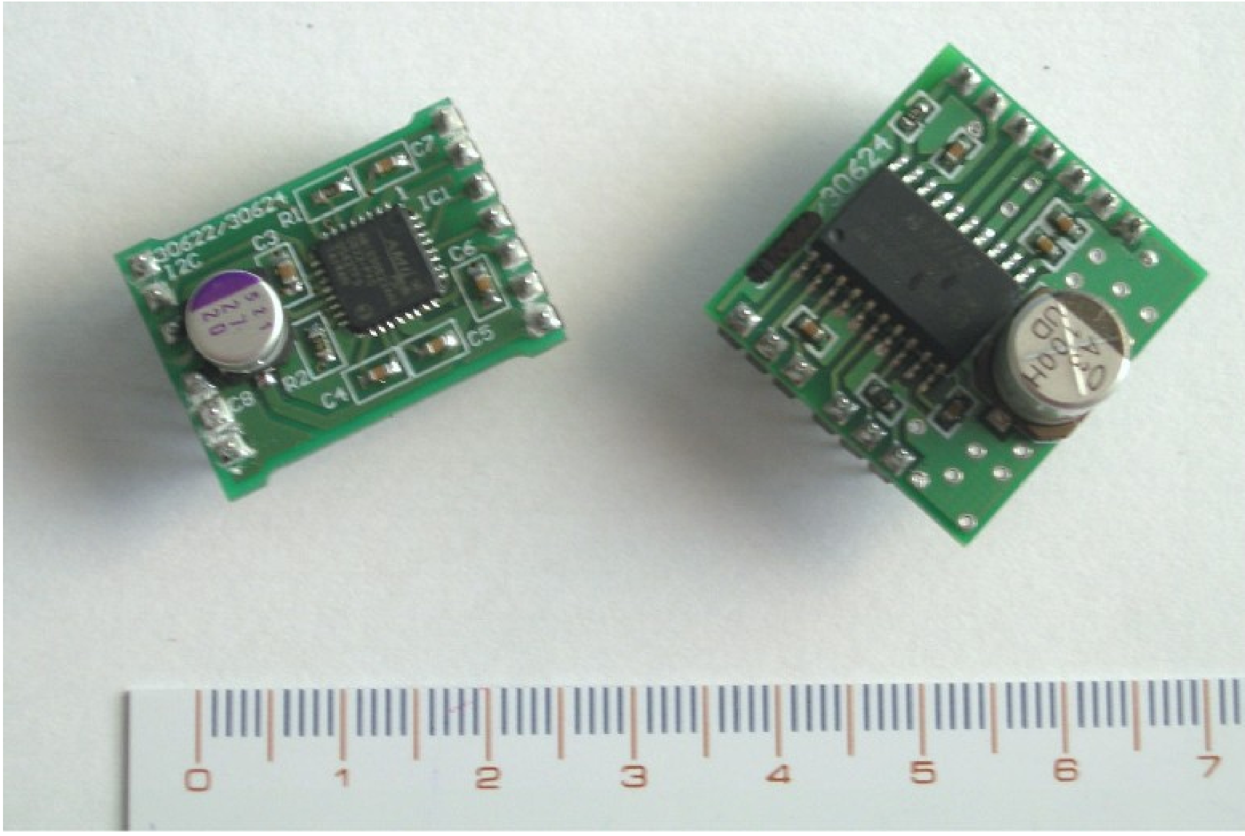

Picture 4: AMIS30624 stamps

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