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An application of programmable controller SIMATIC S7-200 in analogue systems of automation and measurement

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Abstract

Dynamic development in Programmable Logic Controller (PLC) technology has brought about the common use of this equipment in industrial systems of automation and measurement. One popular PLC group creates MICRO class controllers which are cheap but offer many possibilities. In most cases, these controllers are equipped with binary inputs and outputs only. For this reason, their use in analogue control and measurement systems causes certain difficulties. The current paper describes the adaptation of PLC MICRO class controllers with a binary system of inputs and outputs for use in analogue control and measurement systems by the implementation of pseudo-analogue input and pulse-width modulation (PWM)-type output. The current paper presents a detailed design of this type of adaptation for PLC SIMATIC S-7 CPU 222. A practical system was designed, built and tested in the laboratory. The results of tests for pseudo-analogue input and PWM-type output are included in graphic form. The limitations of the proposed solution and its areas of applicability in ship automation are presented.

Introduction

PLCs are now widely used in the design of various systems of automation and measurement. Their low price, compact housing and rich set of instructions have enabled their areas of application to range from simple binary systems (control of lighting, gates, irrigation of crops) to extensive distributed systems consisting of many controllers connected in a network and implementing comprehensive automation at department level or throughout a production facility (Sałat, Korpysz & Obstawski, 2010).

One very popular group of PLCs (given their low cost and wide programming possibilities) is the so-called MICRO class compact controllers. One of these, the SIMATIC S7-200, contains a type 222 CPU with only eight binary inputs and six binary outputs (Kamiński, 2000; SIEMENS, 2009).

Programming applications for the SIMATIC S7-200 can be built using the STEP 7 Micro/WIN software pack (SIEMENS, 2009). Although this software contains function “PID”, the construction of a control system with the use of such controllers causes certain difficulties. The lack of analogue input makes it impossible to measure the system and deliver the value of the controlled quantity to the controller in the form of voltage or current signal. The presence of binary outputs only in the SIMATIC S7-200 causes restrictions in the generation of output signal. Commonly used binary outputs can only be used to form slow-varying impulse signals with a duration time of no longer than one controller-operated cycle (SIEMENS, 2009; Sałat, Korpysz & Obstawski, 2010).

The rich library of instructions of SIMATIC S7-200/CPU 222 makes it possible to solve both the problems connected with the physical limitations of inputs and outputs. One of the methods by which a simple PLC of the MICRO class can be adapted to work in an automatic control system is by using a pseudo-analogue input based on a high-speed counter (HSC) function and the configuration of binary output as pulse-width modulation (PWM) output (GE Fanuc Automation, 1996; SIEMENS, 2009; Sałat, Korpysz & Obstawski, 2010).

The current paper presents the adaptation method by which the SIMATIC S7-200/CPU 222 controller can act in an automatic control system. The action principle, schematic diagram, controlling software and results of laboratory tests on a built system are described.

High-speed counter application in the construction of the pseudo-analogue input of a SIMATIC S7-200/CPU controller

The majority of contemporary PLCs of the MICRO class are fitted with additional non-standard functions, extending their abilities. These include an HSC function and other functions connected with one kind of binary output, namely PWM (SIEMENS, 2009; Sałat, Korpysz & Obstawski, 2010).

HSCs enable the counting of the number of pulses appearing at the input at intervals of less than the duration time of one controller-operated cycle (SIEMENS, 2009). The SIMATIC S7-200/CPU controller contains four HSCs, numbered 0, 3, 4 and 5. The software interrupts are used to control HSCs. For the controller under consideration, the CPU 222, the list of interrupts consists of twenty-five items divided into three groups: interrupts from the communication port, interrupts from inputs/outputs and time interrupts (SIEMENS, 2009).

The time interrupt was applied in the building of a pseudo-analogue input. It is generated cyclically with a period in the range of 1 m to 255 ms and a resolution of 1 m. The interrupt transfers control the defined procedure of interrupt handling each time the predefined cycle time runs out. Therefore, the architecture of the pseudo-analogue input can be reduced to the serial connection of the current/frequency (*I*/*f*) or voltage/frequency (*U*/*f*) converter and the PLC (Figure 1).

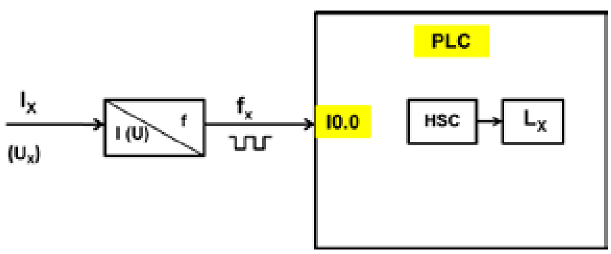

Figure 1. Architecture of the pseudo-analogue input

The input signal of the *I*/*f* or *U*/*f* converter, a rectangular wave of a frequency proportional to the value of the measured current or respective voltage, feeds the appropriate binary input associated with the HSC, which subsequently counts impulses during a window in the time domain defined in the interrupt handling procedure. The result of counting, the L_x number, is proportional to the frequency f_x and, therefore, to the measured value of current I_x or voltage U_x. The application of an *I*/*f* or *U*/*f* converter causes no significant problems. There are numerous simple in-assembly and cheap versions of such converters using popular integrated circuits such as LM 331 or LM 555 (Głocki, 2009). A slightly more expensive solution is the use of ready-to-use converters designed specifically for the input/output systems of PLCs. Typical examples of such converters are models 8505 and 8507 manufactured by the CALEX company and shown in Figure 2 (Calex, 2016).

Figure 2 Voltage/frequency converter 8507 and current/frequency converter 8501, manufactured by CALEX

Practical implementation of analogue input and PWM output with the use of a S7-200/CPU 222 controller

Following on from the remarks in the section above, a S7-200 controller was adapted to act in analogue systems of measurement and control by the application of analogue input and output with PWM. The diagram of the system's wiring is shown in Figure 3.

An analogue-frequency converter was used in the CALEX 8505 system (Calex, 2016), namely an *I*/*f* converter, changing the current signal within a range of 0.20 mA on the proportional output signal, and having the form of a rectangular wave

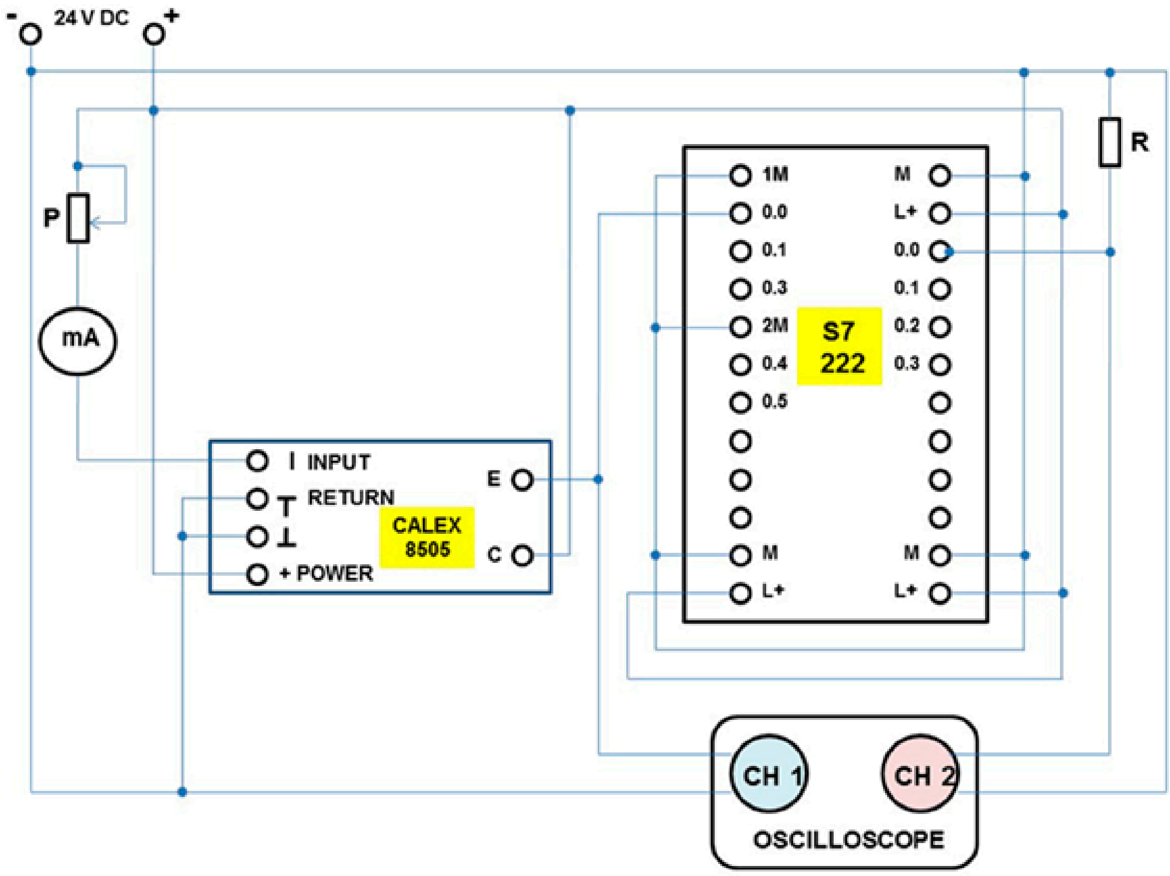

Figure 3. Analogue input and PWM output for a S7-200 controller – wiring diagram

with amplitude 24 V and frequency in the range of 0.5 kHz. The input analogue signal is delivered to the I (Input) terminal of the CALEX system. The output of this system (E) is connected to the binary input at address 0.0 of the S7-200 controller. The mentioned input is associated with the HSC and delivers information to the controller about the frequency proportional to the value of current *I*.

The binary output of the controller, having address 0.0, feeds resistance *R* with the PWM voltage signal.

The system also contains elements designed to set and measure, carry out possible tests and record measurement results.

Description of used software

The control programme for the PLC shown in Figure 3 was written with the use of the STEP-7 Micro Win environment. This environment consists of three main blocks: MAIN, HSC0_INIT and INT_TIME. Block MAIN, after initial settings, periodically reads *n* – the number of pulses counted by HSC0 during a declared period of 250 ms – simultaneously generating a PWM signal of a frequency equal to 1 kHz and of duty cycle proportional to *n*.

Block HSC0_INIT initiates the speed counter by executing the following tasks (SIEMENS, 2009):

- defining the counter and its operation mode;
- setting the control byte;
- setting the counter's initial state;
- setting the counter's final state;
- assigning and activating interrupt;
- activating the speed counter.

Block INT_TIME (INT1) handles time interrupt 10, counting a length of time of 10 ms.

All three of the above blocks were written with the use of a ladder diagram language and are presented in Figures 4, 5 and 6 respectively. Detailed comments are included with each diagram.

Description of MAIN block

Network 1. During the first cycle of scanning (SM 0.1), the subroutine of initiation HSC0_INIT is called once.

Network 2. Storing in register SMB34 the number 250 – the period of time interrupt calling (250 ms).

Network 3. Assignment of interrupt handling procedure to event number 10.

Network 4. Conversion of pulse number counted by speed counter (register VD110) to real number (register VD110) due to rescaling of counting result.

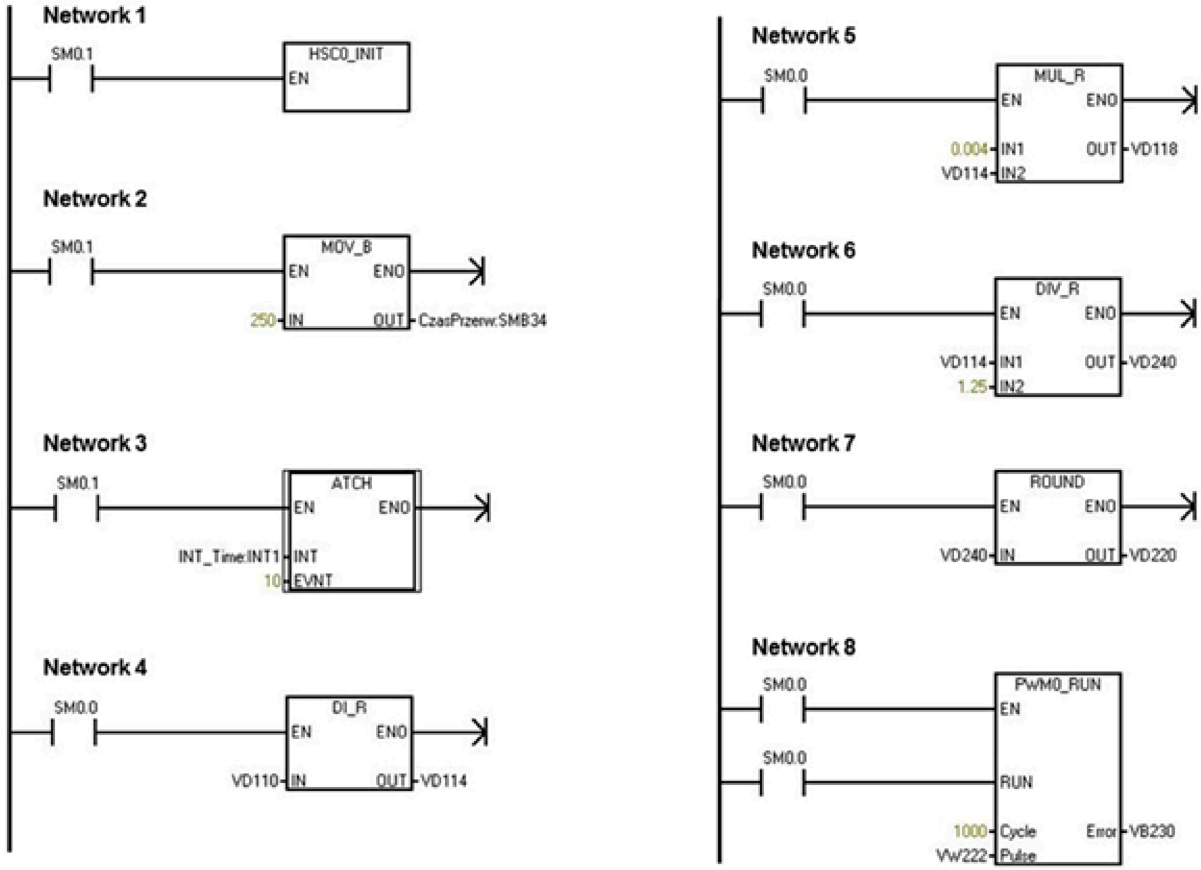

Figure 4. Diagram of MAIN block

Network 5. Determination of the instantaneous value of frequency (expressed in kHz) based on the impulse number by the HSC during a time of 250 ms.

Network 6. Changing the value of the input current (proportional to the number of counted pulses stored in register VD 114) to the number proportional to the duty factor of the PWM signal in such a way as to obtain value 1 for the maximal value of the input current equal to 20 mA.

Network 7. Conversion of duty ratio to integer number.

Network 8. Calling the procedure PWM0 with actual parameters:

- cycle duration 1000 microseconds;
- duration of the signal with a high logic level (register VW222). These are the two last bytes of variable VD220;
- Output – Q0.0.

The above procedure was created by Wizard as part of the STEP-7 instruction set.

Description of initiation of high-speed counter – HSC0 procedure

Using the software STEP-7 Micro Win version, the procedure described above can be created

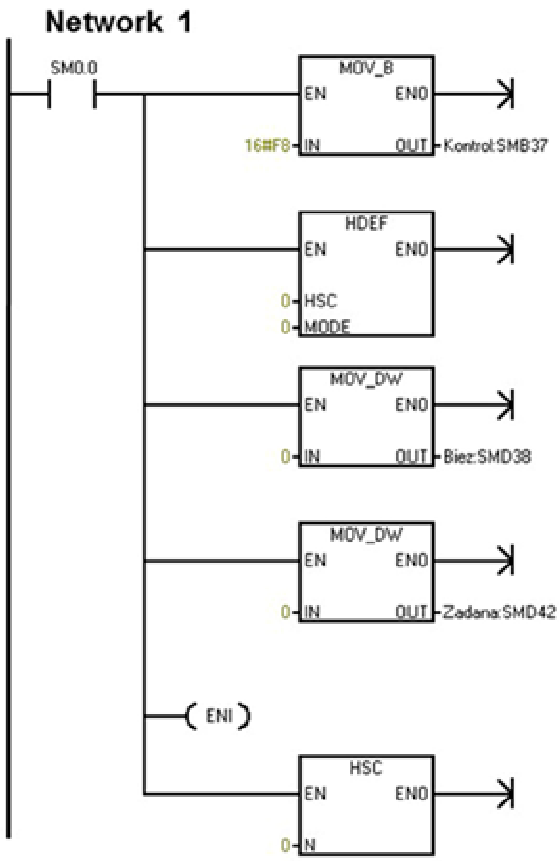

Figure 5. Initiation of high-speed counter – ladder diagram

by Wizard or be written according to the diagram shown in Figure 5.

Network 1

After each calling procedure, high-speed counter HSC0 is prepared for operation. The MOV_B statement loads number 16#F8 to the control byte cell addressed as SMB. The value of the mentioned number determines, among other things, the direction of counting as 'up'.

The HDEF statement defines the HSC with parameters HSC=0 (counter HSC0) and MODE=0 (input for counted pulses with address I.0.0, without inputs Reset or Start).

The second statement, MOV_DW, resets the current content of the double type CV of the HSC0 counter (SMD38).

The third statement, MOV_DW, loads the preset value PV to the SMD42 register. The value can be zero because the programme does not use interrupts from HSC0, but time interrupts.

The ENI relay unlocks all interrupts.

The last statement, HSC with parameter N=0 (start of HSC0), ends the procedure of HSC initiation.

Description of INT-Time interrupt handling procedure

The structure of the INT-Time interrupt handling procedure is shown in Figure 6.

Each time during the periodical execution of the MAIN block that the time of 250 ms runs out and event number 10 is detected, the controller starts to execute the time interrupt handling procedure.

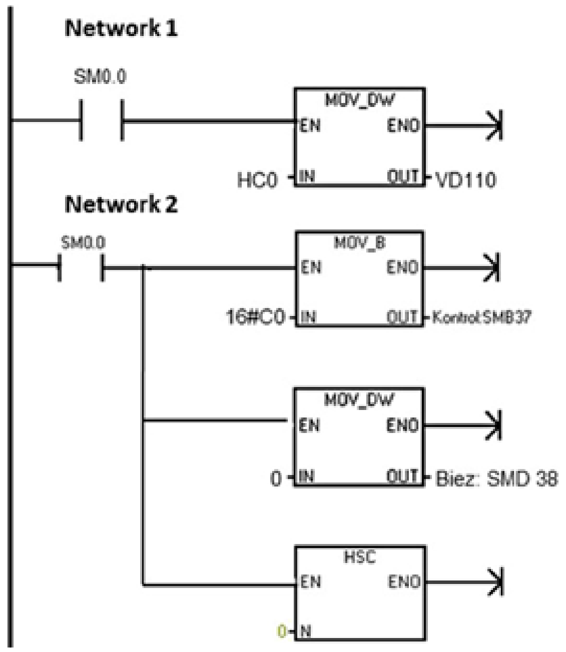

Figure 6. Interrupt handling procedure

Network 1

Statement MOW_DW with parameter HC0 copies the current value, SV, of the HC0 counter to a DOUBLE type memory cell, addressed as VD110. This number can be the subject of processing in the MAIN block.

Network 2

The MOV_B statement changes the content of control byte SMB37 to the new value 16#C0, which enables the storing of the new current value, CV.

Statement MOV_DW, with parameter N=0, stores the new current value in SMD38 register (counter reset).

The HSC statement with parameter N=0 copies the above data to the internal structure of the counter and restarts the speed counter HSC0.

Real-system laboratory tests

A real system was built based on the information given in the sections above. A diagram is shown in Figure 3. Laboratory tests determining whether it could be applied to analogue systems of automation and measurements were performed. For analogue input, the static characteristic showed dependence between the number of pulses N counted by speed counter and stored in variable VD110 of PLC, and input current I. The course of this characteristic is shown in Figure 7.

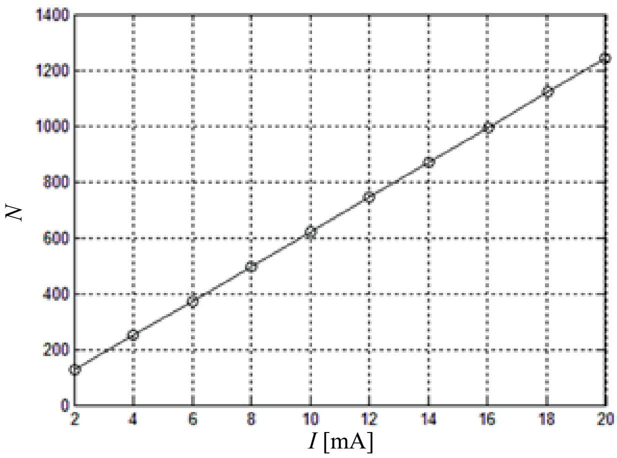

Figure 7. Static characteristic of pseudo-analogue input

In order to illustrate the action of a PWM output, the duty factor or output pulses K were software-dependent (block MAIN in section) from the value of current I, feeding the pseudo-analogue input ($K \sim I$). The recording of the output signal was performed with the use of an oscilloscope for the following values of current I: 4 mA, 8 mA, 12 mA and 19 mA. The oscillograms are presented in Figure 8.

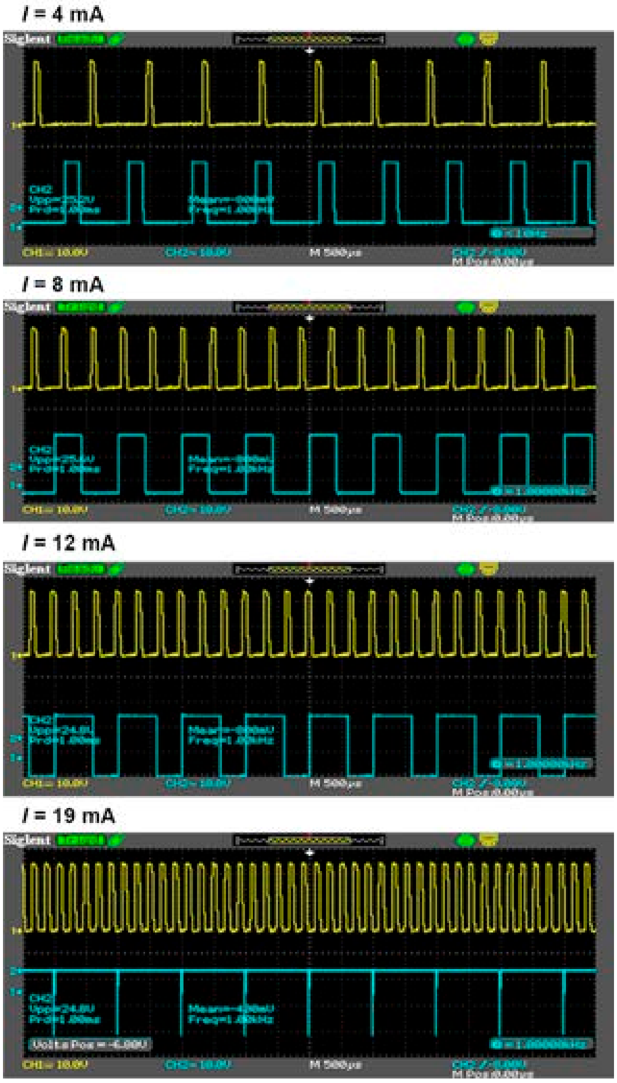

Figure 8. Oscillograms of the PWM output

The output PWM signal was recorded in channel #2 (lower part of figure), whilst the output signal of the CALEX converter was recorded in channel #1 (upper part of figure).

Conclusions

This paper has discussed the problem of applying the PLC MICRO class to the construction of a continuous system of control and measurement. Among the possible solutions is the use of a pseudo-analogue input based on a speed counter HSC and a configuration binary output in PWM mode. For this purpose, a practical system containing a PLC SIMATIC S7-222 was built and tested. The current paper presents the detailed design of the system and the results of laboratory tests in graphic form. The linear static characteristic of the input was observed in the range of current 4 to 20 mA, which allows the proper functioning of the majority of typical measuring transducers. The dynamic properties of input are determined by the cycle duration of the time interrupt of the speed counter HSC, equal to 250 ms in the case of the PLC used, which corresponds to a sampling frequency of 4 Hz, which is fully satisfactory for the measurement of non-electrical signals occurring in the engine room (i.e., temperature, pressure, level of liquid).

A PWM signal generated by the PLC output (Figure 8) can be used to direct control of such actuating devices as valves, shutters or heaters. The output signal can be adapted to the dynamics of the actuator by means of the software selection parameters of the PWM. When the actuator must be controlled by a continuous signal, the conversion of the PWM to a continuous signal can be performed by the use of a low-pass filter.

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