PWM DC MOTOR REGULATOR IC WITH EXCELLENT EMC BEHAVIOR

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Abstract: This is an introduction to the AS8410 control IC and associated device modules for PWM DC motor control. This IC enables equipment manufacturers to combine two features of electronically controlled DC motors, which were previously considered incompatible: High power efficiency (>95 %) and minimal electromagnetic radiation, to include the high frequency range (RF emission significantly below VDE0871, VDE0875, VDE0879 standards) with high PWM frequencies.

Extensive load failure diagnosis and error processing routine, as well as easily programmable operating modes, provide secure and low-cost application over a spectrum of DC motor control application.

Integrirano vezje za PWM regulacijo DC motorja z izvrstno EMC skladnostjo

Ključne besede: motorji električni, DC motorji na tok enosmerni, krmiljenje motorjev, regulacija motorjev, PWM regulatorji modulirani impulzno širinsko, AS8410 IC vezja integrirana, EMC kompatibilnost elektromagnetna, izvedbe na enem chip-u, tehnologije visokonapetostne

Izvleček: V prispevku je predstavljeno integrirano vezje AS8410 proizvajalca AMS za PWM regulacijo DC motorja. To integrirano vezje omogoča uporabnikom kombinacijo dveh lastnosti, ki sta pri elektronsko krmiljenih motorjih do sedaj bili nekompatibilni: visok izkoristek moči (>95%) in minimalno elektromagnetno sevanje zlasti na področju visokih frekvenc (RF sevanje občutno pod standardi VDE0871, VDE0875 in VDE0879).

Možnost nadzora in analize odpovedi bremena, rutina za obdelavo napak, lahko programljivi načini dela omogočajo varno in ceneno uporabo tega integriranega vezja v široki paleti regulacijskih elektronik za krmiljenje DC motorjev.

Motivation

The principle of DC motor speed or power/torque control and regulation through a pulse-width modulated electronic switch is not new. Such switch operation produced the desired motor speed-torque control, but caused electromagnetic emission of significant amplitudes in a wide, mainly high frequency range, making an obstacle to its wide application. It also prevented application in EMC-sensitive environments (e.g. automotive applications near other interference-sensitive electronic systems like car radio, airbag, etc.) or required additional, economically questionable shielding procedures. In such cases, exclusive analog motor control has been used, which holds the great disadvantage of poor power efficiency (high dissipation in the power regulating transistor).

The tremendous demand for energy-saving, convenient, environment-friendly (low-noise, EMC-conform) and cost-effective devices for electric motors with variable (controlled) speed and/or speed-torque has resulted in world-wide R&D activities of considerable expenditure.

These developments match the increasing use of brushless, electronically commutated motors. To reach a broad, low-cost electronic control systems are absolutely necessary for these motors.

We developed our standard product AS8410 and the associated modules for DC motor regulators (voltage regulators) with PWM control. On one hand, this allows the advantage of pulse control without the disadvantage of high interference emission, and on the other hand, provides a low-cost device for a broad application spectrum (for motors power-rated from a few watts to several kilowatts in different operating modes with comprehensive load diagnosis and error processing mechanisms).

The AS8410 realization was also designed to generally enable PWM control of inductive loads and/or inductance-affected loads (e.g. switch regulators) with very good EMC behavior. Since automotive field application was planned from the very beginning, all requirements for 12V or 24V direct system operation had to be met (load dump, burst and surge impulses on the battery supply, EMC susceptibility, minimal RF emission, broad supply voltage range, low current consumption, automatic sleep mode, etc.)

System solution and EMC- conform operation

The AS8410 is made with analog/digital CMOS (BiCMOS) high-voltage technology (2) and delivered in a standard SOIC16 package. The system concept realizes an ana-

log/digital (mixed signal) IC with primary analog functions. It contains a complete load regulator loop. Additionally, comprehensive load diagnosis and failure processing procedures, temperature and supply voltage monitoring and protection are integrated.

The AS8410 operates in a supply voltage range of V_{min} = 6V to V_{max} = 34 V (or 44V) enabling direct application to 12V or 24V automotive power supply. Operating temperature range: -40 °C to +125 °C.

The remarkable feature for achieving this good EMC behavior is the power (switch) transistor drive method. The power FET driver unit consists of fast current and voltage controlled current sources, and the control of these current sources through the instantaneous value of the on-load (motor) voltage (slew rate regulation). Finally, the motor performance rating (rated load current) is selected through the current control of these current sources (externally programmable), and the voltage control realizes the EMC-conform operation. With this application, the gate of an external power FET and the motor voltage time variation during the PWM motor voltage rise and drop is controlled by the motor voltage instantaneous value. In this way, the electromagnetic emissions of the entire control module are minimized and almost totally dissipate in the high-frequency range (Fig. 1). The exceptionally low emission levels, particularly in the high-frequency range, are clearly seen in Fig.1.

The motor regulator application does not require any filter devices.

The AS8410 system concept

The AS8410 forms a complete PWM DC motor regulator loop and consists of the following sub-blocks:

Set value input signal processing, generating the characteristic curve of the regulator (see Fig. 2), feedback value measurement (load detection at the high side of the motor), and a PWM generator (controlled by the set value and the actual motor current value) as well as the power FET gate driver. The control of the external power FET is effected by the special current controlled feedback sources described above. The control voltage is generated by an internal charge pump and is 10 V higher than the system power supply. The AS8410 requires only one supply voltage, which usually is the same as the motor supply, and ranges from 6V to 34V (V_{max} = 40V). Regarding the security concept, load failure detection circuits (over current, motor blocking, no load of the motor, or open wire, commutator and power FET short circuits) as well as over temperature and over or under voltage detection, are integrated. Additionally, a special circuit protects the power FET in generator mode of the motor (coast-down of motor due to mechanical inertia).

Sequence control is performed by a logic block, detecting systems status (failures, operating modes) and translating them into internal control signals and an external failure feedback signal (operating modus 1). See Fig. 2 for AS8410 system schematic.

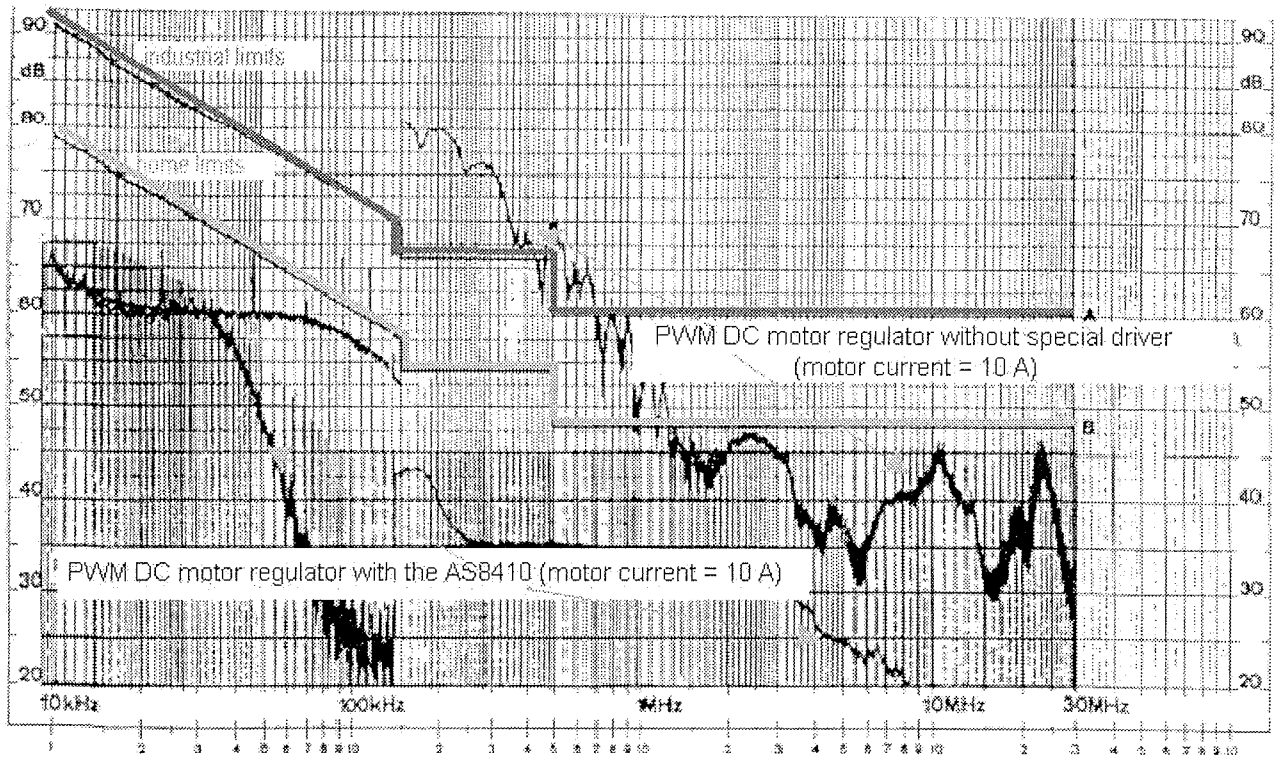

Fig. 1 Emission spectrum comparison - AS8410 controlled motor regulator versus a commercially available solution, showing much lower RF emission using a 10A rated motor current.

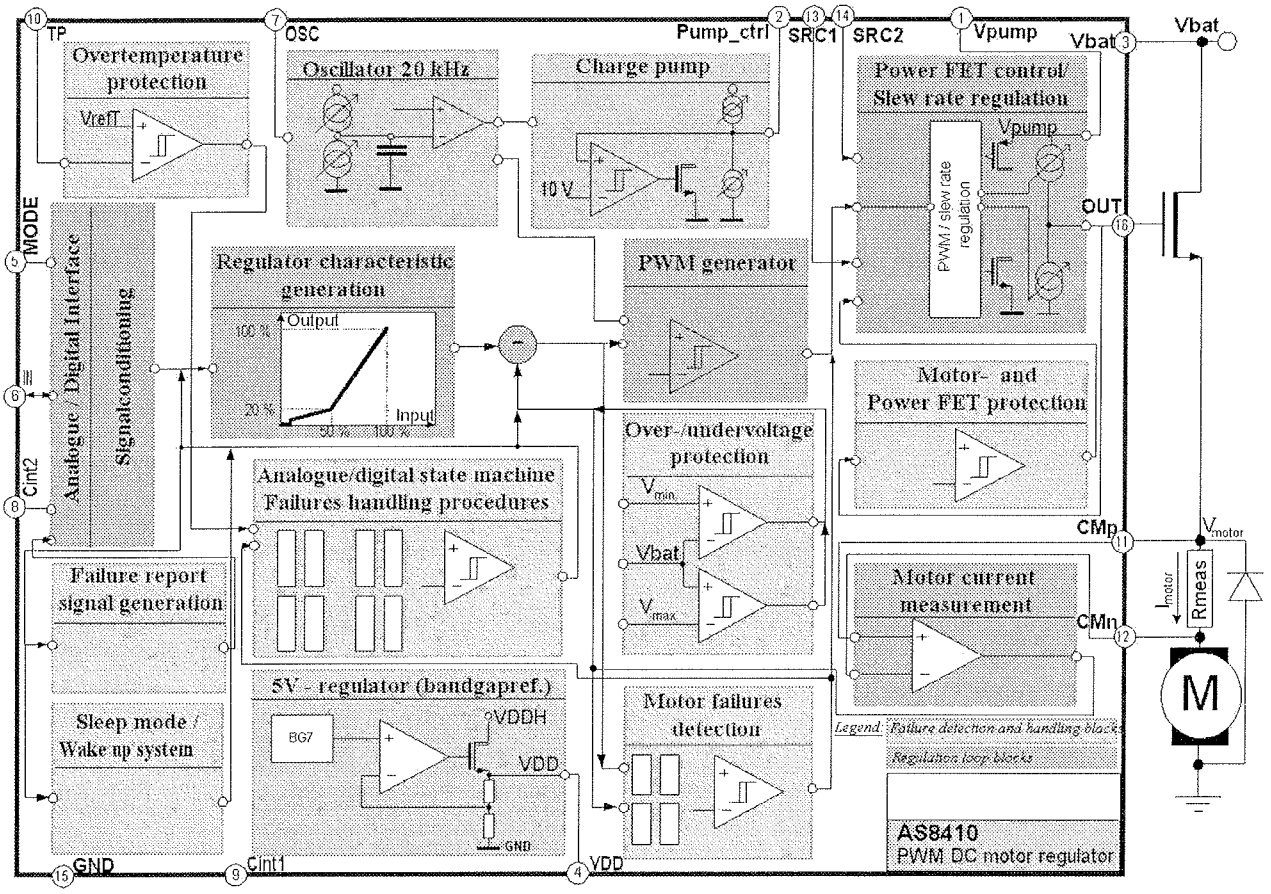

Fig. 2 Block diagram – AS8410 PWM DC Motor Regulator Circuit

Security concept

Another significant aspect in the system design of AS8410 was comprehensive failure diagnosis in the load circuitry (DC motor and power switch) and AS8410 self-controlled failure processing procedures (relieving the IC-controlling MP or IC application in systems without MPs). The AS8410 detects and treats various failure states of the power load circuit, returns a failure report signal to the set value pin, and performs an analog/digital failure processing procedure according to the type of failure.

Load circuit monitoring is performed by analog motor current measurement at the high side of the motor, and motor voltage mean measurement.

The following specified failures are diagnosed by the AS8410 in operating mode 1, and processed with analog/digital procedures by the IC itself:

1. Over current or short circuit of the motor.
2. No load of the motor (e.g. torn belt) or open wire.
3. Short-circuited power switch (power FET).
4. Mechanically blocked motor.
5. Short-circuited commutator (carbon brush clogging).
6. Protective function for the power FET and the AS8410 itself, when motor is in generator mode (during coast-down due to mechanical inertia).
7. Over or under voltage (supply voltage).
8. Over temperature.

Fig. 4 gives an example of some sequences of AS8410 internal events during an analog/digital failure processing procedure.

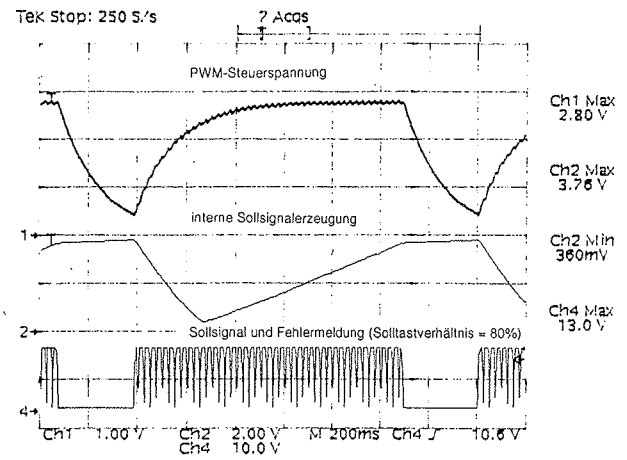

Fig. 4 Example of an AS8410 motor failure processing procedure.

The wide application range and main application properties

An additional aspect in the development of theAS8410 was its wide application scope. The following functional and parametric properties can be customized by simple programming with external devices:

1. Adapting to different DC motor power ratings is effected by programming the control currents at two analog pins. With this, control currents to the gate of the power FET-switch up to 300 mA can be delivered on chip, so that even high-performance FET's (or parallel power FET's for rated load currents in the >100A range) with effective gate source capacities of 10nF switching time down to 150 ns are possible (slew rate > 100 V/ms). Even with these short switching times, good EMC behavior is achieved by the edge-controlled drive. The short switching times allow relatively high PWM frequencies (presently 20kHz are realized) with a power efficiency of > 95 %. At the other end of the motor performance ratings, motors with rated currents in the mA range can be driven with the same properties.
2. The programming of different functional properties is realized by two additional pins (a digital pin and an analog pin):
   2.1. Set value input mode and temperature monitoring are set with the digital pin as follows:
      a) Operating mode 1: The set value (motor current or speed) is given as duty ratio of a low frequency PWM signal. The frequency of this signal is optional within a wide range (e.g. 10Hz, like the PWM output signal of many microprocessors).
      b) Operating mode 2: The set value is given as analog voltage in the range 0 - 5V at the same set value input pin.
      c) Temperature monitoring by an excess-temperature threshold, which is externally and analog programmable, with two different control modes in the case of over temperature:

      Operating mode 1 brings the motor current (motor speed) to 100 % of the rated value, if the temperature threshold is exceeded. This protects a system where dissipation is not produced by the controlled DC motor (e.g. overheated combustion engine fan-cooled by the DC motor).
      Operating mode 2 regulates the load circuitry for the system temperature not to exceed the threshold value (comparable to a thermostat). This protects a system where dissipation is produced by the controlled DC motor (or the switching transistor itself). In this case the motor output is brought down - independent from the set value - to a predefined temperature threshold value (this might even lead to a total DC motor shut-down).
      A special control was planned for cooling an overheated combustion engine (heat accumulation in a parked automobile): The DC motor regulator control is switched over from mode 1 to mode 2 with the ignition key. If the engine was overheated, the DC motor (cooling fan) starts operating in mode 2 after shut off with 100% PWM repetition rate, until the permissible temperature is reached.
   2.2. Within a wide option range, the regulator time constant can be set by the analog pin using a capacitor. A time constant in the seconds range, for example, enables soft regulating behavior, i.e. relatively slow motor speed increase or decrease toward the programmed set value.
3. In operating mode 2 the ASIC is automatically put in power-down mode through set values of < 4 % of the rated current (nominal speed). Current drawing is approx. 300 mA.

Despite its extensive programmability, the AS8410 has only 16 pins and is delivered in a standard SOIC16 package. This standard product is a successful, cost-effective bulk product.

The application circuitry in operating mode 1 and 2 is shown in Fig. 3.

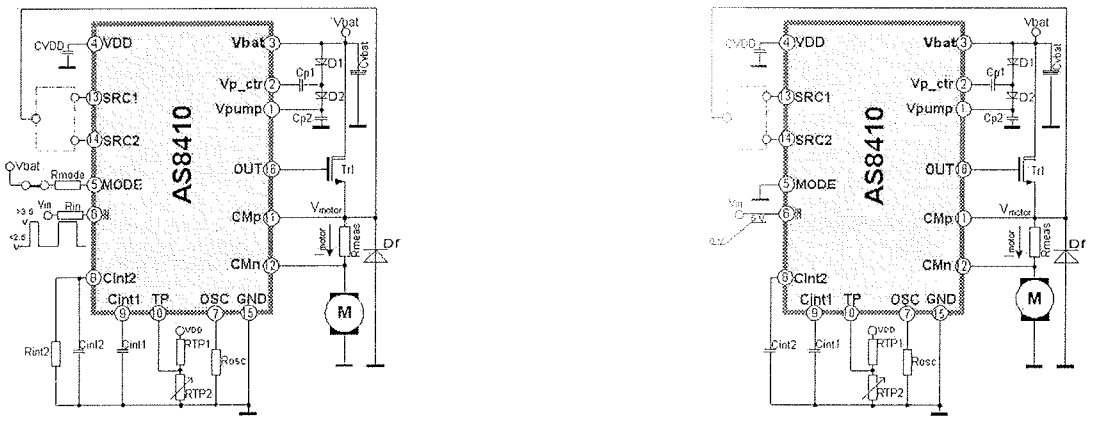

Fig. 3 Application circuits of the DC Motor regulator in operating mode 1 (left) and operating mode 2 (right)

The most remarkable property of DC motor regulator modules associated with the presented AS8410 is certainly the nearly RF emission-free (EMC complying) operation combined with high efficiency (>95 %) and relatively high PWM frequency (approx. 20kHz, which is beyond the audible range). This enables compliance with EMC regulations and application of PWM controlled DC motor regulators in electromagnetic sensitive environments (e.g. automotive field).

The low radiation susceptibility (> 300 mV) and the reliability of the control modules proved successful in their multiple automotive industry application.

The simple programmability for various rated DC motors, the entire security concept, and the operating modes have opened large application fields to the AS8410.

A glimpse of the future

The AS8410 in PWM DC motor regulators can now already be applied, wherever the described properties result in significant, cost-effective inherent utility increase, and favorable EMC behavior of DC motor-operated equipment (e.g. do-it-yourself machines, household appliances, automotive applications, variable speed and actuating drive units in automation systems, etc.). With this PWM control, DC-DC converters can also be applied (good EMC behavior).

Advance developments on the basis of the AS8410 deal with the system concept (e.g. brushless motor control, effective speed control, etc.), single system components, and motor control/regulator ICs with convenient µP interface and, on the other hand, control/regulator ICs that provide a single chip solution to the mass market of controlled DC motors.

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