AS 8446
Programmable PWM DC Motor Driver / Controller

DATA SHEET

Key Features

- Programmable PWM DC Motor Driver / Controller with µP Interface (Three Wire Interface)
- Programmable Functions and Parameters for Motor Current, Voltage and Speed Regulation
- Single Voltage Supply in the range Vbat = 6.0 V to 18 V (Vbat,max = 30 V)[1]
- Total Power Efficiency up to 96 %
- Low RF Emission within the whole frequency range due to an integrated special EMC optimized driver
- Dynamically self-adjusting slew rate regulated switching technology
- Fully protected by programmable failure handling procedures via µP
- Fast Over Current and Over / Under Voltage Detection and Protection, Battery Voltage Monitoring
- External and On Chip Temperature Detection and Protection
- Motor Current and Speed Measurement with a shunt resistor and capability of trimming the chip for an external shunt value
- Programmable Parameters:
  - EMC compliant Driver Functions
  - Over Current, Over / Under Voltage Threshold Values
  - Motor Failure Threshold Levels
  - Motor Current Measurement Range
  - Trimming for the current measurement shunt
  - PWM Frequency, Charge Pump Monitor
- Charge Pump to control high side drivers
- Integrated 5 V Power Supply for external components (µP, etc.)
- Standby and Wake-up capability
- Sleep / Wake-up Mode system controlled by the µP and the Wake-up Pin
- SOIC 28 Package

General Description

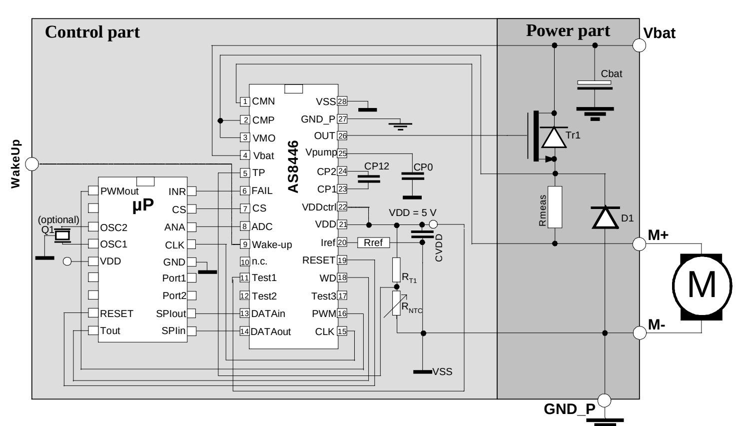
The AS8446 is a complete and fully protected PWM DC motor driver/controller, which can be implemented by interfacing a low cost 8-bit µP and a high-side N-channel power FET switch.

It is an advanced PWM DC motor controller subsystem with an excellent EMC behavior targeted especially for high current automotive applications. The optimization of the EMC behavior of the entire module only by software changes makes it easier to implement it in harsh environments.
The programmability of parameters and functions allows the adaptation of the AS8446 to a wide range of applications. So the system can act either as a motor current or motor speed or motor voltage regulator. Also a full diagnosis of motor failures and power FET failures, over temperature and over/under voltage can be formed by programmable failure handling procedures using the motor characteristic and the real time measured motor current, motor speed and battery voltage.

Applications

- Fan cooler
- Air conditioning
- Fuel pumps
- Water and oil pumps
- General purpose DC Motor Regulators

Typical Application Diagram



[1] Low-Batttery-mode between 6.0 V and 6.5 V

Functional Description

Overview

The AS8446 is a complex integrated circuit, which contains both low and high voltage circuitry to regulate PWM brush DC motors with an external n-channel power FET and an 8-bit µP. The regulation loop is a closed loop environment where a µP is connected to the device with a Three-Wire Interface. The AS8446 measures and delivers the motor current as an analog value to the µP. The µP uses a special algorithm to calculate the motor speed by considering the motor current as a function of time. This technique allows the system to act either as a **motor current** or a **motor speed regulator**. The AS8446 also monitors and delivers the battery voltage to the µP as an analog value and by leveraging this voltage-monitoring feature a **motor voltage regulator** could be implemented also. A full diagnosis of motor and power FET failures is performed automatically by the programmable failure handling functions after carefully analyzing the motor characteristics, real-time motor current, motor speed and battery voltage.

The dynamically self-adjusting slew rate regulated switching technology (patented) is one of the most important features of this ASSP in automotive applications. This technology enables two features of the PWM DC motor regulator, which were up till now impossible to realize:

- **Excellent EMC behavior (very low RF emission in the whole frequency range)**
- **High power efficiency up to 96 % @ f_{PWM} = 20 kHz (fall / rise time down up to < 150 ns)**

Most of the parameters (e.g. PWM frequency, slew rate, over current threshold, current measurement range, etc.) of the AS8446 can be programmed (setting up the internal registers) through the Three-Wire Interface, which makes the regulator a versatile and easily adaptable device to a wide range of regulation modes and motors.

The field programmability option of the slew rate regulation parameters makes it easier to comply with the system level EMC behavior (regulator board, motor, power cables, etc.)

A bandgap is used as a reference for a Low Drop Voltage Regulator with a nominal output voltage of 5 V.

This regulator is capable to deliver a supply current of up to 40 mA. Higher current is possible with an external bipolar transistor.

The device is bundled with a set of software to handle the regulation loop, motor speed measurement and failure detection. A sleep/wake up system is integrated to bring the AS8446 into a power save mode. It is controlled via the specified wake-up pin.

A short overview of the main features follows.

- programmable PWM DC motor current, speed or voltage regulator
- single voltage supply in the range Vbat = 6.0V to 18V (Vbat,max = 30 V)
- Low-Battery-Mode guarantees operation also when battery voltage is between 6.0V and 6.5V; In this mode the output driver is constantly on (100% PWM), Vpump-Vbat ≥ 4.0V.
- applicable directly to the automotive battery supply (burst, surge, load dump)
- closed loop regulation of the motor speed, motor current or motor voltage with a µP.
- high power efficiency of the whole regulator module (up to 96 % @ f_{PWM} = 20 kHz)
- low RF emission within the whole frequency range
- fully protected by programmable failure handling procedures (see below: Security Functions)
- fast over current and over / under voltage detection and protection
- motor current and motor speed measurement with only one shunt resistor (typ. measurement voltage at nominal motor current: 50 mV)
- on chip trimming capability of the external shunt resistor
- Sleep/wake up mode system controlled by the µP and the wake-up pin
- Three Wire Interface
- programming possibilities of the following regulator parameters inside of the AS8446:
  - PWM frequency (generated by µP, e.g. 20 kHz)
  - charge pump voltage monitoring and protection
  - slew rate control parameters (EMC behavior)
  - power FET Gate driver currents up to 500 mA
  - over current threshold level
  - over / under voltage threshold level
  - motor current measurement range and trimming of the external current measurement resistor
- programming possibilities of the following regulator parameters / functions via the µP
  - motor failure threshold levels (motor currents and voltages) for all motor failures: blocked motor, open wire, no load, shorted motor segments, etc.
  - failure handling procedures for all motor failures, over / under voltage and for over temperature (type of reaction and timing)
  - sleep mode criteria and sleep mode signal to the AS8446

- closed loop regulation timing with µP for speed, current and voltage control
- special features e.g. suppression of particular motor speeds, dynamical change of the over current threshold level, etc.

Security Functions

Extensive diagnosis of the DC motor and the power FET as well as failure handling procedures are programmable via a µP.

- over current detection and protection
- no load detection of the motor
- open wire detection (motor or power switch)
- short circuit of the power switch detection
- blocked motor detection and protection
- short circuited motor segments detection and protection
- protection of the power FET and the AS8446, if the motor works in generator mode
- battery voltage monitoring and over / under voltage detection and protection
- two over temperature detection and protection modes
  - external temperature sensor
  - on chip temperature sensor

Item (Start up values)	AS 8446
Over Voltage Threshold	40.0 V
Under Voltage Threshold	2.5 V
Minimum Charge Pump Voltage	4.0 V
Over Current Threshold (Shunt Measurement Voltage)	125 mV
Mode after Start up	sleep mode

Table 1 Start up values of the AS 8446

Pin Description

The AS8446 Motor Driver/Controller contains the driver/controller chip in a SOIC28 package
The complete PWM DC Motor Regulator board needs an additional µP to close the regulation loop and control the whole regulator (dual package solution, free choice of the controlling µP).

Pinout AS8446

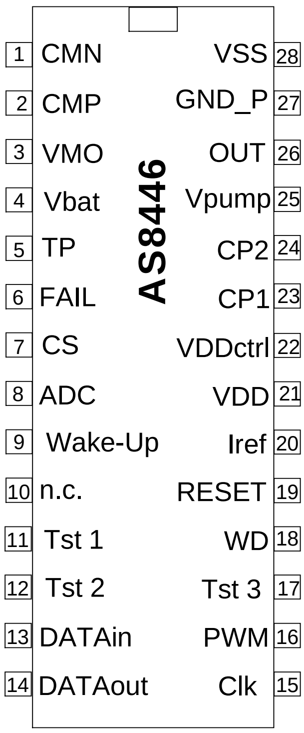


Figure 1 Pinout AS 8446

Pin Description AS8446, Pin Types

S ... power supply
AI ... analog in
AO ... analog out
AIO ... analog in/out
DI ... digital in
DIPU ... digital in with pull-up
DIPD ... digital in with pull-down
DO ... digital out
DIO ... digital in/out
DO_T ... digital out, tristate

LV ... low voltage
HV ... high voltage

Pin	Name	Type	Note
1	CMN	HV AI	Current Measurement Input (negative side)
2	CMP	HV AI	Current Measurement Input (positive side)
3	VMO	HV AI	Motor Voltage Input
4	Vbat	S	Battery Voltage, Main Supply
5	TP	HV AI	Temperature Sensor Input
6	FAIL	LV DO	Error Status Output of AS8446
7	CS	LV DIPU	Chip Select, Enable Pin of Three Wire Interface
8	ADC	HV AO	Analog Measurement Output (multiplexed)
9	Wake-up	HV AIO	Wake-up Pin
10	n.c.		
11	Tst 1	LV DIPU	Test Pin 1 (1)
12	Tst 2	LV DO	Test Pin 2 (2)
13	DATAin	LV DIPD	Data Input of the Three-Wire Interface
14	DATAout	LV DO_T	Data Output of the Three-Wire Interface
15	Clk	LV DIPD	Clock of the Three-Wire Interface
16	PWM	LV DIPU	PWM Input (Control of the Power FET Driver)
17	Tst 3	LV DO	Test Pin 3 (2)
18	WD	LV DIPU	Watch Dog Input
19	RESET	LV DO	Reset Output (controlled by Watch Dog)
20	Iref	LV AIO	Reference Current Pin
21	VDD	AI	VDD feedback input
22	VDDctrl	HV AO	VDD supply (5 V generated by the on chip voltage regulator)
23	CP1	HV AIO	Charge Pump Capacitor (Vbat side)
24	CP2	HV AIO	Charge Pump Capacitor (Vpump side)
25	Vpump	AO	Charge Pump Buffer Capacitor
26	OUT	HV AO	Power FET Driver Output
27	GND_P	S	Power Ground
28	VSS	S	Digital/Analog Ground

Table 2 PIN description of AS 8446

Note (1) Must be connected to VDD
Note (2) Must be left open

Block Diagram

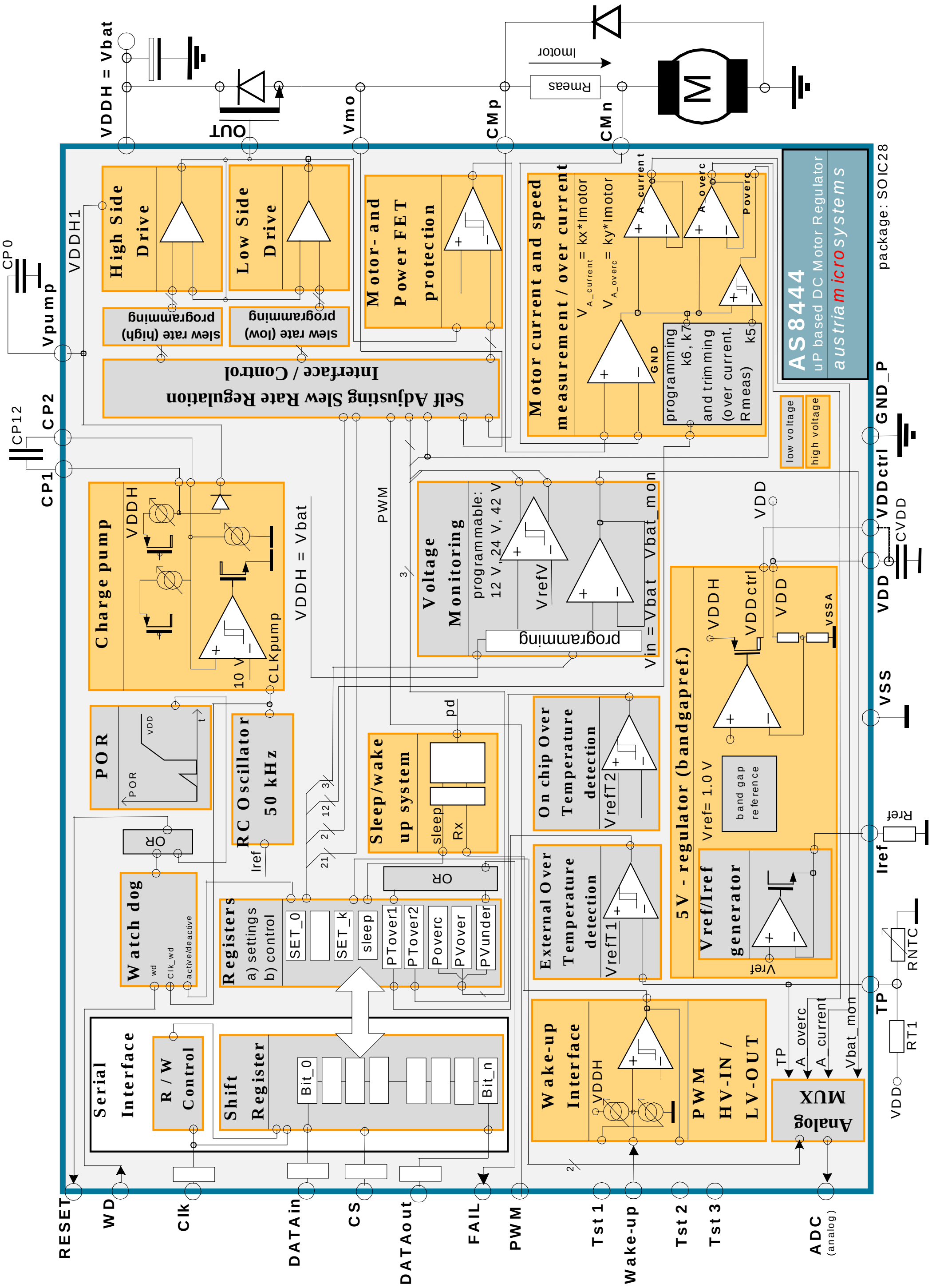


Figure 2 Block Diagram of AS8446

General Application Diagram

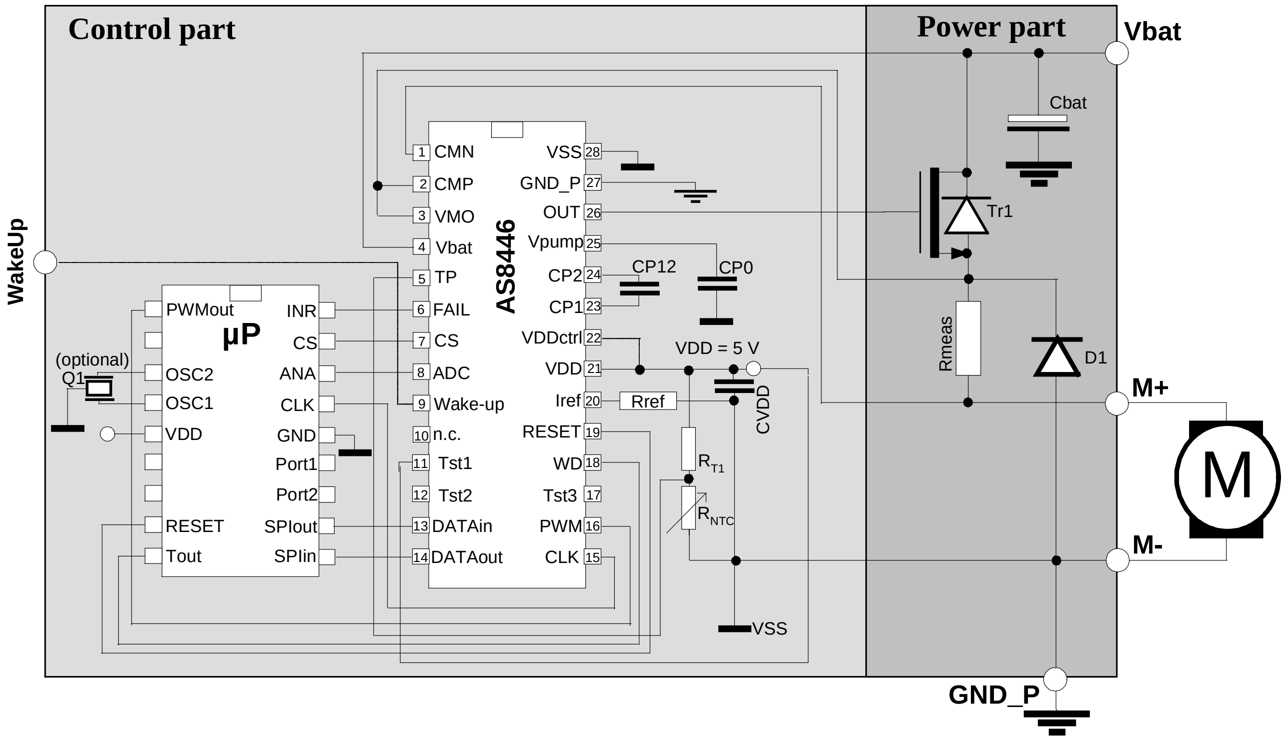


Figure 3 General Board Diagram of a complete PWM DC Motor Regulator

Remarks:

a) The communication between the AS8446 and the controlling µP is realized via the Three-Wire Interface

b) The communication of the whole motor regulator module with the environment can be realized in different ways:
   1. low voltage 5 V digital input using a digital µP port
   2. low voltage 5 V analog output using an analog ADC input of the µP

c) The EMC parameters to optimize the EMC behavior of the whole regulator system can be stored in the program of the µP and transmitted to the AS8446 via Three-Wire Interface during start up of the system.

d) The customer has free choice of the µP.

Absolute Maximum Ratings (NON OPERATING)

Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only. Functional operation of the device at these or any other conditions beyond those indicated under Operating Conditions is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Parameter	Symbol	Min	Max	Unit	Note
Battery voltage	Vbat	-0.3	30	V	(1)
Pumped voltage	Vpump	-0.3	44	V	
Low Power Supply Voltage	VDD	-0.3	7	V	
Input Pin Voltage (Low voltage pins)	Vin	-0.3	VDD+0.3	V	
Input Current (latchup immunity)	Iscr	-100	100	mA	125°C
ESD		-0,9	0,9	kV	Norm: MIL 883 E method 3015 (2)
Total Power dissipation	Pvtot		500	mW	
Junction temperature	Tj		150	°C	
Storage temperature	Tstg	-55	150	°C	
Humidity		5	85	%	Non condensing
Body temperature	TBody		240	°C	Norm: IPC/JEDEC J-STD 020 C
Note (1): Load Dump, 500ms, according to DIN40839 Note (2): Except for Pin 1 (CMN) and Pin 25 (Vpump): ESD = +/- 0,5 kV					

Table 3 Absolute Maximum Ratings

Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit	Note
Battery voltage (normal operating-mode)	Vbat	6.5		18	V	(1)
Battery voltage (Low-Battery-mode)	Vbat	6.0		6.5	V	Vpump-Vbat ≥ 4.0V; Vout = const. high; (2)
Pumped voltage	Vpump	Vbat + 4V	Vbat + 10V	Vbat + 14V	V	(2)
Low Voltage Power Supply	VDD	4.8		5.15	V	(2);(3)
Standby Current (power down)	I_pd1_{Vbat}			(50)	µA	Tamb < 27 °C; (4)
Standby Current (power down)	I_pd2_{Vbat}			90	µA	Tamb < 125 °C; Vbat = 13.5V
Ambient temperature	Tamb	-40		125	°C	
Note (1): Jump Start: Vbat < 28V, 1 min, 1 pulse/h Note (2): Low Battery mode guarantees operation when the battery voltage is below 6.5V; In this mode the output driver is constantly on (100% PWM), Vpump-Vbat ≥ 4.0V at 250µA load on Pin OUT; the load current of VDD is limited to 2.5mA Note (3): Low Drop voltage regulator; 40 mA max. external load at VDD; higher current with external transistor possible Note (4): only as information. Will not be tested						

Table 4 Operating Conditions

Thermal Characteristics

Parameter	Symbol	Min	Max	Unit	Note
Thermal resistance from junction to ambient	Rth,ja		76.2	°C/W	free air, single layer PCB

Table 5 Thermal Characteristic

Characteristics for Analog and Digital Inputs and Outputs

CMOS LV Digital Input

Pins: Clk, DATAin, CS, PWM, WD

Parameter	Symbol	Min	Max	Unit	Note
High Level Input Voltage	VIH	0.7 * VDD		V	
Low Level Input Voltage	VIL		0.3 * VDD	V	
Input Leakage Current	ILEAK	-1	1	µA	pull-up/down current for inputs with pull-up/down typ. 60µA

Table 6 CMOS Input parameters

CMOS LV Digital Output

Pins: RESET, DATAout, FAIL

Parameter	Symbol	Min	Max	Unit	Note
High Level Output Voltage	VOH	VDD -0.5		V	C_{LOAD} = 50 pF
Low Level Output Voltage	VOL		VSS +0.4	V	C_{LOAD} = 50 pF

Table 7 CMOS Output parameters

Analog Signals Input / Output

Pins: Vpump, CP1, CP2, OUT, CMP, CMN, VMO, ADC, TP, Iref

Parameter, Pin Name	Pin type	Symbol	Min	Typ	Max	Unit	Note
Charge Pump Voltage, pin: **Vpump**	HV S	Vpump	Vbat + 6 Vbat + 4	Vbat + 10	Vbat + 14	V	(1)
Charge pump switched capacitor voltage, pin: **CP1**	HV AIO	V_{CP1}	VSS		Vbat	V	
Charge pump switched capacitor voltage, pin: **CP2**	HV AIO	V_{CP2}	VSS		Vbat + 14	V	
HS driver source current, pin: **OUT**	HV AO	Iout_p	-500			mA	(2)
HS driver sink current, pin: **OUT**	HV AO	Iout_n			500	mA	(2)
Motor current measurement inputs, Common mode range, pins: **CMP, CMN**	HV AI	V_{CMP}, V_{CMN}	-1.5		Vbat	V	
Motor voltage input, pin: **VMO**	HV AI	V_{VMO}	-1.5		Vbat	V	
Analog measurement output voltage, pin: **ADC**	LV AO	$V_{A\_current}$	0		VDD	V	Multiplexed analog output (3)
External temperature sensor input, threshold voltage, pin: **TP**	LV AI	V_{TP_th}	0	0.5 VDD	VDD	V	Threshold voltage: VDD / 2
Reference current generation voltage, pin: **Iref**	LV AI	Vref		1.0		V	(4)

Note (1): external capacitors CP1/2 = 100 nF, CP0 = 400 nF recommended; on chip Vpump monitoring and protection: Vpump_min = (Vbat + 6 V) or (Vbat + 4 V), programmable

Note (2): typical rise/ fall time at the external Power MOSFET source: 0.2 µs to 0.5 µs, independently programmable rise and fall times, voltage range of the voltage V_{OUT} = 0 ... Vpump

Note (3): Multiplexed output (controlled by register R15<3:0> = ADC_CH, see section **Summary of all programmable registers (parameters, functions)** Full motor current measurement range corresponds to V_{ADC} = 4.0 V. **Multiplexed output must not be switched during operation!**

Note (4): regulated voltage Vref = 1.0 V, external resistor Rref = 22 kΩ must be connected to generate the 45 µA reference current. Use Pin Iref to connect Rref only.

Table 8 Analog signal parameters

Wake-up system

Parameter	Pin type	Symbol	Min	Max	Unit	Note
Low Level Input Voltage	HV AIO	V_{IL}	-8	0.4 * Vbat	V	
High Level Input Voltage		V_{IH}	0.6 * Vbat	Vbat	V	
Input Hysteresis		V_{HYS}	0.05 * Vbat	0.1 * Vbat	V	V_{IH} - V_{IL}

Table 9 Wake-up system signal parameter

Start up Behavior

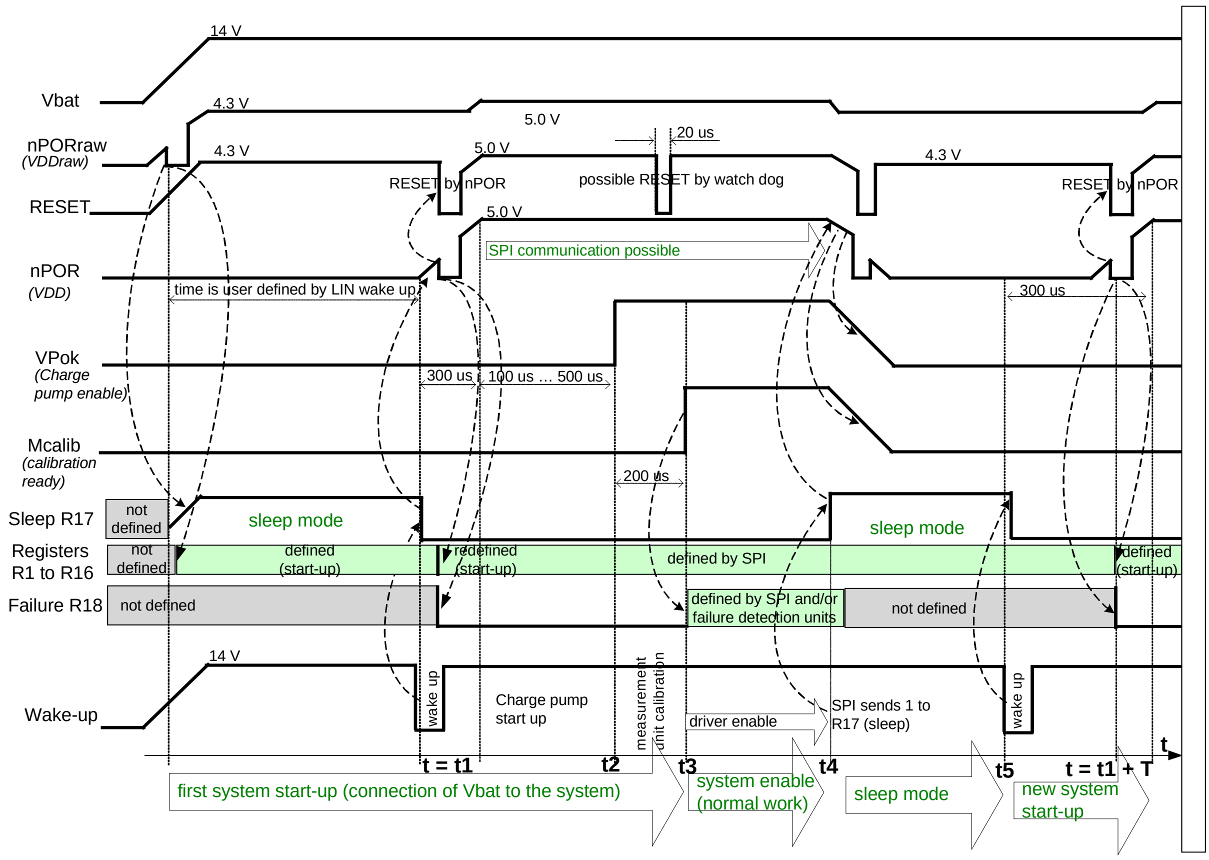


Figure 4 Start up and sleep mode behavior of AS8446 (simplified timing)

Programming Capabilities

There are in total 18 registers to program the behavior of the AS8446 via the Three Wire Interface

Register No	Register Name	Meaning
R1<4:0>	**SRon**	EMC parameter 1, rising edge
R2<4:0>	**SRon_stat**	EMC parameter 2, rising edge
R3<2:0>	**SRon_min**	EMC parameter 3, rising edge
R4<4:0>	**SRoff**	EMC parameter 1, falling edge
R5<3:0>	**Sroff_stat**	EMC parameter 2, falling edge
R6<1:0>	**Acu_on/off**	EMC parameter, rising and falling edge, multiplying factor 1 or 2
R7<4:0>	**AV_TRIMM**	Motor current measurement amplification (steps of 1.25%)
R8<1:0>	**AV_RANG_norm**	Motor current measurement amplification, normal measurement channel (large steps)
R9<2:0>	**OVERC_level**	Over current threshold value
R10<1:0>	**AV_RANG_over**	Motor current measurement amplification, over current measurement channel (large steps)
R11<2:0>	**VBAT_RANG**	Range of supply voltage (max. battery voltage to measure)
R12<2:0>	**OVER_VOLT**	Over voltage threshold value
R13<2:0>	**UNDER_VOLT**	Under voltage threshold value
R14<0:0>	**VPUMP_MIN**	Min. pumped voltage (Vpump – Vbat)
R15<3:0>	**ADC_CH**	Selection of one of the analog channel to be connected to pin ADC (Analog-MUX)
R16<0:0>	**WATCH_D**	Switch on or off of watch dog function
R17<1:0>	**SLEEP**	Switch on or off of sleep mode
R18<7:0>	**FAILURE_STAT**	Failure status register
Full descriptions of all registers see below.		

Table 10 Meaning of the AS 8446 registers.

Driver Programming (Slew Rate Regulation Parameters)

The Power FET driver is controlled in two different ways:

1. By the digital input PWM (output of the PWM generator of the µP) to realize the PWM duty cycle of the motor drive for regulating the motor current, speed or voltage in the closed loop.
2. By the dynamically self-adjusting slew rate regulated switching technology during the rising and falling edges of the motor voltage.

There are 6 registers to program the driving parameters in different time intervals of the rising and the falling edge of the motor voltage independently (definition of the time functions of the power FET driver gate currents in wide ranges):

Rising edge: registers R1<4:0>, R2<4:0>, R3<2:0> and R6<0>

Falling edge: registers R4<4:0>, R5<3:0> and R6<1>

These registers can be programmed via the Three-Wire Interface and thus the EMC behavior of the system (motor, power switches, cables) can be adapted and optimized to a particular application. Although the total rising and falling times are very short (t_{RISE} or t_{FALL} < 150 ns with driver currents to the power FET gate up to 500 mA), the RF emission (EMC) is very low.

See also section **Summary of all programmable registers (parameters, functions)**.

A detailed description of these programming and EMC optimization will be given in the application manual of the AS8446.

Rising edge (switch on): Programmable Gate Drive Source Currents (13 bit)

Register / timing part of rising edge	Programmable range			Programmable range			Unit	Note
	R6<0> = 1, Acu_on/off			R6<0> = 0, Acu_on/off				
	min	max	step	min	max	step		
R1<4:0> = SRon (V_{motor} = 12.7 V)	0	496	16	0	248	8	mA	R1 = 0, 1, 2, ... 31
R1<4:0> = SRon (V_{motor} = 30.7 V)	0	(1240)[1]	40	0	(620)[1]	20	mA	
R2<3:0> = SRon_stat	1.0	32	1.0	0.5	16	0.5	mA	R2 = 0, 1, 2, ... 15
R3<2:0> = SRon_min (V_{motor} = -0.5 V)	20	160	20	10	80	10	mA	R3 = 0, 1, 2, ... 7
Note (1): The total driver current I_{out_on} must be limited to 500 mA (I_{out_on} < 500 mA) in the real application with the given V_{motor_max} = V_{bat} by appropriate programming.								

Table 11 Programming of the slew rate parameters (rising edge)

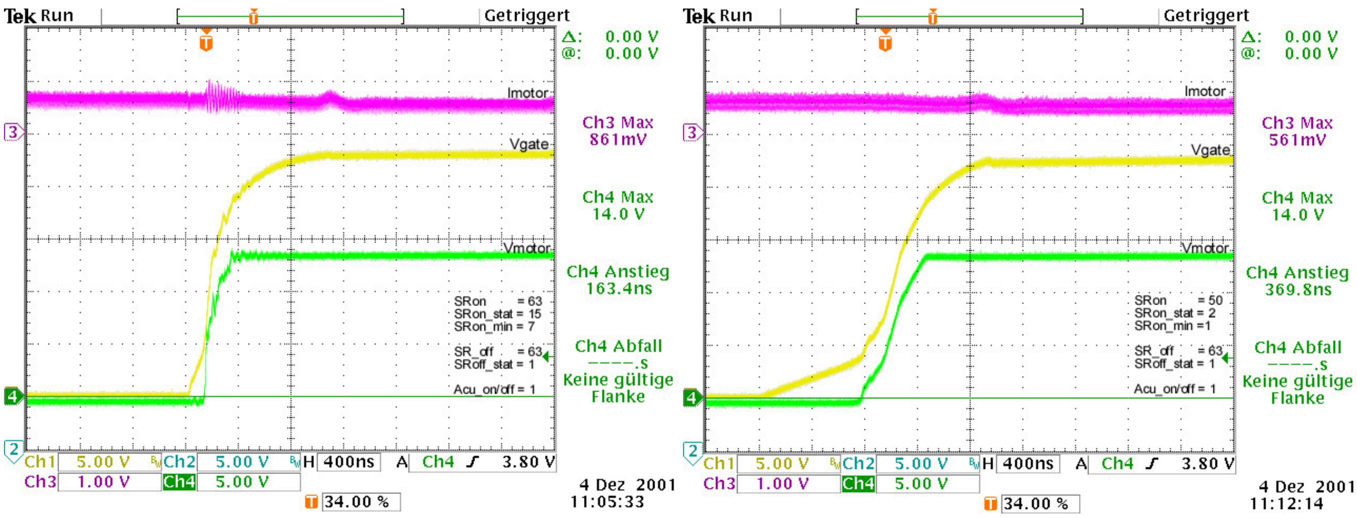


Figure 5 Rising edge of the motor voltage before and after the EMC optimization

Falling edge (switch off): Programmable Gate Drive Sink Currents (10 bit)

Register / timing part of falling edge	Programmable range			Programmable range			Unit	Note
	R6<1> = 1, Acu_on/off			R6<1> = 0, Acu_on/off				
	min	max	step	min	max	step		
R4<4:0> = **SRoff** (V_{motor} = 12.7 V)	0	496	16	0	248	8	mA	R4 = 0, 1, 2, ... 31
R4<4:0>, **SRoff** (V_{motor} = 30.7 V)	0	(1240)[1]	40	0	(620)[1]	20	mA	
R5<3:0>, **SRoff_stat**	1.0	32	1.0	5	80	5	mA	R2 = 0, 1, 2, ... 15
Note (1): The total driver current I_{out_on} must be limited to 500 mA (I_{out_on} < 500 mA) in the real application with the given $V_{motor\_max} = V_{bat}$ by appropriate programming.								

Table 12 Programming of the slew rate parameters (falling edge)

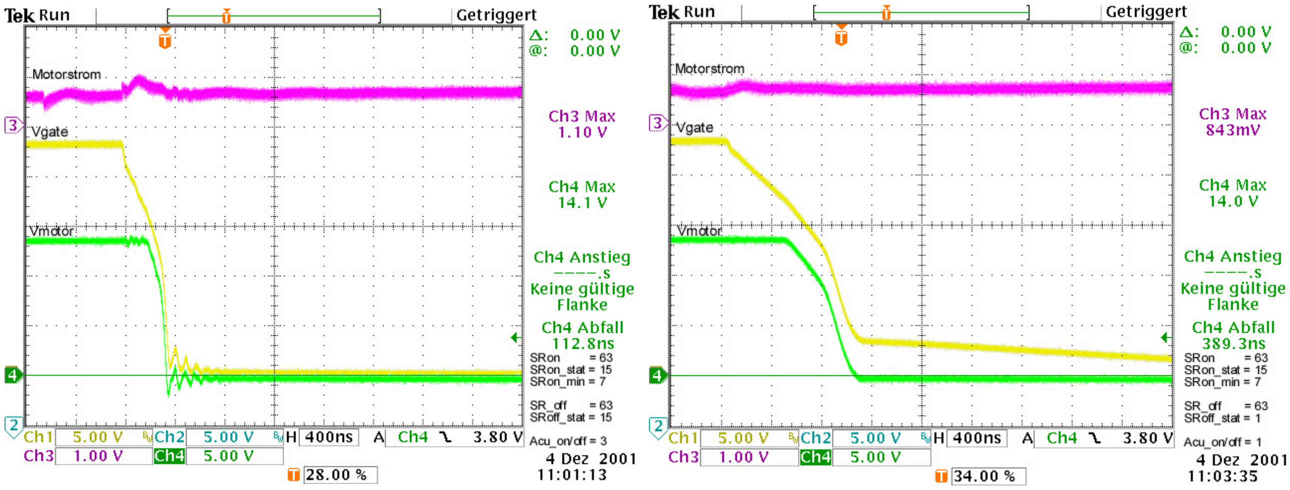


Figure 6 Falling edge of the motor voltage before and after the EMC optimization

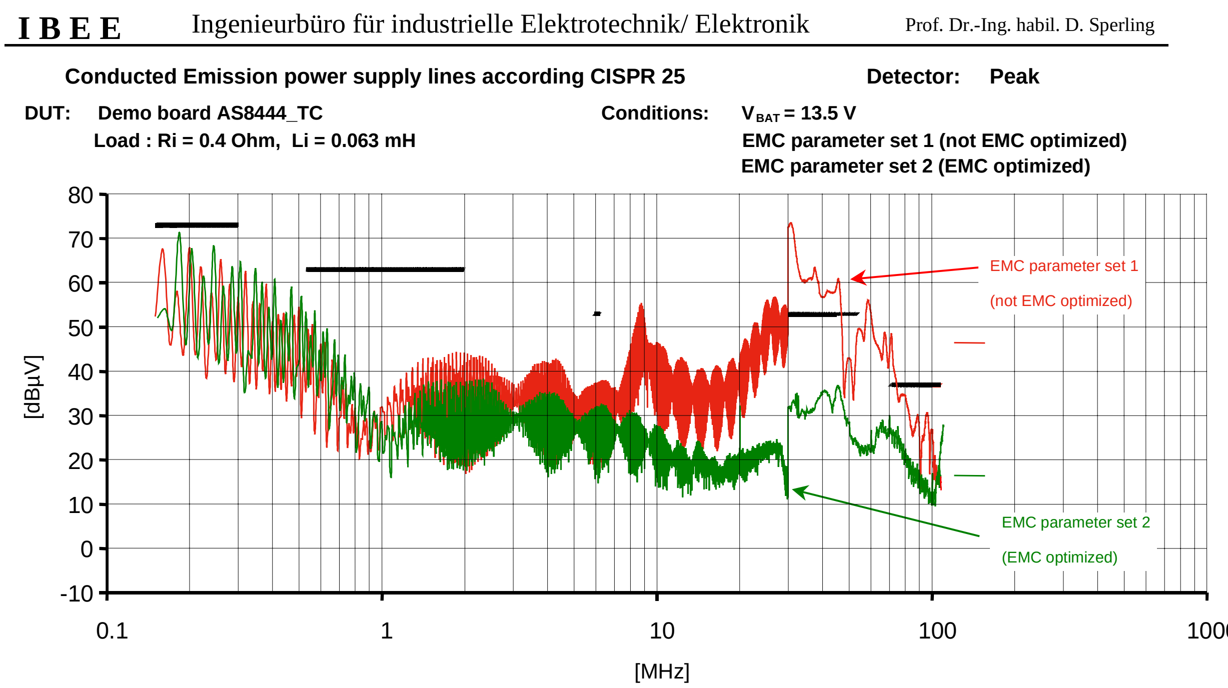


Figure 7 Comparison of the EMC measurement results of the same application with two different EMC parameter sets

Programming of the motor current measurement unit and the over current detection unit

The motor current measurement unit operates with an external current measurement resistor R_{meas} in the high side motor line. The chip has two measurement amplification channels with separately programmable amplification factors:

a) normal motor current measurement, channel 1
$AV_{meas\_norm} = V_{A\_current} / V_{meas}$ with $V_{meas} = (V_{CMP} - V_{CMN})$, analog output **A_current** (multiplexed to output **ADC**) and

b) over current measurement with extended measurement range, channel 2
$AV_{meas\_overc} = V_{A\_overc} / V_{meas}$, analog output **A_overc** (multiplexed to output **ADC**).

In general all programming possibilities in table 14 can be used to build up a measurement system in the defined limits. The programming words are sent from the µP via the Three-Wire Interface to the AS8446 during start up of the system. The typical value of $V_{meas\_nom} = (V_{CMP} - V_{CMN})_{nom}$ is 50 mV, corresponding to 100% of the motor current.
In the whole system the analog outputs **A_current** or **A_overc** are used by the ADC of the µP to regulate and control the system. There is only one exception: The over current detection and protection is realized directly by the over current measurement channel in order to act very fast in case of an over current situation e.g. short circuit of the motor.

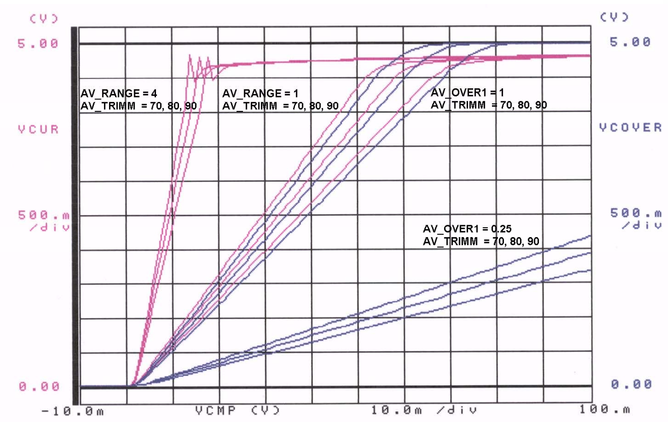


Figure 8 Programming examples of the current measurement channels

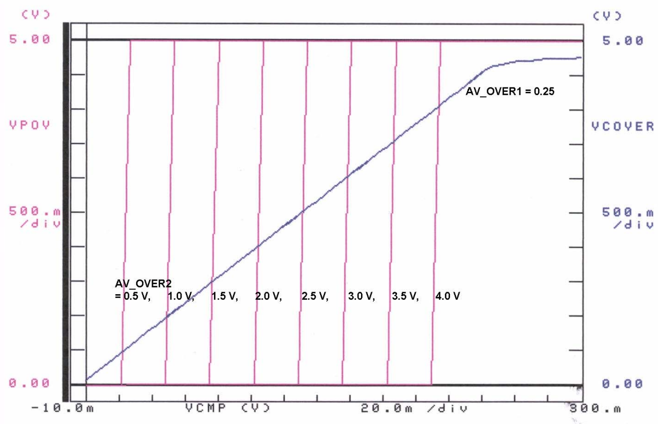


Figure 9 Programming examples of the over current detection

Figure 8 shows the programming of the normal current measurement channel (red lines, output voltage VCUR) and the over current measurement channel with extended measurement range (blue lines, output voltage VCOVER). The three lines with the parameters AV_TRIMM = 70, 80, 90 indicate the trimming range of the external measurement resistor (± 12.5 % in steps of 1.25 %). The total range of the normal measurement amplification is AV_{meas_norm} = 70 to 360 corresponding to input voltages V_{meas_max} = 11 mV to 57 mV. The total range of the over current measurement amplification is AV_{meas_overc} = 17.5 to 90 corresponding to input voltages V_{meas_max} = 44 mV to 229 mV.

Figure 9 shows an example of the programming of the over current threshold level (generation of the over current signal VPOV, red lines): AV_{meas_overc} = 20 and OVERC_level = 0.5 V to 4.0 V in steps of 0.5 V.
All programming possibilities are given in table 14 below.

Programming of the motor current measurement and over current detection unit

The motor current measurement unit transforms the differential voltage over the measurement resistor at the high side motor line (V_{CMP} - V_{CMN}) = Imotor * Rmeas to the ground related voltage $V_{A\_current}$ (channel1) and to the ground related voltage V_{A_overc} (channel2) with a programmable amplification.

Definition and programming of the voltage amplifications AV_{meas_norm} and AV_{meas_overc} of the motor current measurement unit:

a) channel 1: AV_{meas_norm} = $V_{A\_current}$ / (V_{CMP} - V_{CMN}) = AV_TRIMM * AV_RANGE_norm

b) channel 2: AV_{meas_overc} = V_{A_overc} / (V_{CMP} - V_{CMN}) = AV_TRIMM * AV_RANGE_over

Register No	Register Name	Meaning	
R7<4:0>	AV_TRIMM	Voltage amplification factor1 of the current measurement unit in small steps (trimming of the external current measurement resistor) for the normal and over current analog measurement output R7 = 0 → AV_TRIMM = 70 R7 = 1 → AV_TRIMM = 71 R7 = 2 → AV_TRIMM = 72 : R7 = 10 → AV_TRIMM = 80 (default value) R7 = 11 → AV_TRIMM = 81 : R7 = 19 → AV_TRIMM = 89 R7 = 20 → AV_TRIMM = 90 R7 > 20 → AV_TRIMM = 90	
R8<1:0>	AV_RANGE	Voltage amplification factor2 of the normal analog measurement output (A_current) R8 = 0 → AV_RANGE = 1 (default value) R8 = 1 → AV_RANGE = 2 R8 = 2 → AV_RANGE = 3 R8 = 3 → AV_RANGE = 4	
R9<2:0>	OVERC_level	Threshold value of the internal over current detection Def.: Vocmax = 4/5 * VDD (typ. 4.0 V) Vocstep = (4/5 * VDD) / 8 (typ. 0.5 V) R9 = 0 → OVERC_level = Vocmax (typ. 4.0 V) R9 = 1 → OVERC_level = Vocmax – Vocstep (typ. 3.5 V) R9 = 2 → OVERC_level = Vocmax - 2*Vocstep (typ. 3.0 V) R9 = 3 → OVERC_level = Vocmax - 3*Vocstep (typ. 2.5 V) : R9 = 7 → OVERC_level = Vocmax - 7*Vocstep (typ. 0.5 V)	
R10<1:0>	AV_RANGE_over	Voltage amplification factor2 of the over current analog measurement output (A_overc) R10 = 0 → AV_RANGE_over = 1 * 1/4 (default value) R10 = 1 → AV_RANGE_over = 2 * 1/4 R10 = 2 → AV_RANGE_over = 3 * 1/4 R10 = 3 → AV_RANGE_over = 4 * 1/4	

Remark 1: The maximum of the valid analog output voltage of the outputs A_current and A_overc must be 4.0 V.

Remark 2: The total voltage amplification of the current measurement unit is determined by
normal current analog output A_current: AV_{meas_norm} = $V_{A\_current}$ / (V_{CMP} - V_{CMN}) = AV_TRIMM * AV_RANGE
(default value: 80)
over current analog output A_overc: AV_{meas_overc} = V_{A_overc} / (V_{CMP} - V_{CMN}) = AV_TRIMM * AV_RANGE_over
(default value: 20)

Remark 3: The external current measurement voltage over the measurement resistor Rmeas (V_{CMP} - V_{CMN}) = Imotor * Rmeas where the internal over current detection is switched on can be determined by: (V_{CMP} - V_{CMN})$_{overc}$ * AV_TRIMM * AV_RANGE_over = OVERC_level **(V_{CMP} - V_{CMN})$_{overc}$ = OVERC_level / (AV_TRIMM * AV_RANGE_over)** example: OVERC_level = 4 V, AV_TRIMM = 80, AV_RANGE_over = 1/4 → (V_{CMP} - V_{CMN})$_{overc}$ = 200 mV
Remark 4: Example of the programming of the current measurement / over current detection unit: Step1: Definition of the nominal voltage drop over the external current measurement resistor Rmeas (V_{CMP} - V_{CMN})$_{nom}$ = $Imotor_{nom}$ * Rmeas e.g. (V_{CMP} - V_{CMN})$_{nom}$ = 50 A * 1 mΩ = 50 mV Step2: Definition of the over current threshold value of (V_{CMP} - V_{CMN}) e.g. (V_{CMP} - V_{CMN})$_{overc}$ = 100 mV Step3: Determination of the voltage amplification of the normal current measurement channel so that the nominal output voltage $V_{A\_current\_nom}$ = 4.0 V e.g. AV_TRIMM * AV_RANGE = 80 * 1 → $V_{A\_current-nom}$ = 50 mV * 80 = 4.0 V Step4: Determination of the voltage amplification of the over current measurement e.g. AV_TRIMM * AV_RANGE_over = 80 * 1/4 → $V_{A\_overc\_max}$ = 100mV * 20 = 2.0 V $\leq$ 4.0 V Step5: Determination of the programming of the internal over current threshold value (OVERC_level) With the formula: (V_{CMP} - V_{CMN})$_{overc}$ = OVERC_level / (AV_TRIMM * AV_RANGE_over) and all values above: OVERC_level = (V_{CMP} - V_{CMN})$_{overc}$ * (AV_TRIMM * AV_RANGE_over) = 100 mV * 80 *1/4 = 2.0 V → R9 = 4
Remark 5: The amplifications AV_{meas_norm} and AV_{meas_overc} of the current measurement unit can be adapted to the external measurement resistor R_{meas} by the programming word **AV_TRIMM** in steps of 1.25 % in the range of $\pm$ 12.5% (trimming of R_{meas}).

Table 13 Programming of the motor current measurement an over current detection unit

Summary of all programmable registers (parameters, functions)

<table>
<tr><th>Register / address</th><th>Internal name</th><th colspan="8">Meaning</th><th>Note</th></tr>
<tr><td colspan="11">Ra<b1:b0> means: address = a, most significant data bit = b1, least significant data bit = b0
All registers can be write and read by the Three-Wire Interface (write priority has the Three-Wire Interface).
1. The start up reset of all registers unless the R17 and the R18 is done by the signal nPOR (controlled by the VDD).
2. The start up reset of the register R17 is done by the nPORraw (controlled by the voltage VDDraw) <u>only</u>.
3. The start up reset of the register R18 (failure register) is done with a delay after the nPOR, this delay is generated by the enable signal of the charge pump VPok.</td></tr>
<tr><th colspan="11">Programming of the driver output currents (independent for switch on and switch off)</th></tr>
<tr><td>R0<7:0></td><td></td><td colspan="8">Not used</td><td></td></tr>
<tr><td rowspan="3">R1<4:0></td><td rowspan="3">SRon</td><td colspan="8">Slew rate regulation programming, on switch,
voltage V_{Vmo} dependent driver output current for positive V_{VMO} voltage
SRon = 0, 1, 2, ... 31
$I_{SRon} = V_{Vmo} * Acu\_on * SRon * K1$ $V_{VMO} > 0$

Register write by: Three Wire Interface
Register read by: Three Wire Interface and FET driver unit</td><td rowspan="3">start up values</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>d4</td><td>d3</td><td>d2</td><td>d1</td><td>d0</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td rowspan="3">R2<4:0></td><td rowspan="3">SRon_stat</td><td colspan="8">Slew rate regulation programming, on switch,
constant driver output current
SRon_stat = 0, 1, 2, ... 31
$I_{SRon\_stat} = 2.0\ \mu A * (SRon\_stat + 1) * Acu\_on$

Register write by: Three Wire Interface
Register read by: Three Wire Interface and FET driver unit</td><td rowspan="3">start up values</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>d4</td><td>d3</td><td>d2</td><td>d1</td><td>d0</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td rowspan="3">R3<2:0></td><td rowspan="3">SRon_min</td><td colspan="8">Slew rate regulation programming, on switch,
voltage V_{VMO} dependent driver output current for negative V_{VMO} voltage
SRon_min = 0, 1, 2, ...7
$I_{SRon\_min} = V_{Vmo} * (SRon\_min + 1) * Acu\_on * K2$ $V_{VMO} < 0$

Register write by: Three Wire Interface
Register read by: Three Wire Interface and FET driver unit</td><td rowspan="3">start up values</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>d2</td><td>d1</td><td>d0</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>1</td><td>1</td><td>1</td></tr>
</table>

<table>
<tr><td rowspan="3">R4<4:0></td><td rowspan="3">SRoff</td><td colspan="8">Slew rate regulation programming, off switch,
voltage V_{VMO} dependent driver input current for positive V_{VMO} voltage
SRoff = 0, 1, 2, ... 31
$I_{SRoff} = V_{Vmo} * Acu\_off * SRoff * K3$

Register write by: Three Wire Interface
Register read by: Three Wire Interface and FET driver unit</td><td></td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>d4</td><td>d3</td><td>d2</td><td>d1</td><td>d0</td><td></td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>start up values</td></tr>
<tr><td rowspan="3">R5<3:0></td><td rowspan="3">SRoff_stat</td><td colspan="8">Slew rate regulation programming, off switch,
constant driver input current
SRoff_stat = 0, 1, 2, ... 15
$I_{SRoff\_stat} = 20\ \mu A * (SRoff\_stat + 1) * Acu\_off$

Register write by: Three Wire Interface
Register read by: Three Wire Interface and FET driver unit</td><td></td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>d3</td><td>d2</td><td>d1</td><td>d0</td><td></td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>1</td><td>1</td><td>1</td><td>1</td><td>start up values</td></tr>
<tr><td rowspan="3">R6<1:0></td><td rowspan="3">Acu_on Acu_off</td><td colspan="8">Current amplification of the driver for on and off switch
R6<0> = 0 → Acu_on = $(Iout / Iin)_{on}$ = 256
R6<0> = 1 → Acu_on = $(Iout / Iin)_{on}$ = 512

R6<1> = 0 → Acu_off = $(Iout / Iin)_{off}$ = 256
R6<1> = 1 → Acu_off = $(Iout / Iin)_{off}$ = 512

Register write by: Three Wire Interface
Register read by: Three Wire Interface and FET driver unit</td><td></td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>Acu_off</td><td>Acu_on</td><td></td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0</td><td>0</td><td>start up values</td></tr>
</table>

Programming of the motor current measurement and over current detection unit

The motor current measurement unit transforms the differential voltage over the measurement resistor $(V_{CMP} - V_{CMN})$ = Imotor * Rmeas to the ground related voltages $V_{A\_current}$ (channel1: normal current measurement channel) and V_{A_overc} (channel2: over current measurement channel) with a programmable amplification.

Def. of the voltage amplification of the motor current measurement unit:

Voltage amplification of the normal current measurement channel:

1. $AV_{meas\_norm} = V_{A\_current} / (V_{CMP} - V_{CMN}) = AV\_TRIMM * AV\_RANGE\_norm$

Voltage amplification of the normal current measurement channel

2. $AV_{meas\_overc} = V_{A\_overc} / (V_{CMP} - V_{CMN}) = AV\_TRIMM * AV\_RANGE\_over$

<table>
<tr><td rowspan="3">R7<4:0></td><td rowspan="3">AV_TRIMM</td><td colspan="8">R7 = 0 → AV_TRIMM = 70
R7 = 1 → AV_TRIMM = 71
R7 = 2 → AV_TRIMM = 72
:
R7 = 10 → AV_TRIMM = 80 (default value)
R7 = 11 → AV_TRIMM = 81
:
R7 = 19 → AV_TRIMM = 89
R7 = 20 → AV_TRIMM = 90
R7 > 20 → AV_TRIMM = 90
Register write by: Three-Wire Interface
Register read by: Three-Wire Interface and current measurement unit</td><td rowspan="2"></td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>d4</td><td>d3</td><td>d2</td><td>d1</td><td>d0</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>0</td><td>1</td><td>0</td><td>1</td><td>0</td><td>start up values</td></tr>
<tr><td rowspan="3">R8<1:0></td><td rowspan="3">AV_RANGE_norm</td><td colspan="8">R8 = 0 → AV_RANGE-norm = 1 (default value)
R8 = 1 → AV_RANGE-norm = 2
R8 = 2 → AV_RANGE-norm = 3
R8 = 3 → AV_RANGE-norm = 4
Register write by: Three-Wire Interface
Register read by: Three-Wire Interface and current measurement unit</td><td rowspan="2"></td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>d1</td><td>d0</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0</td><td>0</td><td>start up values</td></tr>
<tr><td rowspan="3">R9<2:0></td><td rowspan="3">OVERC_level</td><td colspan="8">Threshold value of the internal over current detection
Def.: Vocmax = 4/5 * VDD (typ. 4.0 V)
Vocstep = (4/5 * VDD) / 8 (typ. 0.5 V)
R9 = 0 → OVERC_level = Vocmax (typ. 4.0 V)
R9 = 1 → OVERC_level = Vocmax – Vocstep (typ. 3.5 V)
R9 = 2 → OVERC_level = Vocmax - 2*Vocstep (typ. 3.0 V)
R9 = 3 → OVERC_level = Vocmax - 3*Vocstep (typ. 2.5 V)
:
R9 = 7 → OVERC_level = Vocmax - 7*Vocstep (typ. 0.5 V)
Register write by: Three-Wire Interface
Register read by: Three-Wire Interface and current measurement unit</td><td rowspan="2"></td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>d2</td><td>d1</td><td>d0</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0</td><td>1</td><td>1</td><td>start up values</td></tr>
<tr><td rowspan="3">R10<1:0></td><td rowspan="3">AV_RANGE_over</td><td colspan="8">Voltage amplification factor2 of the over current analogue measurement output (A_overc)
R10 = 0 → AV_RANGE_over = 1 * 1/4 (default value)
R10 = 1 → AV_RANGE_over = 2 * 1/4
R10 = 2 → AV_RANGE_over = 3 * 1/4
R10 = 3 → AV_RANGE_over = 4 * 1/4
Register write by: Three-Wire Interface
Register read by: Three-Wire Interface and current measurement unit</td><td rowspan="2"></td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>d1</td><td>d0</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0</td><td>0</td><td>start up values</td></tr>
</table>

Programming of the battery voltage monitor and over / under voltage detection										
R11<2:0>	VBAT_RANGE	R11= 0 → VBAT_RANGE = 5 → Vbat-max = 20 V R11= 1 → VBAT_RANGE = 8 → Vbat-max = 32 V R11= 2 → VBAT_RANGE = 10 → Vbat-max = 40 V R11= 3 → VBAT_RANGE = 15 → Vbat-max = 60 V R11= 4 → VBAT_RANGE = 20 → Vbat-max = 80 V Register write by: Three-Wire Interface Register read by: Three-Wire Interface and voltage monitor								
		-	-	-	-	-	d2	d1	d0	
		-	-	-	-	-	0	1	0	start up values
R12<2:0>	OVER_VOLT	R11= 0 → VBAT_RANGE = 5 → Vbat-max = 20 V R11= 1 → VBAT_RANGE = 8 → Vbat-max = 32 V R11= 2 → VBAT_RANGE = 10 → Vbat-max = 40 V R11= 3 → VBAT_RANGE = 15 → Vbat-max = 60 V R11= 4 → VBAT_RANGE = 20 → Vbat-max = 80 V Register write by: Three-Wire Interface Register read by: Three-Wire Interface and voltage monitor								
		-	-	-	-	-	d2	d1	d0	
		-	-	-	-	-	1	1	1	start up values
R13<2:0>	UNDER_VOLT	Step of UNDER_VOLT = 0.25 V * VBAT_RANGE UNDER_VOLT = 0.25 V * VBAT_RANGE * (R13 + 1) Start up value: UNDER_VOLT = 7.5 V Register write by: Three-Wire Interface Register read by: Three-Wire Interface and voltage monitor								
		-	-	-	-	-	d2	d1	d0	
		-	-	-	-	-	0	0	0	start up values

Programming of the charge pump voltages										
R14<0:0>	VPUMP_MIN	R14 = 0 → VPUMP_MIN = 4.0 V R14 = 1 → VPUMP_MIN = 6.0 V Register write by: Three-Wire Interface Register read by: Three-Wire Interface and charge pump								
		-	-	-	-	-	-	-	d0	
		-	-	-	-	-	-	-	0	start up values

Programming of the analog MUX			
R15<3:0>	ADC_CH	R15 = 0 → A_current (normal current measurement channel) R15 = 1 → A_overc (over current measurement channel) R15 = 2 → Vbat_mon (Vbat measurement channel) R15 = 3 → TP (temperature measurement channel) The following signals can be given at the ADC output for chip test purposes: R15 = 4 → Vtemp (temperature voltage of the internal sensor) R15 = 5 → PVover (Over voltage Vbat signal) R15 = 6 → PVunder (Under voltage Vbat signal) R15 = 7 → PTover_in (Over temperature signal, internal) R15 = 8 → PTover_ex (Over temperature signal, external) Register write by: Three-Wire Interface Register read by: Three-Wire Interface and analog MUX	

-	-	-	-	d3	d2	d1	d0	
-	-	-	-	0	0	0	0	start up values

Note: Do not switch the analog MUX during operation!

Programming of the watch dog			
R16<0:0>	WATCH_D	R16 = 0 → watch dog is off (watch dog not used) R16 =1 → watch dog is on (watch dog used) Register write by: Three-Wire Interface Register read by: Three-Wire Interface and watch dog	

-	-	-	-	-	-	-	d0	
-	-	-	-	-	-	-	0	start up values

Programming of the sleep mode			
R17<0:0>	SLEEP	R17 = 0 → no sleep mode (normal operation) R17 = 1 → sleep mode (power down) Register reset to low by the Wake-up Interface. Wake-up = low (high / low edge) → R17<0:0> set to low	

-	-	-	-	-	-	-	d0	
-	-	-	-	-	-	-	1	start up values

<table>
<tr><th colspan="9">Failure Registers and Test Mode Register (on chip temperature detection)</th></tr>
<tr><td>R18<7:0></td><td>FAILURE_STAT</td><td colspan="6">R18<0> → Poverc (bit 0 contains the over current status)
R18<1> → PVover (bit 1 contains the over voltage status of Vbat)
R18<2> → PVunder (bit 2 contains the under voltage status of Vbat)
R18<3> → PTover_in (bit 3 contains the on chip over temperature status)
R18<4> → PTover_ex (bit 4 contains the external over temperature status)
R18<5> → VDDover (bit 5 contains the over voltage status of VDD, 5 V)
R18<6> → VDDunder (bit 6 contains the under voltage status of VDD, 5 V)

R18<7> = 0 → band gap Voltage is the reference voltage for the on chip over temperature detection (normal function)
R18<7> = 1 → the voltage at pin TP is the reference voltage for the on chip over temperature detection (test mode)

Registers R18<6:0> set and reset by Three-Wire Interface and only set by corresponding failure detection units (Three Wire-Interface has write priority)
Register R18<6:0> read by Three-Wire Interface and corresponding logic
Register R18<7> write by Three-Wire Interface only
Register R18<7> read by Three-Wire Interface and corresponding analog switch</td><td></td></tr>
<tr><td>TEMP_TEST</td><td>VDDunder</td><td>VDDover</td><td>PTover_ex</td><td>PTover_in</td><td>PVunder</td><td>PVover</td><td>Poverc</td><td rowspan="2">start up values</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>

Table 14 Summary of the programming capabilities of the AS 8446

Three -Wire µP-Interface

Data transfer from the microprocessor or PC to the AS8446 and vice versa is accomplished by means of Three-Wire Interface. The Three-Wire Interface of the AS8446 acts generally in slave mode. The master in the whole regulator board is either the controlling µP (normal regulator module in volume production) or a PC (development or field programming mode e.g. to realize the EMC optimization).
All registers (see section **Summary of all programmable registers (parameters, functions)**) can be written and read by the Three-Wire Interface.

Pin DATAout is high ohmic if the Three-Wire Interface chip select signal CS is not active (high).
During an over voltage situation the write access to the Three-Wire Interface is blocked.

Physical Interface

Supported modes, and bit order are shown in Figure 10 and Figure 11.
The DATAin signal must be valid with the rising edge of the clock Clk, the DATAout is valid with the falling edge of the clock Clk.
The clock frequency should be as low as useful in the particular application. It is recommended not to use a clock frequency f_{clk} higher than 10 MHz.
The MSB is always transmitted / received first.

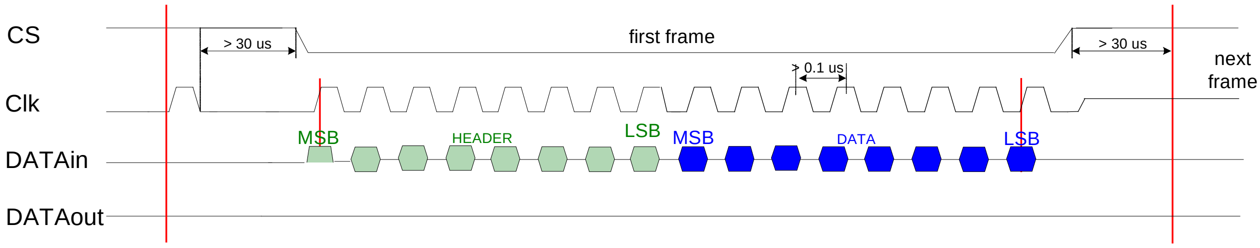


Figure 10 Physical Interface of Three-Wire Interface in write mode

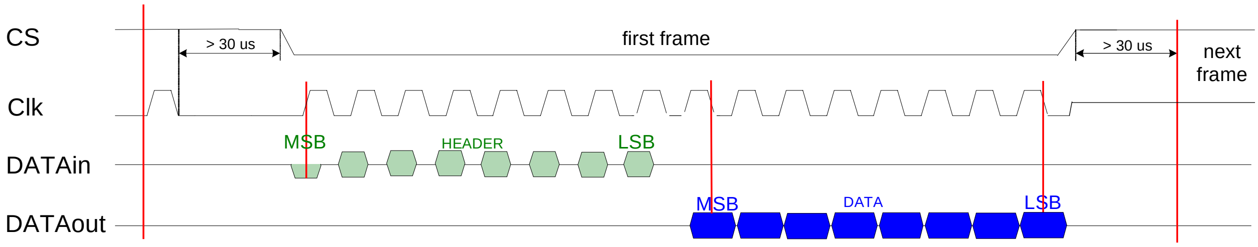


Figure 11 Physical Interface of Three-Wire Interface in read mode

Communication Protocol

The Three-Wire Interface -interface acts as communication interface between the µP or PC and the registers within the AS8446. For efficient register access, a protocol has been defined with the following features:
Purely master-slave protocol with µP or PC as master
Two different frames: One read and one write frame
Frame is delimited by the status of CS (CS = frame delimiter or chip select signal), one frame consists of 16 Bits (header byte and data byte).

Special remark for interface lock condition: If a frame does not consist of 16 bits (can be caused e.g. by spiking, noise or interrupt), the interface will be locked. In order to leave this lock situation CS = high and one or several clock pulses must be set. Setting CS = high alone will not be sufficient.
Referring to Figure 10 and Figure 11, a Clk pulse with CS = high must be set in order to reset the interface and to ensure a safe communication.

Data Fields

HEADER H

MSB				H			LSB
R/W	**-**	**-**	**A4**	**A3**	**A2**	**A1**	**A0**

A4, A3, A2, A1, A0: Address A (Register address to read or to write)
R/W = MSB, A0 = LSB.
R/W: Read or Write
R/W =0: Read (Data are read/transmitted from the AS8446 via the DATAout pin.)
R/W =1: Write (Data are write/transmitted from the µP or PC to the AS8446 via the DATAin pin.)

DATA D

MSB				D			LSB
D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**

D7...D0: Data (Denotes the data of the register addressed. D7=MSB, D0=LSB)

Note:
To ensure a correct register setting the use of µP based verification (Write, Read-Back, Verify) is mandatory.

Electrical Parameters and Functionality of the Subblocks

All parameters are valid in the temperature range Tamb = -40 °C to +125 °C if not otherwise mentioned.

5V Regulator

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	NOTE
Regulated Output Voltage	VDD	4.8	5.0	5.15	V	(1)
Load Current at VDD	IOUT			40	mA	(2), (3), (4)
Under voltage detection threshold	VDDunder	4.3			V	
Over voltage detection threshold	VDDover			5.6	V	

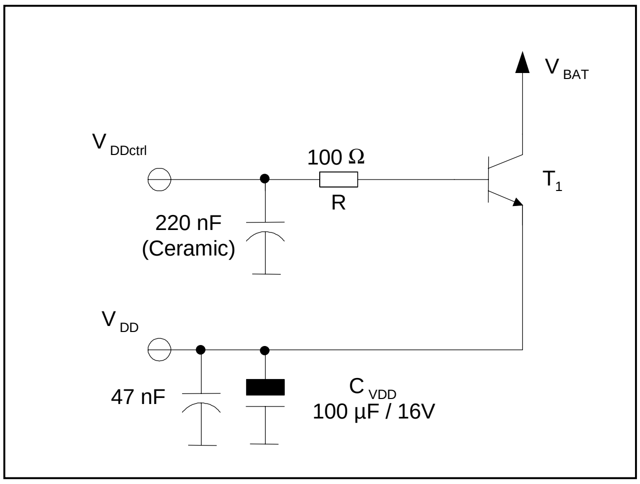
Note (1): For use of the internal voltage regulator the Pins V_{DD} and V_{DDctrl} must be connected. An external capacitor of 4.7µF to 10µF needs to be connected at the VDD pin.

Note (2): Valid for Vbat ≥ 6.5V; for 6.0V ≤ Vbat < 6.5V the load current is limited to 2.5mA.

Note (3): There is also the possibility to use an external regulator (Bipolar transistor). It is up to the user to select the suitable external components.

Note (4): The max. power dissipation on chip must be respected (estimation: Pchip_vdd = ((Vbatmax - 5 V) * Ivdd_ex + Vbat * Ivdd_in) < 400 mW)

Design Example



T_1... Philips NPN medium power transistor BCX 56
C_{VDD}... Panasonic FK-series 100µF / 16V

Figure 12: Design example for operation of external voltage regulator

Power on Reset

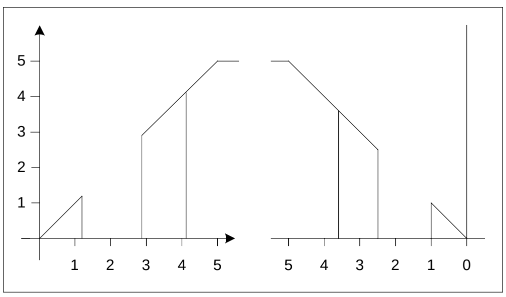


Figure 13 Transfer characteristic of PORn circuitry

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	NOTE
Off threshold for Reset generation	Voff_PORS	2.1	3.5	4.5	V	Ramp up
Hysteresis of Reset signal	Hyst_PORS	0.1		0.8	V	

Sleep / wake up system

The whole IC is put in sleep mode (power down mode) by the control signal SLEEP set via the Three Wire Interface (SLEEP = high, content register R17).

The whole start up and sleep mode behavior is shown in figure 4.

In sleep mode the following actions are done:

- the power FET driver output OUT is hold at low (VSS)
- the oscillator, the charge pump and all other blocks are put in a high ohmic status
- the 5 V regulator is switched off (no external supply at pin VDD, this way all devices on the motor regulator board supplied by VDD, e.g. the µP and the external temperature sensor, are powered down)
- a raw internal 5 V supply V_{DDraw} is generated to supply the wake up system and the whole logic block
- the total current consumption of the IC is less than 90 µA

During sleep mode the Wake-up Pin must be at high level (V_{BAT}).

Applying a “low”-pulse on the wake-up pin will wake up the IC.

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	NOTE
Current Consumption in Sleep Mode (Tamb = -40 °C to 125 °C)	Ivbat_pd			90	µA	R17<0> = 1 (SLEEP = high)
Current Consumption in Sleep Mode (Tamb = -40 °C to 27 °C) (1)	Ivbat_pd27			(50)	µA	
Note (1): only as information. Will not be tested.						

Reference Current Generator

The reference current generator uses a bandgap based 1 V reference voltage to generate a buffered 1 V voltage reference at pin **Iref**. A 22 kΩ external resistor must be used to generate the 45 µA current reference.

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	NOTE
Voltage at pin Iref	Vref	0.95	1.0	1.05	V	

High Side Power FET Driver / Slew Rate Regulation

The supply voltage of this driver is about 10 V higher than the Vbat (n-channel power FET to drive) and is delivered by the on chip charge pump at pin Vpump.

The Power FET driver is controlled in two different ways:

First by the digital output of the PWM generator of the µP to realizing a certain duty cycle of the motor drive and so to regulate the motor current, voltage or speed in a closed loop.

The driver output OUT is set to low (the motor is switched off) independently of the PWM signal under the following conditions:

- over current condition: (Poverc = high) — The over current signal Poverc is set to high by the over current detection unit and reset to low via the Three Wire Interface
- under voltage condition of Vbat: (PVunder = high) — The under voltage signal PVunder is set and reset by the voltage monitor.
- over voltage condition of Vbat: (PVover = high) — The over voltage signal PVover is set and reset by the voltage monitor.

- charge pump voltage Vpump - Vbat is too low: (VPok = low) The charge pump OK signal VPok is set and reset by the charge pump monitor.
  The threshold values of these parameters are programmable (see section **Summary of all programmable registers (parameters, functions)**).
- the calibration of the motor current measurement unit is not yet finished: Mcalib = low. The motor current must be zero respectively the voltage (V_{CMP} - V_{CMN}) must be zero during the calibration.

This calibration is done after the start up of the system including the ready signal of the charge pump: power on reset signal nPOR and Vpok = high starts the calibration. The calibration procedure needs about 200 µs (see figure 4).
Summary of logic driver function: OUT = PWM and /Poverc and /PVunder and /PVover and VPok and Mcalib

Second by the analog motor voltage to regulate the slew rate during the rising and falling edge of the motor voltage (EMC conform technology). This slew rate control respectively regulation is executed by a feedback of the motor voltage V_{motor} available at the pin Vmo. The characteristics (parameters) of this slew rate regulation can be programmed via the Three-Wire Interface independently for the falling and rising edge of the motor voltage and can therefore be adapted to a specific application (motor and its environment).
This programming of the output current characteristics (gate current of the external power FET) in both directions is shown in section **Summary of all programmable registers (parameters, functions)**.

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	NOTE
Tolerances of driver output current (pin OUT), sourcing	IOUTon	-50%		+50%		$I_{out\_on} = I_{SRon-stat} + I_{SRon} + I_{SRon\_min}$ The relative tolerances between adjacent programming steps of the driver current are less than 10%.
Tolerances of driver output current (pin OUT), sinking	IOUToff	-50%		+50%		$I_{out\_off} = I_{SRoff-stat} + I_{SRoff}$ The relative tolerances between adjacent programming steps of the driver current are less than 10%.
- max. pulse duration = 1µs @ 20 kHz or max. external charge to load: 250 nC @ 20 kHz - valid for I_{OUT} = 5 mA … 500 mA and Vbat = 12 V , Vpump = 22 V - Programmable by the registers R1 to R6						

Charge Pump and internal Oscillator

The charge pump is a one-stage pump that generates a pumped voltage Vpump about 10 V higher than the supply voltage Vbat for Vbat > 13.5 V. It uses two external capacitors only, the capacitor Cp12 as the switched capacitor and Cp0 as the storage capacitor.
The pumped voltage (Vpump - Vbat) is monitored to detect over or under voltages (protection of the power FET gate):
(Vpump - Vbat) = 10 V to 12 V : Normal voltage regulation of the charge pump
(Vpump - Vbat) < $(Vpump - Vbat)_{low}$: The digital signal VPok is indicating this under voltage and disabling the power FET driver.
The threshold value $(Vpump - Vbat)_{low}$ can be programmed to be 6 V or 4 V (VPUMP_MIN).

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	NOTE
Pumped voltage	Vpump - Vbat	10	10.5	12	V	Vbat = 13.5 V, Iload = 5 mA
Pumped voltage	Vpump - Vbat	4.0	5.0		V	Vbat = 6.5 V, Iload = 2.5 mA
Pumped voltage	Vpump - Vbat	4.0			V	6.0V ≤ Vbat < 6.5V (low-Battery-mode), Iload = 250µA
Under voltage threshold (VPUMP_MIN = 1)	$(Vpump - Vbat)_{low}$	5.4	6.0	6.6	V	falling (Vpok)
Under voltage threshold (VPUMP_MIN = 0)	$(Vpump - Vbat)_{low}$	3.4	4.0	4.6	V	falling (Vpok)
regulated voltage threshold	$(Vpump - Vbat)_{high}$	10	10.5	12	V	rising
frequency	f_{pump}	40	50	70	kHz	

Motor Current Measurement Unit / Over Current Detection

The motor current measurement unit functions with an external current measurement resistor R_{meas} in the high side motor line. The chip has two measurement amplification channels with separately programmable amplification factors $AV_{meas\_normal} = V_{A\_current} / (V_{CMp} – V_{CMn})$ (analogue output **A_current**) and $AV_{meas\_over} = V_{A\_overc} / (V_{CMp} – V_{CMn})$ (analogue output **A_overc**). The maximal valid nominal analogue output voltage level $V_{A\_current}$ and V_{A_overc} of theses channels is 4.0 V (100% value of the output voltage $V_{A\_current}$ (nominal value).
In general, all programming possibilities can be used to build up a measurement system within the defined limits.
It is recommended to use a nominal differential voltage $(V_{CMp} – V_{CMn})$ > 50 mV to avoid larger tolerances of the amplification factor caused by offset.

The programming of theses two amplification channels is usually realized in a way that the measurement range of the over current measurement channel is wider than the normal current measurement channel.
In the whole system the analogue outputs **A_current** and **A_overc** are used via an ADC in the controlling µP to regulate and control the system. There is one exception only: The over current detection and protection is realized directly by the over current measurement channel to be able to act very fast in case of an over current situation (short circuit).
The measurement unit contains a low pass filter to prevent wrong measurement if short transients of the measurement input voltage occurs (cut-off frequency about 500 kHz).
The motor current measurement unit is endowed with an auto calibration procedure for the offset voltage. The motor current respectively the measurement voltage (Vcmp - Vcmn) must be zero during this calibration.
This calibration is done after the start up of the system including the ready signal of the charge pump: power on reset signal nPOR and Vpok = high starts the calibration. The calibration procedure needs about 200 µs.

a) Motor current measurement (normal current amplification channel: A_{CMV_normal} , programmed by **AV_RANGE_norm (Register R8<1:0>)** and **AV_TRIMM (Register R7<4:0>**)
The nominal measurement differential voltage V_{meas_nom} (corresponding to 100% of the nominal motor current)
$V_{meas\_nom} = (V_{CMp} – V_{CMn})_{nom} = I_{motor\_nom} * R_{meas}$ must be fixed by the value of R_{meas} . So the value of this measurement resistor is given by $R_{meas} = (V_{CMp} – V_{CMn})_{nom} / I_{motor\_nom}$.

The voltage amplification of this motor current measurement unit $AV_{meas\_normal} = V_{A\_current} / (V_{CMp} – V_{CMn})$ is programmable in the range **AV_RANGE_norm** * **AV_TRIMM** = (1, 2, 3, 4) * (70, 71, ... 89, 90)
Examples:
AV_RANGE_norm = 1: A_{CMV_normal} = 70, 71, 72, ... , 80, ... , 89, 90
AV_RANGE_norm = 4: A_{CMV_normal} = 280, 284, 288, ..., 320, ... , 360
(The programming values of **AV_RANGE_norm** >1 are intended for a measurement of low currents with a higher digital resolution, but in this cases the tolerances of the amplification factor is high due to the remaining offset of the measurement amplifier.)
This way the analog output value $V_{A\_current}$ of the current measurement unit can be adapted to the external measurement resistor R_{meas} (trimming of this resistor in the range ± 12.5%).
The nominal (respectively 100%) voltage of the measurement unit $V_{A\_current}$ (this is the nominal input voltage of the ADC on the µP) must be 4.0 V.

b) Over current detection and protection (over current amplification channel A_{CMV_over})
The over current amplification channel uses the same input voltage $V_{meas} = (V_{CMp} – V_{CMn})$ as the normal current amplification channel.
The voltage amplification of this over current measurement channel $A_{CMV\_over} = V_{A\_overc} / (V_{CMp} – V_{CMn})$ is programmable by **AV_RANGE_over (Register R10<1:0>)** and **AV_TRIMM (Register R7<4:0>**)
in the range
A_{CMV_over} = **AV_RANGE_over** * **AV_TRIMM** = (1/4, 2/4, 3/4, 4/4) * (70, 71, ... 89, 90)

Examples:
AV_RANGE_over = 1/4: A_{CMV_over} = 17.5, 17.75, 18, … , 20, … , 22.25 , 22.5
AV_RANGE_over = 4/4: A_{CMV_over} = 70, 71, 72, …, 80, … , 89, 90
The adjustment (trimming) of the measurement resistor R_{meas} is realized by the same programming parameter **AV_TRIMM** (± 12.5%) like in a)**.**
The maximal output voltage of the over current amplification channel V_{A_overc} (this is the nominal input voltage of the ADC on the µP) must be 4.0 V.
The threshold value of the over current detection can be programmed by the programming parameters **OVERC_level** (in conjunction with **AV_RANGE_over** and **AV_TRIMM**) in the following way.
The voltage over the external measurement resistor where the over current situation is detected (Vmeas_over) is given by:
V_{meas_over} = **OVERC_level** / (**AV_TRIMM** * **AV_RANGE_over)** with **OVERC_level** = 0.5 V, 1.0 V, 1.5 V, … 4.0 V
See also section **Summary of all programmable registers (parameters, functions)** for the programming of the parameters above.

PARAMETER	SYMBOL	MIN	MAX	UNIT	NOTE (Programming, nominal amplification)
Tolerance of voltage amplification, normal current measurement channel 1)	ΔA_{CMV_normal}	- 6	+ 6	%	V_{meas} = 50 mV, R8 = 0 → 80
		- 10	+ 10	%	V_{meas} = 25 mV, R8 = 1 → 160
		- 20	+ 20	%	V_{meas} = 16.67mV, R8 = 2 → 240
		- 20	+ 20	%	V_{meas} = 12.5 mV, R8 = 3 → 360
Tolerance of voltage amplification, over current measurement channel 1)	ΔA_{CMV_over}	- 6	+ 6	%	V_{meas} = 200 mV, R10 = 0 → 20
		- 6	+ 6	%	V_{meas} = 100 mV, R10 = 1 → 40
		- 6	+ 6	%	V_{meas} = 60.6 mV, R10 = 2 → 60
		- 6	+ 6	%	V_{meas} = 50 mV, R10 = 3 → 80
Tolerance of linearity A_{CMV_normal}	Δlincurrent	- 3	+ 3	%	$((\Delta V_{A\_current} / \Delta V_{meas\_nom}) - A_{CMV\_normal}) / A_{CMV\_normal}$
Tolerance of linearity A_{CMV_overc}	Δlinoverc	- 3	+ 3	%	$((\Delta V_{A\_overc} / \Delta V_{meas\_nom}) - A_{CMV\_overc}) / A_{CMV\_overc}$
Tolerance of over current thresholds	Δoverclevel	- 10	+ 10	%	R10 = 0, R9 ≤ 3, Tamb > 25 °C
Tolerance of over current thresholds	Δoverclevel	- 20	+ 10	%	R10 = 0, R9 ≤ 3, Tamb = -40 °C
Tolerance of over current thresholds	Δoverclevel	- 20	+ 20	%	R10 = 0, R9 > 3, Tamb = (-40 to 125) °C
Cut off frequency	fcut-off	400	800	kHz	
Note (1): The offset voltage of the current measurement unit at calibration temperature V_{meas_offset} is < 1.5 mV (typical: 0.5 mV), the maximal offset temperature drift is + 20 µV / K.					

Battery Voltage Monitor and Over / Under Voltage Detection

The Battery voltage monitor has to deliver an analog voltage Vbat_mon in the 5V range which is proportional to the high voltage supply Vbat (normally VDDH = Vbat). The measurement range of the supply voltage Vbat is programmable via the register R11<2:0> to adapt the AS8446 to different application supply voltages.

Programming of the MEASUREMENT RANGE of Vbat (programmed by register R11<2:0> → VBAT_RANGE)

PARAMETER	Programming Register R11	SYMBOL	MIN	MAX	UNIT	NOTE
Programmable Measurement Voltage Ranges of Vbat	R11= 0 → VBAT_RANGE = 5	$Vbat_{max1}$		20	V	(1)
	R11= 1 → VBAT_RANGE = 8	$Vbat_{max2}$		32	V	
	R11= 2 → VBAT_RANGE = 10	$Vbat_{max3}$		40	V	
	R11= 3 → VBAT_RANGE = 15	$Vbat_{max4}$		60	V	
	R11= 4 → VBAT_RANGE = 20	$Vbat_{max5}$		80	V	
Note (1):	The programmable value of VBAT_RANGE determines the max. value of Vbat measurable by the voltage monitor (condition: Vbat / VBAT_RANGE ≤ 4 V).					
Note (2):	VBAT must not exceed the specified abs. Max. ratings (see Table 3)					

PARAMETER	SYMBOL	MIN	MAX	UNIT	NOTE
Tolerance of the division factor	ΔVBAT_RANGE	- 6	+ 6	%	
Tolerance of the programmed over voltage threshold	ΔVovervolt	-10	+10	%	
Tolerance of the programmed ounder voltage threshold	ΔVundervolt	-10	+10	%	

a) **Programming of the OVER VOLTAGE detection level of Vbat (programmed by register R12<2:0> → OVER_VOLT and R11<2:0> → VBAT_RANGE)**

Remark: The maximum over voltage limit of Vbat for safe functionality of AS8446 is limited to Vbat ≤ 30 V and must be respected by appropriate programming.

Programmable steps of OVER_VOLT = 0.25 V * VBAT_RANGE = (1.25 or 2.0 or 2.5 or 3.75 or 5.0) V

OVER_VOLT = 0.25 V * VBAT_RANGE * (R12 + 9) = 11.25 V ... 80 V

During an over voltage situation the write access to the Three Wire Interface is blocked and the driver is switched off.

b) **Programming of the UNDER VOLTAGE detection level of Vbat (programmed by register R13<2:0> → UNDER_VOLT and R11<2:0> → VBAT_RANGE)**

Remark: The minimum Vbat for full functionality of AS8446 is limited to Vbat ≥ 6.5 V (except for Low-battery-mode reduced functionality is still given between 6V and 6.5V, see Table 4 Operating Conditions).

Programmable steps of UNDER_VOLT = 0.25 V * VBAT_RANGE = (1.25 or 2.0 or 2.5 or 3.75 or 5.0) V

UNDER_VOLT = 0.25 V * VBAT_RANGE * (R13 + 1) = 1.25 V ... 40 V

Over Temperature Detection

On Chip Over Temperature Detection

The on chip temperature detection sets the signal PTover_in high if the chip temperature climbs above the specified level. This over temperature detection has a hysteresis of about 20 °C.

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	NOTE
Recovery Temperature	$T_{recovery}$	+130	+140	+150	°C	Information Parameter
Shutdown Temperature	$T_{shutdpwn}$	+150	+160	+170	°C	Information Parameter
On chip temperature voltage	VTEMP	1		1.4	V	T_{ON_CHIP} = 27 °C
threshold voltage of the on chip over temperature comparator	VOTI	0.8		1	V	Information Parameter
Hysteresis of the over temperature comparator	VOTIHYST	30		50	mV	Information Parameter

External Over Temperature Detection

The over temperature detection is realized with an external temperature sensor (e.g. NTC). The threshold value of the voltage at pin TP is defined to V_{th_TP} = 0.5* VDD (typical 2.5 V) and has a hysteresis.

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	NOTE
Over Temperature threshold value	V_{th_TP}	VDD/2 – 0.05		VDD/2 + 0.05	V	
Negative Hysteresis	$V_{th\_TP\_HYS\_N}$	30		70	mV	
The over temperature signal PTover_ex is defined in the following way: PTover_ex = high if $V_{IN} < V_{th\_TP}$ (over temperature) PTover_ex = low if $V_{IN} > V_{th\_TP}$ (no over temperature)						

Analog MUX and Analog Output Buffer

The following analog measurement channels and digital signals are output via an analog MUX and an analog buffer to the pin ADC, the MUX is controlled by register R15<3:0>

Analog MUX function

PARAMETER	SYMBOL	TYP	NOTE
A_current	Normal motor current measurement channel	R15 = 0	Used in normal application to control / regulate the system
A_overc	Motor over current measurement channel	R15 = 1	
Vbat_mon	Battery voltage monitoring	R15 = 2	
TP	Temperature sensor analog value	R15 = 3	
Vtemp	Temperature voltage	R15 = 4	Used for test purposes only
PVover	Over voltage signal	R15 = 5	
PVunder	Under voltage signal	R15 = 6	
PTover_ex	Over temperature signal, extern	R15 = 7	
PTover_in	Over temperature signal, intern	R15 = 8	

Analog buffer characterization

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	NOTE
Input/Output voltage range	V_{IO}	0.0		4.0	V	
Offset voltage	V_{offset}			80	mV	
Slew rate	SR_{buffer}	1.0			V/µs	(1)
Note (1): C_{Load} = 20 pF						

Failure Feedback Signal

There are two different ways to detect failures in the whole regulator system:

- System failures detected directly on chip (e.g. over current, under voltage, ...) and indicated by the appropriate failure signal (e.g. Poverc, PVunder, ..., respectively FAIL)
- System failures detected by software of the controlling µP via the monitoring of the motor current, motor speed, battery voltage, temperature and duty cycle of the PWM signal (e.g. motor failures like blocked motor, open wires, ...). This part of system failures must be defined by the motor and system know how of the customer.

The following system failures are detected directly on the AS8446 chip:

1. Over current of the motor (signal: Poverc)
2. Under voltage of the battery voltage Vbat (signal: PVunder)
3. Over voltage of the battery voltage Vbat (signal: PVover)
4. Over temperature of external temperature (signal: PTover_ex)
5. Over temperature of on chip temperature (signal: PTover_in)
6. Under voltage of VDD (5 V) (signal: VDDunder)
7. Over voltage of VDD (5 V) (signal: VDDover)

All these seven failures are stored in register R18 and can be read by the controlling µP via the Three Wire Interface.
A failure signal FAIL is created by OR conjunction of these failures and put to the pin FAIL (can be used as an interrupt signal for the µP to start a read access via the Three Wire Interface to the failure register R18):

FAIL = Poverc **or** PVunder **or** PVover **or** PTover_ex **or** PTover_in **or** VDDunder **or** VDDover **or** TEMP_TEST

The first three failures (over current, over and under voltage) are used to switch off the driver output OUT immediately by on chip hardware, the two temperature failure and the VDD over / under voltage failure are only detected and can be treated by software of the µP.
The signal TEMP_TEST is only used for test purposes and must be set low in the normal application. If there is a wrong value (high) of TEMP_TEST during the normal application the FAIL signal is set and must be reset via the Three Wire Interface.

Wake-up System (Pin Wake-up)

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	NOTE
DC Characteristics						
Low Level Input Voltage	V_{IL}	-8		0.4 V_{BAT}	V	
High Level Input Voltage	V_{IH}	0.6 V_{BAT}		V_{BAT}	V	
Input Hysteresis	V_{HYS}	0.05 V_{BAT}		0.1 V_{BAT}	V	V_{IH} - V_{IL}
Pull- up Current on Input	I_{PU}	-400		5	µA	> 30 kΩ internal pull- up @ V_{IH} = 0.7 V_{BAT}

Watch Dog and RESET

The watch dog can be used to supervise the function of the controlling µP. In cases where this supervising is not necessary, the watch dog is switched off via the Three Wire Interface by sending a zero to R16<0:0>.
The default value after the start up of the system is R16<0:0> = 0 (watch dog is not active).

The trigger of the watch dog is done by the high / low edge of the external signal WD (start of the counter). The output signal of the watch dog WDout goes high if the watch dog time is over.

The output signal of the watch dog WDout or the nPOR are generate the low active signal RESET (used for external µP only):
if nPOR = low **or** (WDout = high) and R16<0> = high) → RESET = low

PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT	NOTE
time out of the watch dog	T_{watch}	110	160	190	ms	
RESET pulse duration	T_{watch_d}	14	20	25	µs	

Package Drawing and Marking

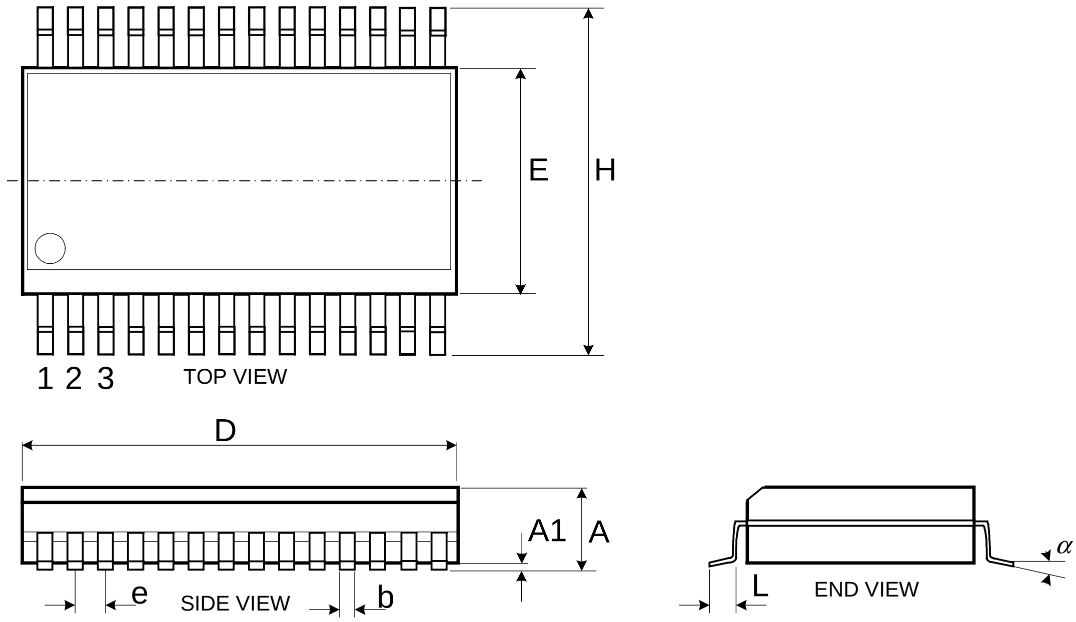


Figure 14 Physical Dimensions (SOIC28) of AS 8446

Physical Dimensions SOIC28 (millimeters)

	D	E	H	A	A1	e	b	L	α
MIN.	17.81	7.42	10.16	2.46	0.127	1.27 BSC	0.35	0.61	0 °
NOM.	17.93	7.52	10.31	2.56	0.22		0.41	0.81	5 °
MAX.	18.06	7.59	10.41	2.64	0.29		0.48	1.02	8 °

Physical Dimensions SOIC28 (inches)

	D	E	H	A	A1	e	b	L	α
MIN.	.701	.292	.400	.097	.0050	.050 BSC	.014	.024	0 °
NOM.	.706	.296	.406	.101	.0090		.016	.032	5 °
MAX.	.711	.299	.410	.104	.0115		.019	.040	8 °

Table 15 Physical Dimensions of AS 8446

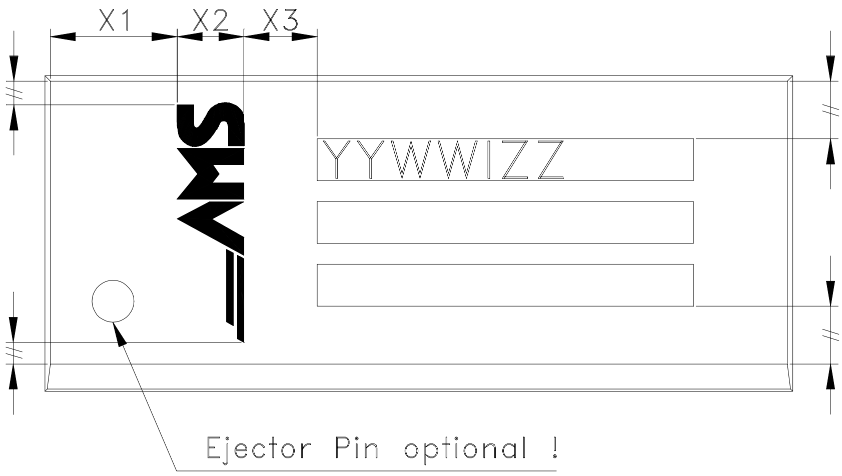


Figure 15 Marking of AS 8446

Marking:

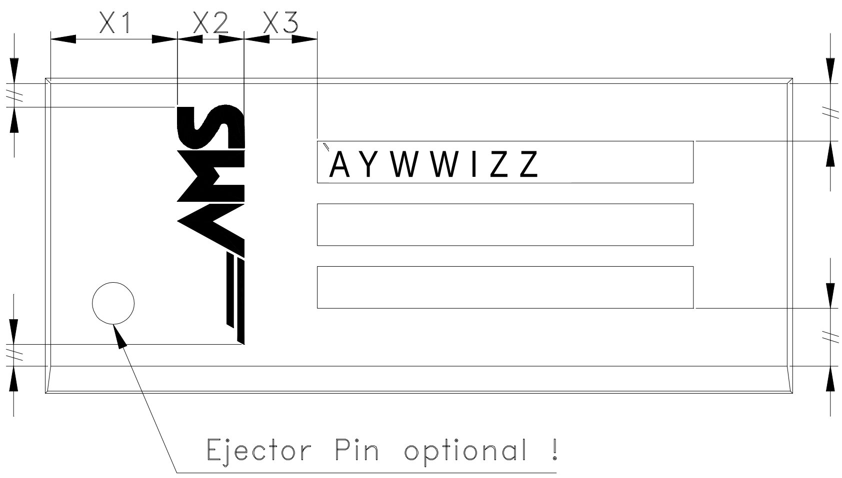


Figure 16 PB-free Marking of AS 8446

Marking: AYWWIZZ

AYWWIZZ	A:	Pb-Free Identifier
	Y:	Last Digit of Manufacturing Year
	WW:	Manufacturing Week
	I:	Plant Identifier
	ZZ:	Traceability Code

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