iC-WD, iC-WDS

SWITCH-MODE DUAL 5V REGULATOR

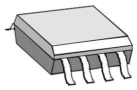
FEATURES

- ♦ Input voltage 8..30(36)Vdc
- ♦ Highly efficient step-down regulator
- ♦ Switching transistor and free-wheeling diode integrated
- ♦ Adjustment of the regulator cut-off current with external resistor
- ♦ Integrated 100kHz oscillator without external components
- ♦ Switching frequency above the audible range
- ♦ Internal reference voltages
- ♦ Two downstream 5V series regulators with 200mA/25mA output current
- ♦ Small residual ripple with low capacitances in the µF range
- ♦ Fault message at overtemperature and undervoltage at current-limited open-collector output
- ♦ Shutdown of switching regulator at overtemperature
- ♦ ESD protection
- ♦ SO8 package and only few external components
- ◊ Option: enhanced temperature range of -40..85°C
- ◊ **iC-WDS** for input voltages of up to 36Vdc

APPLICATIONS

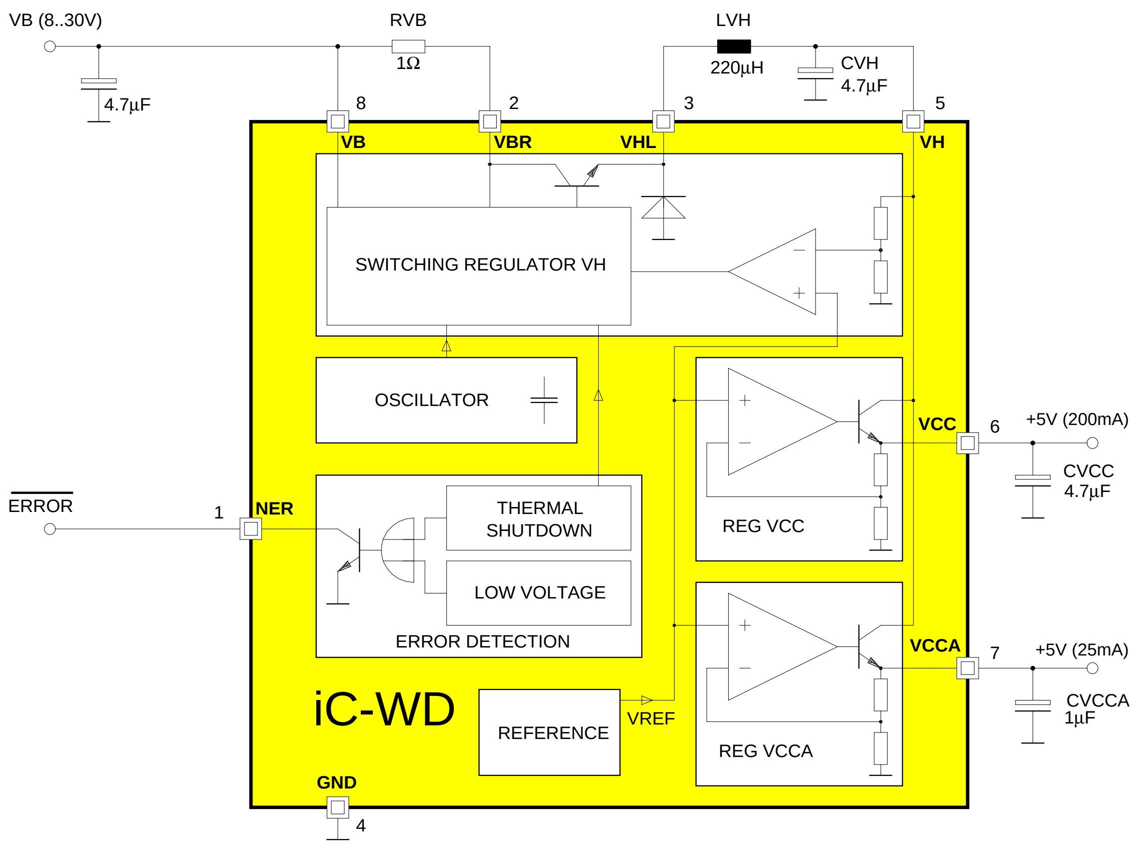
- ♦ 5V supply from 24V industrial network

PACKAGES



SO8

BLOCK DIAGRAM



Rev A0

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DESCRIPTION

The device iC-WD/WDS is a monolithic switching regulator with 2 downstream 5V series regulators. In view of the high efficiency of the step-down regulator for an input voltage range of 8V to 30(36)V, the iC-WD is well-suited for applications in industry which require stabilized 5V power supply with minimal power dissipation and few components.

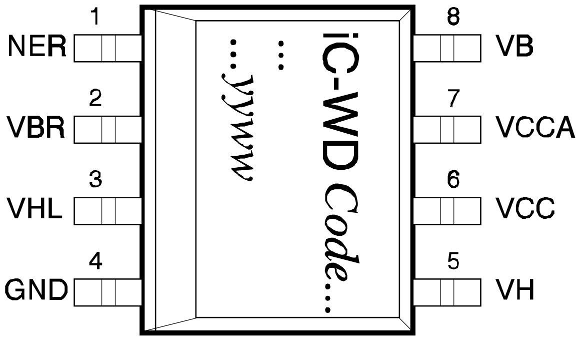
Switching transistor, free-wheeling diode and oscillator are integrated, limiting the necessary external elements for the switching regulator to the inductor, the back-up capacitor and one resistor. This resistor determines the regulator's cut-off current and thus its efficiency in the particular application at hand.

The downstream series regulators have relatively small smoothing capacitors in the µF range and thus feature a low residual ripple. The output voltages have an internal reference and are specified as 5V ±5% in the entire operating and temperature range. The use of two mutually independent series regulators makes it possible to isolate the voltage supply of sensitive analog circuits or sensors from the supply for logic and driver devices.

The chip temperature and the 5V output voltages are monitored. A fault is signalled via the current-limited open-collector output NER, for example by an LED display or a logical link with other fault signals from the system. In the event of overtemperature, the switching regulator is switched off to reduce the power dissipation of the chip.

PACKAGES SO8 to JEDEC Standard

PIN CONFIGURATION SO8
(top view)



PIN FUNCTIONS

No.	Name	Function
1	NER	Fault Message Output
2	VBR	Pin for shunt
3	VHL	Pin for inductor
4	GND	Ground (reference potential)
5	VH	Intermediate Voltage
6	VCC	5V Output (200mA)
7	VCCA	5V Output (25mA)
8	VB	Supply Voltage

ABSOLUTE MAXIMUM RATINGS

Values beyond which damage may occur; device operation is not guaranteed.

Item	Symbol	Parameter	Conditions	Fig.	Min.	Max.	Unit
G001	VB	Supply Voltage			-0.3	31	V
G002	V(VBR)	Voltage at VBR			-0.3	31	V
G003	I(VHL)	Current in VHL	Peak duration ≤ 50µs		-800	800	mA
G004	V(VH)	Voltage at VH			-0.3	8	V
G005	I(VCC)	Current in VCC			-500	4	mA
G006	I(VCCA)	Current in VCCA			-100	4	mA
G007	V(NER)	Voltage at NER			-0.3	31	V
E001	Vd()	ESD Susceptibility at all pins	MIL-STD-883, Method 3015, HBM 100pF discharged through 1.5kΩ			2	kV
TG1	Tj	Junction Temperature			-40	150	°C
TG2	Ts	Storage Temperature			-40	150	°C
iC-WDS 36V version Max. ratings for iC-WD are valid with the following replacements:							
G001	VB	Supply Voltage			-0.3	38	V
G002	V(VBR)	Voltage at VBR			-0.3	38	V
G007	V(NER)	Voltage at NER			-0.3	38	V

THERMAL DATA

Operating Conditions: VB= 8..30V (iC-WDS: VB= 8..36V), L_{VH}= 220µH, Ri(L_{VH})< 2Ω, C_{VH}= 4.7µF, R_{VB}= 1Ω

Item	Symbol	Parameter	Conditions	Fig.	Min.	Typ.	Max.	Unit
T1	Ta	Operating Ambient Temperature Range (extended temperature range on request)			-25		70	°C
T2	Rthja	Thermal Resistance Chip to Ambient	SMD mounting on PCB, without special cooling				170	K/W
T3	Rthja	Thermal Resistance Chip to Ambient	SMD mounting on PCB, with approx. 3cm² cooling surface (see Demo Board)				100	K/W

All voltages are referenced to ground unless otherwise noted.
All currents into the device pins are positive; all currents out of the device pins are negative.

ELECTRICAL CHARACTERISTICS

Operating Conditions: VB= 8..30V (iC-WDS: VB= 8..36V)
L_{VH}= 220µH, Ri(L_{VH})< 2Ω, C_{VH}= 4.7µF, R_{VB}= 1Ω, Tj= -40..125°C, unless otherwise noted

Item	Symbol	Parameter	Conditions	Tj °C	Fig.	Min.	Typ.	Max.	Unit
Total Device									
001	VB	Permissible Supply Voltage Range				8		30	V
Series Regulator VCC (5V/200mA)									
101	VCCnom	Output Voltage	I(VCC)= -200..0mA			4.75	5.00	5.25	V
102	I(VCC)	Permissible Load Current				-200		0	mA
103	C_{VCC}	Min. Output Capacity for Stability				4.7			µF
104	VCCrip	Residual Ripple	Demo Board: I(VCC)= -200mA, I(VCCA)= -20mA	27	8		35		mVss
Series Regulator VCCA (5V/25mA)									
201	VCCAnom	Output Voltage	I(VCCA)= -25..0mA			4.75	5.00	5.25	V
202	I(VCCA)	Permissible Load Current				-25		0	mA
203	C_{VCCA}	Min. Output Capacity for Stability				1			µF
204	VCCArip	Residual Ripple	Demo Board: I(VCC)= -200mA, I(VCCA)= -20mA	27	8		30		mVss
Switching Regulator VB, VBR, VHL, VH									
301	I0(VB)	Quiescent Current in VB	I(VCC)= 0, I(VCCA)= 0; VB= 12V VB= 24V VB= 30V	 27 27 27			 4.5 3.0 2.5		 mA mA mA
302	I(VB)	Current in VB with partial load	I(VCC)+I(VCCA)= -100mA; VB= 12V VB= 24V VB= 30V	 27 27 27			 72 37 30		 mA mA mA
303	I(VB)	Current in VB with full load	I(VCC)+I(VCCA)= -200mA; VB= 12V VB= 24V VB= 30V	 27 27 27			 132 69 55		 mA mA mA
304	C_{VH}	Charging Capacitor at VH				4.7			µF
305	R(C_{VH})	Series Resistance of C_{VH} for stability						12	Ω
306	f0(VHL)	Switching Frequency with no load	I(VCC)= 0, I(VCCA)= 0			20			kHz
307	fl(VHL)	Switching Frequency with load	I(VCC)+I(VCCA)= -200mA	 27		70	 90	120	kHz kHz
308	V0(VH)	No-load Voltage VH	I(VCC)= 0, I(VCCA)= 0, VB= 30V	 27			 7	7.5	V V
309	Vl(VH)	Voltage VH with load	I(VCC)+I(VCCA)= -200mA, VB= 8V	 27		6	 6.3		V V
310	I_{off}	Max. Cut-off Current in VHL	VH < Vl(VH), R_{VB}= 1Ω			-500	-460	-400	mA
Error Detection NER									
401	Toff	Thermal Shutdown Threshold				130		150	°C
402	Thys	Thermal Shutdown Hysteresis				3		15	°C
403	ΔVCC ΔVCCA	Relative Undervoltage Threshold at VCC, VCCA	ΔVCC= VCCnom -VCCoff, ΔVCCA= VCCAnom -VCCAoff;			200	400	600	mV
404	VCChys VCCAhys	Undervoltage Hysteresis				100		350	mV

ELECTRICAL CHARACTERISTICS

Operating Conditions: VB= 8..30V (iC-WDS: VB= 8..36V)
L_{VH}= 220µH, Ri(L_{VH})< 2Ω, C_{VH}= 4.7µF, R_{VB}= 1Ω, Tj= -40..125°C, unless otherwise noted

Item	Symbol	Parameter	Conditions	Tj °C	Fig.	Min.	Typ.	Max.	Unit
Error Detection NER (continued)									
405	Vs(NER)	Saturation Voltage lo at NER	I(NER)= 5mA					0.7	V
406	Isc(NER)	Short-Circuit Current lo in NER	V(NER)= 1..30V	 -40 27 70 125		5	 15 12 10 8	21	mA mA mA mA mA
407	I0(NER)	Collector Off-State Current in NER	NER= off, V(NER)= 0..30V			0		10	µA
iC-WDS 36V version Characteristics for iC-WD are valid with the following replacements:									
001	VB	Permissible Supply Voltage Range				8		36	V
308	V0(VH)	No-Load Voltage VH	I(VCC)= 0, I(VCCA)= 0, VB= 36V					7.5	V
406	Isc(NER)	Short-Circuit Current lo in NER	V(NER)= 1..36V			5	15	21	mA
407	I0(NER)	Collector Off-State Current in NER	NER= off, V(NER)= 0..36V			0		10	µA

FUNCTIONAL DESCRIPTION

SWITCHING REGULATOR

Fig. 1 illustrates the operating principle of the switching regulator in simplified form. When the switch S closes in steady-state condition, a linearly increasing charging current for the capacitor C_{VH} flows through the coil L_{VH} in addition to the load current in R_L. The energy from the supply VB is stored in the coil's magnetic field.
When the switch opens, the current flows via the diode through the coil; its energy content is supplied to capacitor and load.

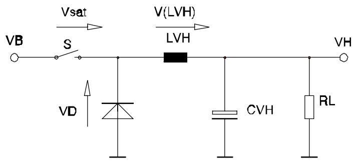


Fig. 1: Principle of operation

The block diagram on page 1 shows the iC-WD/WDS with typical wiring. The internally generated clock pulse closes the switch between VBR and VHL and the current in the coil rises (charging phase). A manipulated variable, ΔV_R in accordance with the regulating characteristic in Fig. 4, is obtained from the voltage VH and the internal reference voltage and is compared to the voltage at shunt R_{VB}. When the cut-off current $I_{off}=\Delta V_R / R_{VB}$ is reached, the switch opens and the coil current runs free via the integrated power diode (discharge phase). When the next clock signal occurs, this charging and discharging process is repeated. Fig. 2 shows the resultant current and voltage characteristics.
The current rise (t_r) and fall times (t_f) depend on the voltage VH at the inductor. The following approximation applies:

$$t_r = L_{VH}\frac{I_{off}}{VB - V_{sat} - VH} \qquad t_f = L_{VH}\frac{I_{off}}{VH + V_D} \tag{1}$$

$V_{sat} = VB - VHL$: Saturation voltage of the switching transistor plus voltage drop at R_{VB}
V_D : Forward voltage of the free-wheeling diode

The current dependencies of the saturation and diode forward voltage (Fig. 6 and 7) are ignored here, as are the losses due to the internal resistance of the coil. The regulator operates at a constant frequency under load. To prevent VH from rising without load, the oscillator frequency is reduced as the level of voltage VH rises (Fig.5).

The following three operating states of the regulator are described as a function of the supply voltage and the load current:

SWITCHING REGULATOR: Intermittent flow

When charging and discharging operation are concluded within a single clock pulse period ($t_r+t_f<T$) and the coil current drops to zero in each case, "intermittent flow" prevails (Fig. 2). This is the case when the supply voltage is sufficiently high or the load current sufficiently low. The current-carrying capacity and power consumption of the regulator can be specified simply for this operating state. Since both the charging and the discharging current flow in VH, the initial approximation of the mean current-carrying capacity of VH is:

$$I_L(VH) = \frac{1}{2} I_{off}\frac{t_r + t_f}{T} \tag{2}$$

$T=1/f_{osz}$: Period of internal oscillator (Fig. 5)
For load current I_L at output VH, the iC-WD/WDS adjusts the cut-off current I_{off} to the following value ($VB>VH+V_{sat}$):

$$I_{off} = \sqrt{2\, I_L(VH)\,\frac{T}{L_{VH}}\,\frac{1}{\frac{1}{VB - V_{sat} - VH} + \frac{1}{VH + V_D}}} \tag{3}$$

Since current is only drawn from supply voltage VB during the charging phase, the mean current consumption is:

$$I(VB) = I_{off}\frac{t_r}{T} + I_0(VB) \tag{4}$$

$I_0(VB)$: current consumption without load at VCC, VCCA (no-load operation)

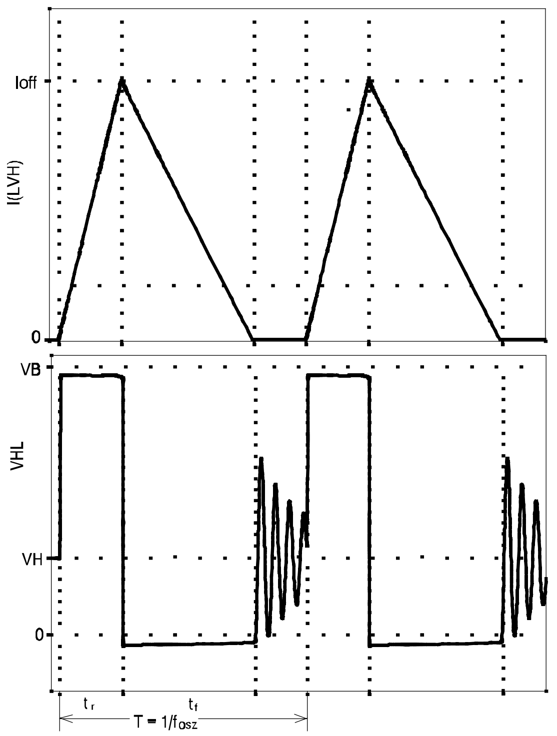


Fig. 2: Intermittent flow

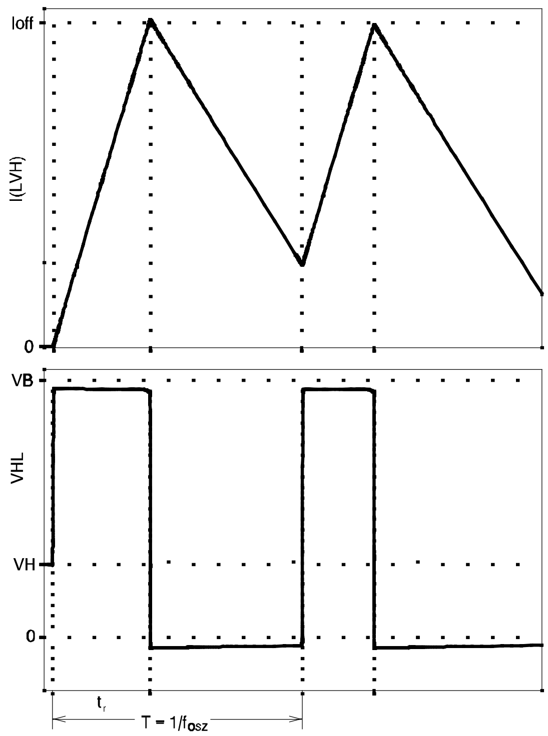


Fig. 3: Continuous flow

SWITCHING REGULATOR: Continuous flow

If the inductor receives recharge with the next clock signal before the coil current has run free, no gap is created in the current. Such "continuous flow" (Fig. 3) occurs when the supply voltage is too low or the load current too high. Since the charging process begins at various current levels not equal to zero, the timing and the required cut-off current are difficult to express. In general, fluctuations occur in the clock frequency at the time constants of the charging and discharging phase, which in turn depend on the of supply voltage and the load current. Since no current gap occurs, the cut-off current may be lower than during intermittent flow (at the same load). The losses in the switching transistor, in the free-wheeling diode and due to the internal resistance of the inductor are consequently lower; the efficiency of the regulator is thus higher. In addition, interference due to the internal resistance of supply voltage source and standby capacitor C_{VH} is lower. Depending on the model and quality of the coil, however, the low frequent fluctuations may be audible.

SWITCHING REGULATOR: Operation at low supply voltage

A third operating state occurs when the supply voltage VB is scarcely higher than VH. The cut-off current can no longer be reached in this case since: $(VB\text{-}VH\text{-}V_{sat}) / R_{LVH} < I_{off}$. The switching transistor is switched on continuously and VH reaches: $VH = VB\text{-}V_{sat}\text{-}I(VH) \times R_{LVH}$. Factoring in this special feature makes it possible to operate the iC-WD/WDS even at low supply voltage. Operability is still guaranteed at VB≈ 7.6 V. Nonetheless, the maximum current-carrying capacity depends on the coil's internal resistance and supply voltage VB. The transition from regulator mode to continuously activated transistor is fluid. To avoid feedback of interference voltage from VH to VCC or VCCA the size of standby capacitor C_{VH} should be increased for this type of operation (e.g. 22 µF).

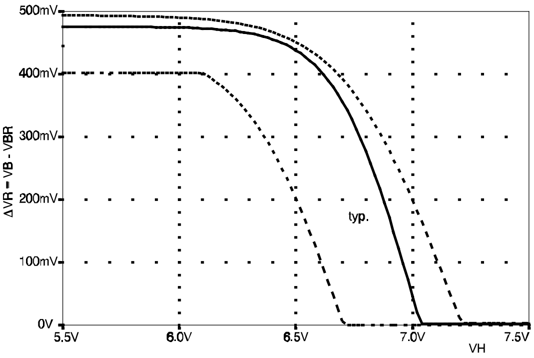


Fig. 4: Regulating characteristic ΔV_R = f(VH)

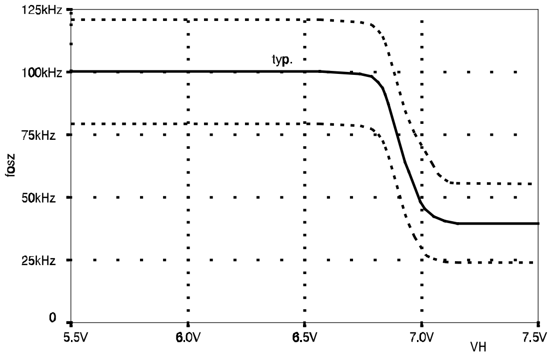


Fig. 5: Oscillator Frequency

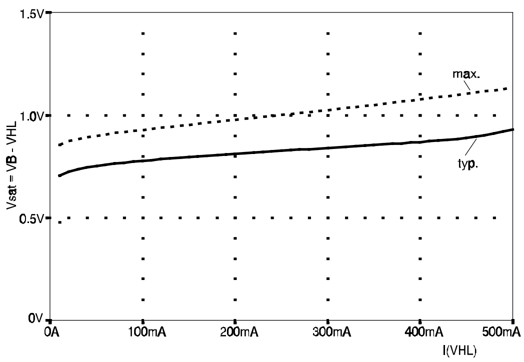


Fig. 6: Sat. voltage of switching transistor

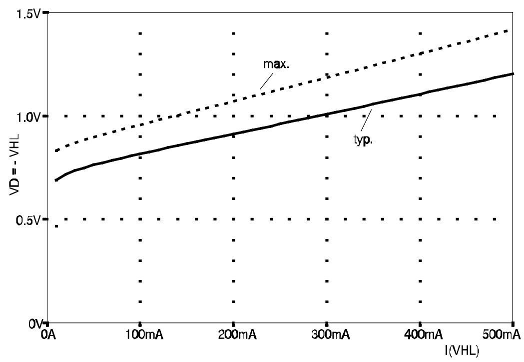


Fig. 7: Forward voltage of free-wheeling diode

SERIES REGULATORS VCC and VCCA

To obtain the lowest possible interference voltage even with the small smoothing capacitor C_{VH}, two independent series regulators with a npn emitter follower stage are connected downstream of intermediate voltage VH. The Output voltages VCC or VCCA are constantly 5.0 ±5%. The suppression of interference voltage for the output voltages is best when VH is also no lower than 6.0V dynamically.
The series regulators are compensated internally, hence they are stable during no-load operation, without external capacitance. Stability over the entire load range is ensured by the minimum capacitance values for C_{VCC} and C_{VCCA} given in the electrical characteristics. Current-limited outputs are used as protection against destruction in the event of a short circuit.

FAULT EVALUATION

The two output voltages VCC and VCCA are monitored. When the voltage drops below the undervoltage threshold (due to overload, etc.), a message is sent to the current-limited open-collector output NER (active low). The chip temperature is also checked. In the event of overtemperature the switching regulator is turned off and it is not enabled against until the chip temperature has declined. This thermal shutdown of the regulator is indicated by NER=low.
Since the fault output NER is current-limited, an LED can be connected directly for the optical message display, however the additional power dissipation which occurs

$$P_v = I(NER) \times (VB - V_{fw}(LED))$$

must be taken into account. A resistor R_{LED} in series with the LED can reduce the additional chip power dissipation in the event of a fault. CMOS- or TTL-compatible logic inputs can be activated with a pull-up resistor at NER.

APPLICATIONS INFORMATION

DIMENSIONING

The size of shunt R_{VB} determines the cut-off current I_{off}. By varying this in combination with the value for the inductor L_{VH}, the power input, the efficiency and the timing can be adapted to the application.

Normally the supply voltage range and the maximum output current for VCC and VCCA must specified. Define whether or not only intermittent flow is desired. The maximum inductance L_{VH} can be estimated on the following basis: In the worst situation, charging and discharging process last exactly one period, which is the case at minimum supply power. The cut-off current adjusts to $I_{off}=2\times I_{Lmax}(VH)$. From equation (1) is follows that:

$$L_{VHmax} = \frac{T_{min.}}{2\ I_{Lmax}(VH)} \cdot \frac{1}{\frac{1}{VB_{min.} - V_{sat} - VH} + \frac{1}{VH + V_D}}$$

Using equation (3) it is possible to determine the maximum cut-off current for intermittent flow. The maximum value for VB must be inserted:

$$I_{off\,max} = \sqrt{2 \cdot I_{Lmax}(VH)\ \frac{T_{max}}{L_{VH}} \cdot \frac{1}{\frac{1}{VB_{max} - V_{sat} - VH} + \frac{1}{VH + V_D}}}$$

The shunt R_{VB} can be dimensioned with this information. ΔV_{Rmax} can be obtained from Fig. 4:

$$R_{VB} = \frac{\Delta V_{R\,max}}{I_{off\,max}}$$

EXAMPLE

Specified are: VB= 18V .. 30V, I_{Lmax} = 100mA; the maximum inductance can be estimated at:

$$L_{VHmax} = \frac{1/\ 125kHz}{200mA} \cdot \frac{1}{\frac{1}{18V - 1.1V - 7.0V} + \frac{1}{7.0V + 1.1V}} = 178\mu H$$

The inductance selected is 150 µH, for example. Consequently, the maximum required cut-off current and the shunt are found to be:

$$I_{off\,max} = \sqrt{2 \cdot 100mA\ \frac{1/\ 75kHz}{150\mu H} \cdot \frac{1}{\frac{1}{30V - 1.1V - 7V} + \frac{1}{7V + 1.1V}}} = 324mA$$

$$\Rightarrow\ R_{VB} = \frac{400mV}{324mA} \approx 1.2\Omega$$

It is not always possible to dimension the circuit for intermittent flow, particularly not when high output currents are required with a low supply voltage. Permitting continuous flow may prove conducive to higher efficiency and less interference. The inductance selected is to be higher than in the above formula; the equations for maximum cut-off current and the shunt can be used with the selected coil. It is simplest to ascertain the correct dimensioning by experimentation in a test set-up (Demo Board). The dimensioning shown in the block diagram (L_{VH} = 220µH, R_{VB}= 1Ω is suitable for maximum performance throughout the entire specification range.

SELECTING THE COMPONENTS

Since the coil must not to become saturated, it should be designed for maximum cut-off current. This can be checked by testing the coil current with a current probe: In the event of saturation the current rises much more sharply than with low currents. A low internal resistance of the coil reduces the losses and increases the regulator's efficiency. When the supply voltage is low, this internal resistance can determine the maximum available output current (equation 4).
The EMI (electromagnetic interference) caused by the coil should be taken into account. Toroidal core coils have little noise radiation but are expensive and difficult to install. Bar cores are reasonably priced and easy to handle but emit higher radiation. Reasonably priced RF chokes in the range of a few tens to a few hundreds µH are suitable for modest EMI requirements (*).
Additional interference may be caused by decaying of the voltage at VHL when the coil current drops to zero (Fig. 2). Parasitic capacitances at VHL form an oscillating circuit with the coil. This undesirable oscillating circuit can be damped to an uncritical magnitude by installing a resistor (> 10kΩ) parallel to the coil.

The selection of the standby capacitor C_{VH} is unproblematic. The ripple of intermediate voltage VH, due to the series regulators, does not affect the output voltages VCC and VCCA. Therefore a low capacitance level without special demands on the internal resistance is sufficient. A combination of electrolytic and ceramic capacitor (e.g. 4.7µF/100nF) is recommended. Tantalum capacitors are also possible when they are allowed to operate at ac amplitudes like the residual ripple of voltage VH.

The stability of the series regulators is guaranteed for the entire load range when the values for C_{VCC} and C_{VCCA} named in the electrical characteristics are selected. The suppression of interference voltage is improved by small capacitor series resistors. The combination of tantalum and ceramic capacitors is also recommended in this case. If one of the two outputs remains open, it's capacitor can be eliminated.

To avoid feedback of interference from supply voltage VB onto output voltages VCC and VCCA, provide blocking directly at pin VB. A combination of tantalum and ceramic capacitors is also recommended in this case (several µF/100 nF).

*: e.g.: Siemens Matsushita B78108-S1224-J (220µH/250mA, axial leads),
TDK series NLC565050T-... (SMD), TOKO series 10RF459-... (SMD shielded)

PRINTED CIRCUIT BOARD LAYOUT

The GND path from the switching regulator and from each series regulator should be strictly separated to avoid cross couplings. The neutral point of all GND conductors is the GND connection at the iC-WD/WDS. It is possible and not critical, however, to run the GND of the supply VB and the base point of capacitor C_{VH} together to the neutral point. The capacitor C_{VH} should be very close to the pin VH however. To keep down the decay at the open end of the coil (pin VHL), the capacitance of this connection should be low, that means the connection should be short.

The blocking capacitors of supply voltage VB are to be placed as close as possible to pins VB and GND. The capacitors for the outputs VCC and VCCA should be placed directly by the load to also block interferences which are coupled via the wiring to the load. The printed circuit conductor between VB, the shunt R_{VB}, and VBR should have a low impedance, since voltage drops in the supply path change the effective size of the shunt and reduce the maximum cut-off current.

A substantial portion of the heat produced in the iC-WD/WDS due to power dissipation is drawn off via the pins. Printed circuit conductors with a large area are therefore advantageous for heat dissipation. Aspects of automatic placement and solderability must also be taken into consideration in the design. The layout implemented in the WD Demo Board may serve as a model for suitable PCB designs.

DEMO BOARD

The iC-WD device is equipped with a Demo Board for test purposes. The following figures show the wiring as well as the top and bottom layout of the test PCB.

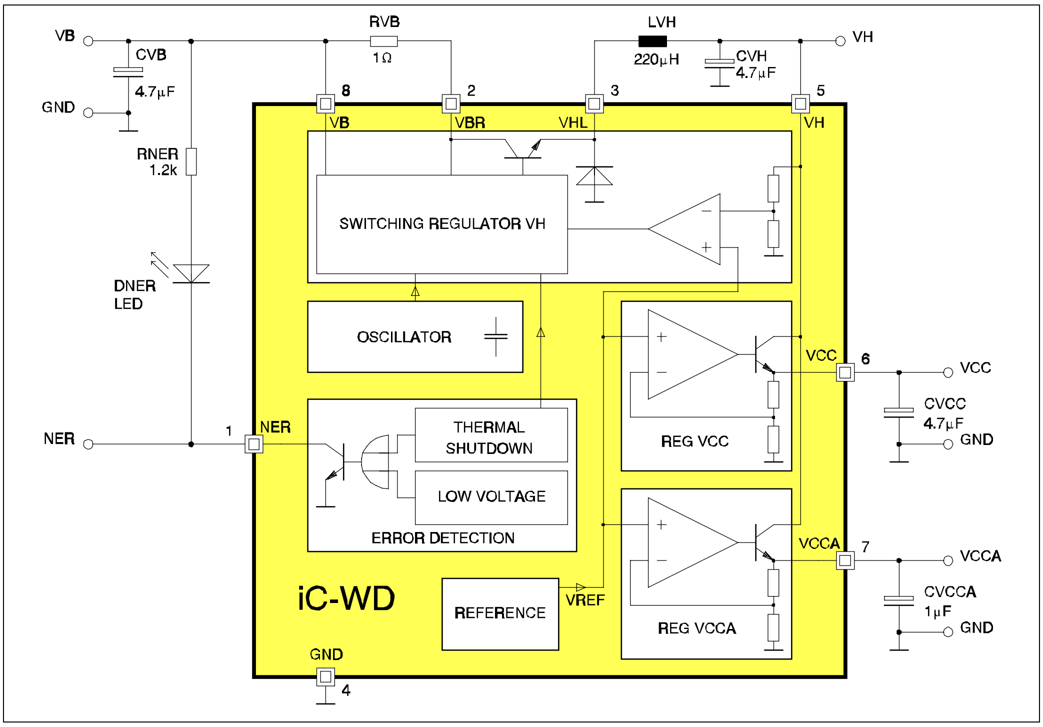


Fig. 8: Schematic diagram of the Demo Board

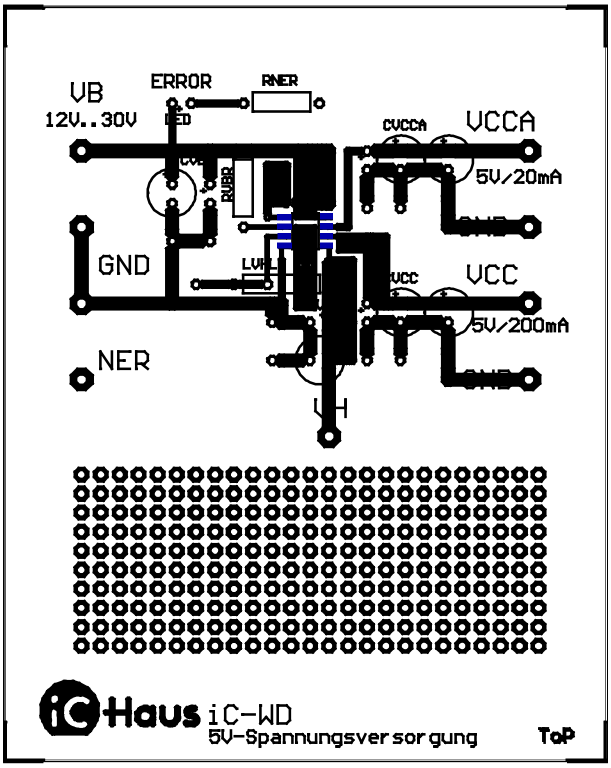


Fig. 9: Demo Board (components side)

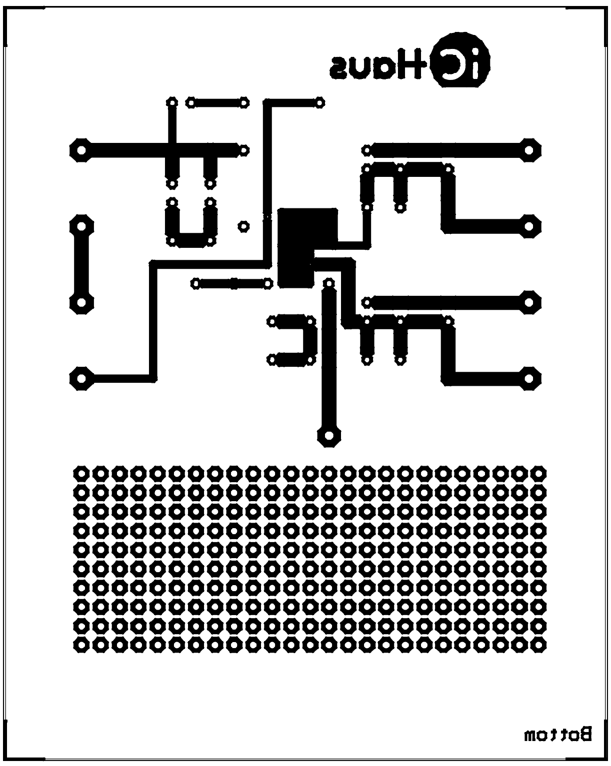


Fig. 10: Demo Board (solder dip side)

ORDERING INFORMATION

Type	Package	Order designation
iC-WD	SO8	iC-WD-SO8
iC-WDS	SO8	iC-WDS-SO8
WD Demo Board	-	WD Demo Board

For information about prices, terms of delivery, options for other case types, etc., please contact:

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