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Document Number: MC33981
Rev. 11.0, 7/2012

RoHS

Single High Side Switch (4.0 mOhm), PWM clock up to 60 kHz

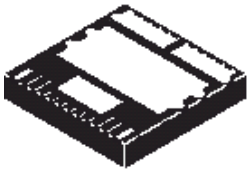
33981

HIGH SIDE SWITCH

The 33981 is a high frequency, self-protected 4.0 mΩ $R_{DS(ON)}$ high side switch used to replace electromechanical relays, fuses, and discrete devices in power management applications.

The 33981 can be controlled by pulse-width modulation (PWM) with a frequency up to 60 kHz. It is designed for harsh environments, and it includes self-recovery features. The 33981 is suitable for loads with high inrush current, as well as motors and all types of resistive and inductive loads.

The 33981 is packaged in a 12 x 12 mm non-leaded power-enhanced PQFN package with exposed tabs.



Bottom View

FK (Pb-Free Suffix)
98ARL10521D
16-PIN PQFN (12 X 12)

Features

- Single 4.0 mΩ $R_{DS(ON)}$ maximum high side switch
- PWM capability up to 60 kHz with duty cycle from 5% to 100%
- Very low standby current
- Slew-rate control with external capacitor
- Over-current and over-temperature protection, under-voltage shutdown, and fault reporting
- Reverse battery protection
- Gate drive signal for external low side N-channel MOSFET with protection features
- Output current monitoring
- Temperature feedback

ORDERING INFORMATION		
Device (Add R2 Suffix for Tape and Reel)	**Temperature Range (T_A)**	**Package**
MC33981BHFK	-40 to 125 °C	16 PQFN
MC33981ABHFK		

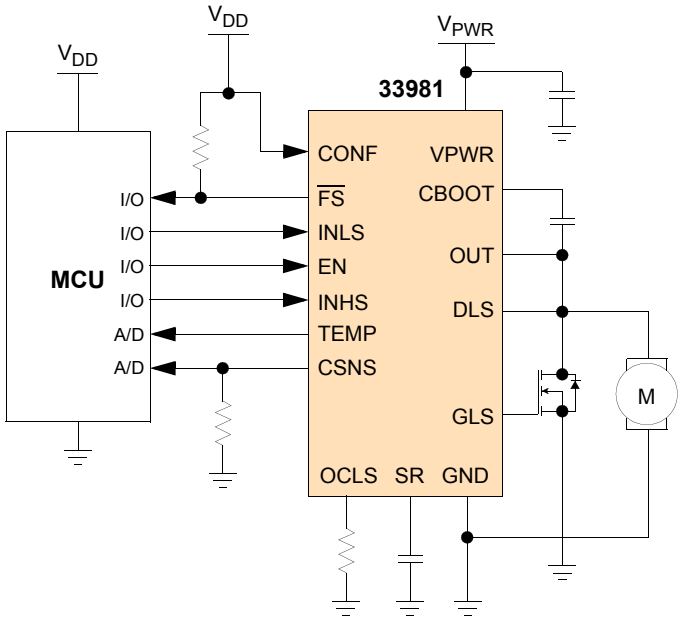


Figure 1. 33981 Simplified Application Diagram

DEVICE VARIATIONS

Table 1. Device Peak Solder Temperature

Device	Description [1]
MC33981BHFK	Original BOM and lower Peak Package Temperature solderability.
MC33981ABHFK	Improved BOM and higher Peak Package Temperature solderability.

Notes

1. PPT values can be found on Freescale's web site, or contact sales. Reference Peak Package Reflow Temperature During Reflow[6], [7]

INTERNAL BLOCK DIAGRAM

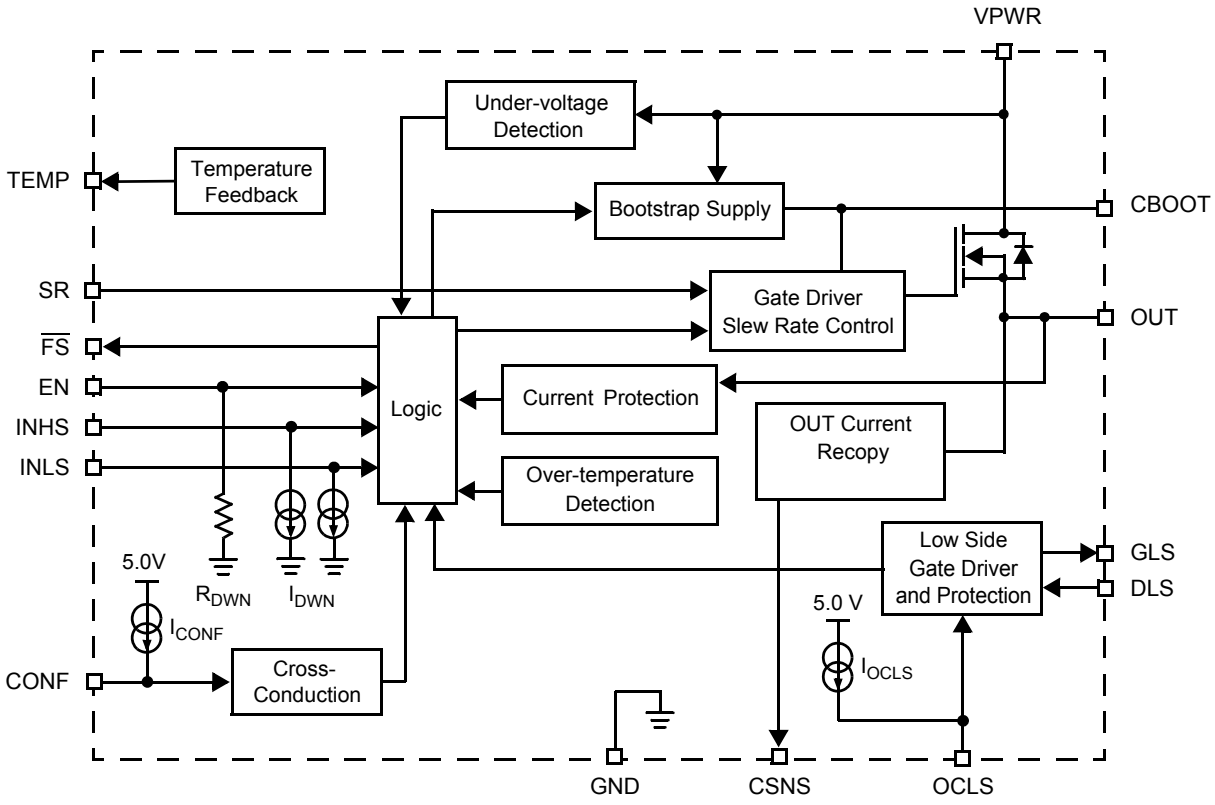


Figure 2. 33981 Simplified Internal Block Diagram

PIN CONNECTIONS

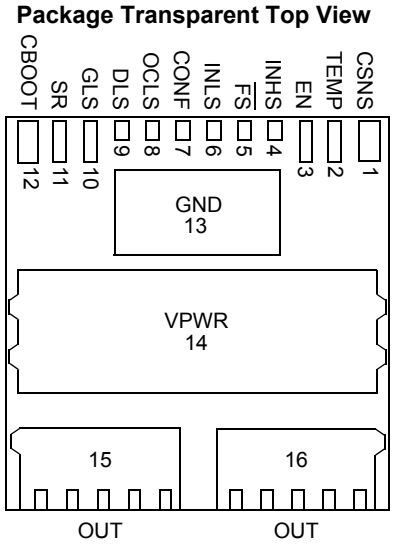


Figure 3. Pin Connections

Table 2. PIN DEFINITIONS

Descriptions of the pins listed in the table below can be found in the Functional Description section located on page 15.

Pin Number	Pin Name	Pin Function	Formal Name	Definition
1	CSNS	Reports	Output Current Monitoring	This pin is used to generate a ground-referenced voltage for the microcontroller (MCU) to monitor output current.
2	TEMP	Reports	Temperature Feedback	This pin is used by the MCU to monitor board temperature.
3	EN	Input	Enable (Active High)	This pin is used to place the device in a low-current Sleep mode.
4	INHS	Input	Serial Input High Side	This input pin is used to control the output of the device.
5	$\overline{FS}$	Reports	Fault Status (Active Low)	This pin monitors fault conditions and is active LOW.
6	INLS	Input	Serial Input Low Side	This pin is used to control an external low side N-channel MOSFET.
7	CONF	Input	Configuration Input	This input manages MOSFET N-channel cross-conduction.
8	OCLS	Input	Low Side Overload	This pin sets the V_{DS} protection level of the external low side MOSFET.
9	DLS	Input	Drain Low Side	This pin is the drain of the external low side N-channel MOSFET.
10	GLS	Output	Low Side Gate	This output pin drives the gate of the external low side N-channel MOSFET.
11	SR	Input	Slew Rate Control	This pin controls the output slew rate.
12	CBOOT	Input	Bootstrap Capacitor	This pin provides the high pulse current to drive the device.
13	GND	Ground	Ground	This is the ground pin of the device.
14	VPWR	Input	Positive Power Supply	This pin is the source input of operational power for the device.
15, 16	OUT	Output	Output	These pins provide a protected high side power output to the load connected to the device.

ELECTRICAL CHARACTERISTICS

MAXIMUM RATINGS

Table 3. Maximum Ratings

All voltages are with respect to ground unless otherwise noted.

Rating	Symbol	Value	Unit
ELECTRICAL RATINGS			
Power Supply Voltage Steady-state	V_{PWR}	 -16 to 41	V
Input/Output Pins Voltage[2]	INHS, INLS, CONF, CSNS, $\overline{FS}$, TEMP, EN	-0.3 to 7.0	V
Output Voltage Positive Negative	V_{OUT}	 41.0 -5.0	V
Continuous Output Current[3]	I_{OUT}	40.0	A
CSNS Input Clamp Current	$I_{CL(CSNS)}$	15.0	mA
EN Input Clamp Current	$I_{CL(EN)}$	2.5	mA
SR Voltage	V_{SR}	-0.3 to 54.0	V
C_{BOOT} Voltage	C_{BOOT}	-0.3 to 54.0	V
OCLS Voltage	V_{OCLS}	-5.0 to 7.0	V
Low Side Gate Voltage	V_{GLS}	-0.3 to 15.0	V
Low Side Drain Voltage	V_{DLS}	-5.0 to 41.0	V
ESD Voltage[4] Human Body Model (HBM) Charge Device Model (CDM) Corner Pins (1, 12, 15, 16) All Other Pins (2-11, 13-14)	V_{ESD}	 ±2000 ±750 ±500	V

Notes

2. Exceeding voltage limits on INHS, INLS, CONF, CSNS, $\overline{FS}$, TEMP, and EN pins may cause a malfunction or permanent damage to the device.
3. Continuous high side output rating as long as maximum junction temperature is not exceeded. Calculation of maximum output current using package thermal resistance is required.
4. ESD testing is performed in accordance with the Human Body Model (HBM) (C_{ZAP} = 100 pF, R_{ZAP} = 1500 Ω) and the Charge Device Model (CDM), Robotic (C_{ZAP} = 4.0 pF).

Table 3. Maximum Ratings

All voltages are with respect to ground unless otherwise noted.

Rating	Symbol	Value	Unit
THERMAL RATINGS			
Operating Temperature Ambient Junction	 T_A T_J	 -40 to 125 -40 to 150	°C
Storage Temperature	T_{STG}	-55 to 150	°C
Thermal Resistance[5] Junction to Power Die Case Junction to Ambient	 $R_{\theta JC}$ $R_{\theta JA}$	 1.0 30.0	°C/W
Peak Package Reflow Temperature During Reflow[6], [7]	T_{PPRT}	Note 7	°C

Notes

5. Device mounted on a 2s2p test board per JEDEC JESD51-2.
6. Pin soldering temperature limit is for 40 seconds maximum duration. Not designed for immersion soldering. Exceeding these limits may cause malfunction or permanent damage to the device.
7. Freescale's Package Reflow capability meets Pb-free requirements for JEDEC standard J-STD-020. For Peak Package Reflow Temperature and Moisture Sensitivity Levels (MSL), Go to www.freescale.com, search by part number [e.g. remove prefixes/suffixes and enter the core ID to view all orderable parts. (i.e. MC33xxxD enter 33xxx), and review parametrics.

STATIC ELECTRICAL CHARACTERISTICS

Table 4. Static Electrical Characteristics

Characteristics noted under conditions 6.0 V ≤ V_{PWR} ≤ 27 V, -40 °C ≤ T_A ≤ 125 °C, unless otherwise noted. Typical values noted reflect the approximate parameter mean at T_A = 25 °C under nominal conditions, unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
POWER INPUT (VPWR)					
Battery Supply Voltage Range	V_{PWR}				V
Fully Operational		6.0	–	27.0	
Extended[8]		4.5	–	27.0	
VPWR Supply Current	$I_{PWR(ON)}$				mA
INHS = 1 and OUT Open, INLS = 0		–	10.0	12.0	
VPWR Supply Current	$I_{PWR(SBY)}$				mA
INHS = INLS = 0, EN = 5.0 V, OUT Connected to GND		–	10.0	12.0	
Sleep-state Supply Current	$I_{PWR(SLEEP)}$				µA
(V_{PWR} < 14 V, EN = 0 V, OUT Connected to GND)					
T_A = 25 °C		–	–	5.0	
T_A = 125 °C		–	–	50.0	
Under-voltage Shutdown	$V_{PWR(UV)}$	2.0	4.0	4.5	V
Under-voltage Hysteresis	$V_{PWR(UVHYS)}$	0.05	0.15	0.3	V
POWER OUTPUT (IOUT, VPWR)					
Output Drain-to-Source ON Resistance (I_{OUT} = 20 A, T_A = 25 °C)	$R_{DS(ON)25}$				mΩ
V_{PWR} = 6.0 V		–	–	6.0	
V_{PWR} = 9.0 V		–	–	5.0	
V_{PWR} = 13.0 V		–	–	4.0	
Output Drain-to-Source ON Resistance (I_{OUT} = 20 A, T_A = 150 °C)	$R_{DS(ON)150}$				mΩ
V_{PWR} = 6.0 V		–	–	10.2	
V_{PWR} = 9.0 V		–	–	8.5	
V_{PWR} = 13.0 V		–	–	6.8	
Output Source-to-Drain ON Resistance (I_{OUT} = -20 A, T_A = 25 °C)[9]	$R_{SD(ON)}$				mΩ
V_{PWR} = - 12 V		–	–	8.0	
Output Over-current Detection Level	I_{OCH}				A
9.0 V < V_{PWR} < 16 V		75	100	125	
Current Sense Ratio	C_{SR}				–
9.0 V ≤ V_{PWR} ≤ 16 V, CSNS ≤ 4.5 V		–	1/20000	–	
Current Sense Ratio (C_{SR}) Accuracy	C_{SR_ACC}				%
9.0 V ≤ V_{PWR} ≤ 16 V, CSNS ≤ 4.5 V					
Output Current					
5.0 A		-20	–	20	
15 A, 20 A, and 30 A		-15	–	15	

Notes

8. OUT can be commanded fully on, PWM is available at room. Low Side Gate driver is available. Protections and Diagnosis are not available. Min/max parameters are not guaranteed.
9. Source-Drain ON Resistance (Reverse Drain-to-Source ON Resistance) with negative polarity V_{PWR}.

Table 4. Static Electrical Characteristics (continued)

Characteristics noted under conditions 6.0 V ≤ V_{PWR} ≤ 27 V, -40 °C ≤ T_A ≤ 125 °C, unless otherwise noted. Typical values noted reflect the approximate parameter mean at T_A = 25 °C under nominal conditions, unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
POWER OUTPUT (VPWR) (continued)					
Current Sense Voltage Clamp I_{CSNS} = 15 mA	$V_{CL(CSNS)}$	4.5	6.0	7.0	V
Current Sense Leakage[10] INHS = 1 with OUT opened of load or INHS = 0	$I_{LEAK(CSNS)}$	0	13	17	µA
Over-temperature Shutdown	T_{SD}	160	175	190	°C
Over-temperature Shutdown Hysteresis[11]	T_{SDHYS}	5.0	–	20	°C
LOW SIDE GATE DRIVER (VPWR, VGLS, VOCLS)					
Low Side Gate Voltage V_{PWR} = 6.0 V V_{PWR} = 9.0 V V_{PWR} = 13 V V_{PWR} = 27 V	V_{GLS}	 5.0 8.0 12.0 12.0	 5.4 8.4 12.4 12.4	 6.0 9.0 13.0 13.0	V
Low Side Gate Sinked Current V_{GLS} = 2.0 V, V_{PWR} = 13 V	I_{GLSNEG}	–	100	–	mA
Low Side Gate Sourced Current V_{GLS} = 2.0 V, V_{PWR} = 13 V	I_{GLSPOS}	–	100	–	mA
Low Side Overload Detection Level versus Low Side Drain Voltage V_{OCLS} - V_{DLS}, (V_{OCLS} ≤ 4.0 V)	V_{DS_LS}	-50	–	+50	mV
CONTROL INTERFACE (CONF, INHS, INLS, EN, OCLS)					
Input Logic High-voltage (CONF, INHS, INLS)	V_{IH}	3.3	–	–	V
Input Logic Low-voltage (CONF, INHS, INLS)	V_{IL}	–	–	1.0	V
Input Logic Voltage Hysteresis (CONF, INHS, INLS)	V_{INHYS}	100	600	1200	mV
Input Logic Active Pull-down Current (INHS, INLS)	I_{DWN}	5.0	10	20	µA
Enable Pull-down Resistor (EN)	R_{DWN}	100	200	400	kΩ
Enable Voltage Threshold (EN)	V_{EN}		2.5		V
Input Clamp Voltage (EN) I_{EN} < 2.5 mA	V_{CLEN}	7.0	–	14	V
Input Forward Voltage (EN)	$V_{F(EN)}$	-2.0	–	-0.3	V
Input Active Pull-up Current (OCLS)	I_{OCLSp}	50	100	200	µA
Input Active Pull-up Current (CONF)	I_{CONF}	5.0	10	20	µA

Notes

10. This parameter is achieved by the design characterization by measuring a statistically relevant sample size across process variations but not tested in production.
11. Parameter is guaranteed by process monitoring but is not production tested.

Table 4. Static Electrical Characteristics (continued)

Characteristics noted under conditions 6.0 V ≤ V_{PWR} ≤ 27 V, -40 °C ≤ T_A ≤ 125 °C, unless otherwise noted. Typical values noted reflect the approximate parameter mean at T_A = 25 °C under nominal conditions, unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
CONTROL INTERFACE (CONF, INHS, INLS, EN, OCLS) (continued)					
$\overline{FS}$ Tri-state Capacitance[12]	C_{FS}	–	–	20	pF
$\overline{FS}$ Low-state Output Voltage $I_{\overline{FS}}$ = -1.6 mA	V_{FSL}	–	0.2	0.4	V
Temperature Feedback T_A = 25°C for V_{PWR} = 14 V	V_{TFEED}	3.35	3.45	3.55	V
Temperature Feedback Derating[12]	DT_{FEED}	-8.5	-8.9	-9.3	mV/°C

Notes

12. Parameter is guaranteed by process monitoring but is not production tested.

DYNAMIC ELECTRICAL CHARACTERISTICS

Table 5. Dynamic Electrical Characteristics

Characteristics noted under conditions 6.0 V ≤ V_{PWR} ≤ 27 V, -40 °C ≤ T_A ≤ 125 °C, unless otherwise noted. Typical values noted reflect the approximate parameter mean at T_A = 25 °C under nominal conditions, unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
CONTROL INTERFACE AND POWER OUTPUT TIMING (CBOOT, VPWR)					
Charge Blanking Time (CBOOT)(14)	t_{ON}	10	25	50	µs
Output Rising Slew Rate V_{PWR} = 13 V, from 10% to 90% of V_{OUT}, SR Capacitor = 4.7 nF, R_L = 5.0 Ω	SR_R	8.0	16	35	V/µs
Output Falling Slew Rate V_{PWR} = 13 V, from 90% to 10% of V_{OUT}, SR Capacitor = 4.7 nF, R_L = 5.0 Ω	SR_F	8.0	16	35	V/µs
Output Turn-ON Delay Time(15) V_{PWR} = 13 V, SR Capacitor = 4.7 nF	t_{DLYON}	200	400	700	ns
Output Turn-OFF Delay Time(16) V_{PWR} = 13 V, SR Capacitor = 4.7 nF	t_{DLYOFF}	500	1000	1500	ns
Input Switching Frequency(13)	f_{PWM}	–	20	60	kHz
Output PWM ratio at 60 kHz(17)	R_{PWM}	5.0	–	95	%
Time to Reset Fault Diagnosis (overload on high side or external low side)	$t_{RSTDIAG}$	100	200	400	µs
Output Over-current Detection Time	t_{OCH}	1.0	10	20	µs

Notes

13. The MC33981 fully operates down to DC. To reset a latched Fault the INHS pin must go low for the “Time to reset Fault Diagnosis” ($t_{RSTDIAG}$).
14. Values for CBOOT=100 nF. Refer to Sleep Mode on page 16. Parameter is guaranteed by design and not production tested.
15. Turn-ON delay time measured from rising edge of INHS that turns the output ON to V_{OUT} = 0.5 V with R_L = 5.0 Ω resistive load.
16. Turn-OFF delay time measured from falling edge of INHS that turns the output OFF to V_{OUT} = V_{PWR} -0.5 V with R_L = 5.0 Ω resistive load.
17. The ratio is measured at V_{OUT} = 50% V_{PWR} without SR capacitor. The device is capable of 100% duty cycle.

TIMING DIAGRAMS

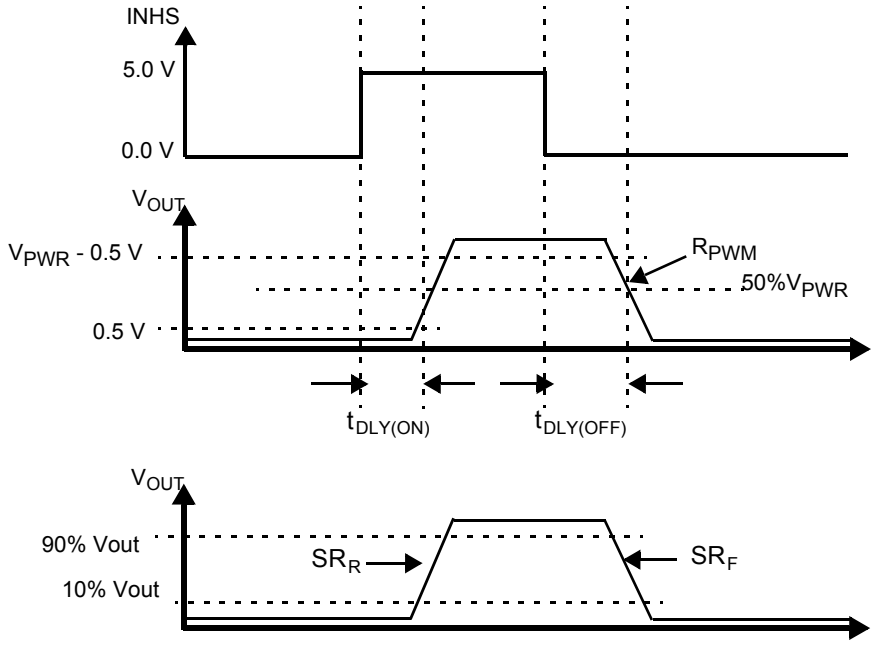


Figure 4. Time Delays Functional Diagrams

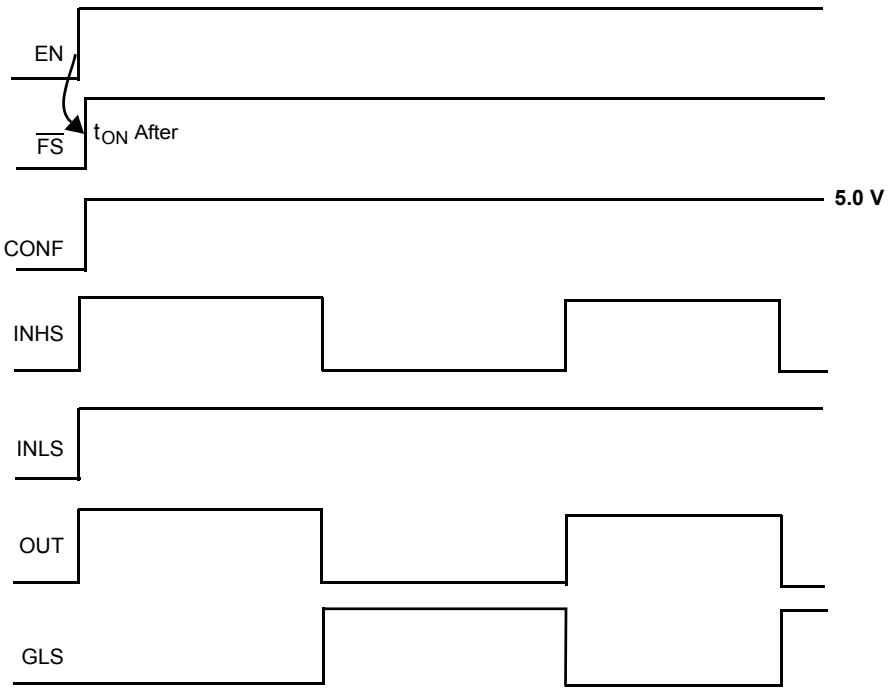


Figure 5. Normal Mode, Cross-Conduction Management

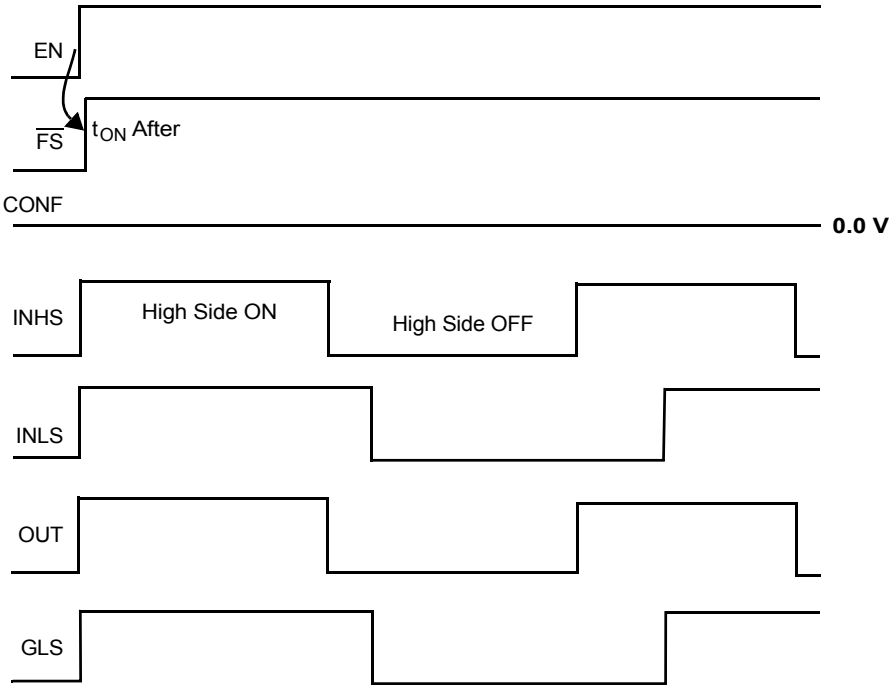


Figure 6. Normal Mode, Independent High Side and Low Side

ELECTRICAL PERFORMANCE CURVES

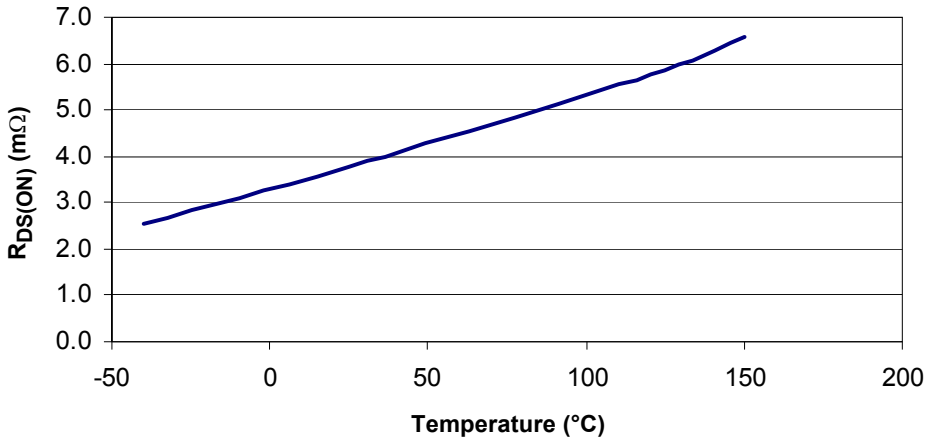


Figure 7. Typical $R_{DS(ON)}$ vs. Temperature at V_{PWR} = 13 V

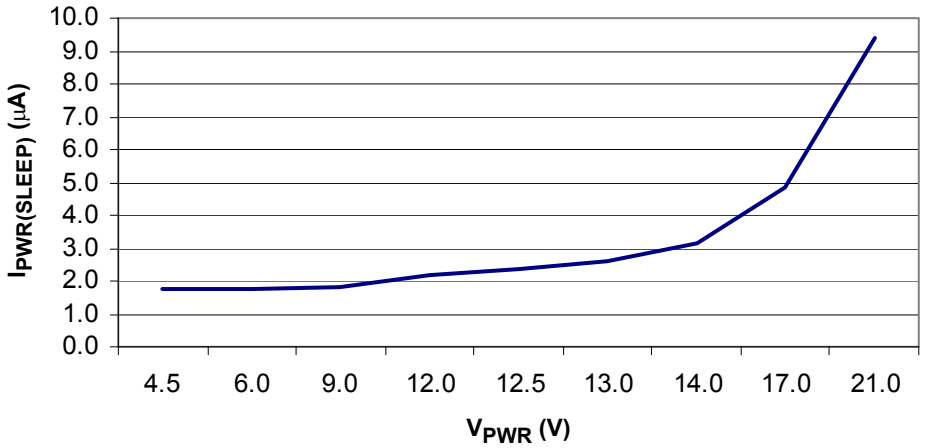


Figure 8. Typical Sleep-state Supply Current vs. V_{PWR} at 150 °C

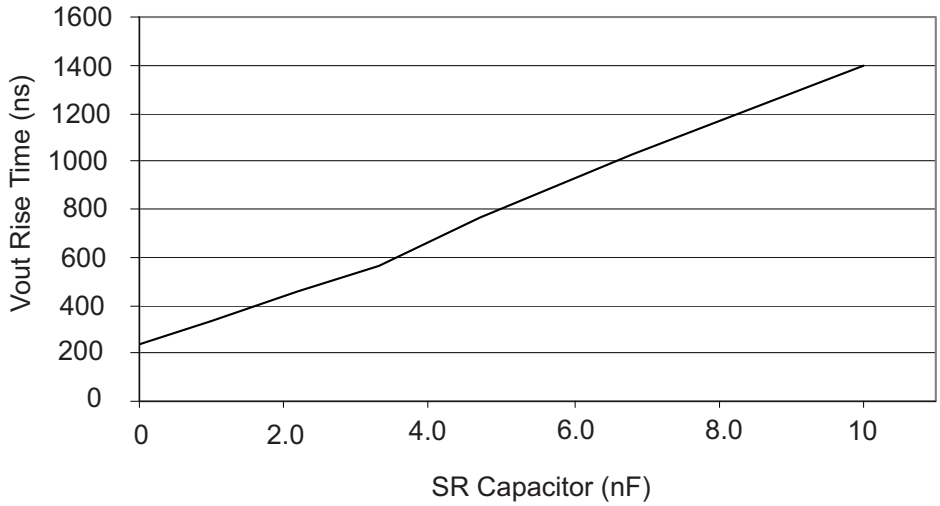


Figure 9. V_{OUT} Rise Time vs. SR Capacitor From 10% to 90% of V_{OUT} at 25 °C and V_{PWR} = 13 V

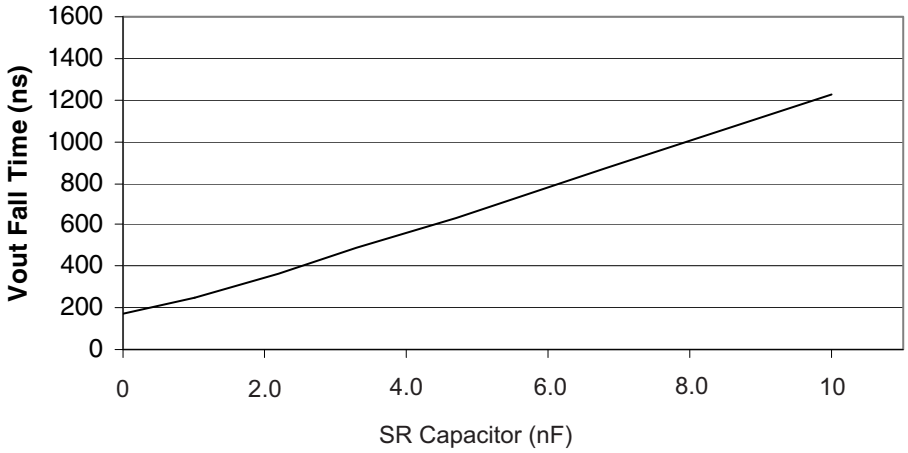


Figure 10. V_{OUT} Fall Time vs. SR Capacitor From 10% to 90% of V_{OUT} at 25 °C and V_{PWR} = 13 V

FUNCTIONAL DESCRIPTION

INTRODUCTION

The 33981 is a high-frequency self-protected silicon 4.0 mΩ $R_{DS(ON)}$ high side switch used to replace electromechanical relays, fuses, and discrete devices in power management applications. The 33981 can be controlled by pulse-width modulation (PWM) with a frequency up to 60 kHz. It is designed for harsh environments, and it includes self-recovery features.

The 33981 is suitable for loads with high inrush current, as well as motors and all types of resistive and inductive loads. A dedicated parallel input is available for an external low side control with protection features and cross-conduction management.

FUNCTIONAL PIN DESCRIPTIONS

OUTPUT CURRENT MONITORING (CSNS)

This pin is used to output a current proportional to the high side OUT current and is used externally to generate a ground-referenced voltage for the microcontroller (MCU) to monitor OUT current.

TEMPERATURE FEEDBACK (TEMP)

This pin reports an analog value proportional to the temperature of the GND flag (pin 13). It is used by the MCU to monitor board temperature.

ENABLE [ACTIVE HIGH] (EN)

This is an input used to place the device in a low-current Sleep Mode. This pin has an active passive internal pull-down.

INPUT HIGH SIDE (INHS)

The input pin is used to directly control the OUT. This input has an active internal pull-down current source and requires CMOS logic levels.

FAULT STATUS ($\overline{FS}$)

This pin is an open drain-configured output requiring an external pull-up resistor to V_{DD} (5.0 V) for fault reporting. When a device fault condition is detected, this pin is active LOW.

INPUT LOW SIDE (INLS)

This input pin is used to directly control an external low side N-channel MOSFET and has an active internal pull-down current source and requires CMOS logic levels. It can be controlled independently of the INHS depending of CONF pin.

CONFIGURATION INPUT (CONF)

This input pin is used to manage the cross-conduction between the internal high side N-channel MOSFET and the external low side N-channel MOSFET. The pin has an active internal pull-up current source. When CONF is at 0 V, the two MOSFETs are controlled independently. When CONF is at V_{DD} 5.0 V, the two MOSFETs cannot be on at the same time.

LOW SIDE OVERLOAD (OCLS)

This pin sets the V_{DS} protection level of the external low side MOSFET. This pin has an active internal pull-up current source. It must be connected to an external resistor.

DRAIN LOW SIDE (DLS)

This pin is the drain of the external low side N-channel MOSFET. Its monitoring allows protection features: low side short protection and V_{PWR} short protection.

LOW SIDE GATE (GLS)

This pin is an output used to drive the gate of the external low side N-channel MOSFET.

SLEW RATE CONTROL (SR)

A capacitor connected between this pin and ground is used to control the output slew rate.

BOOTSTRAP CAPACITOR (CBOOT)

A capacitor connected between this pin and OUT is used to switch the OUT in PWM mode.

GROUND (GND)

This pin is the ground for the logic and analog circuitry of the device.

POSITIVE POWER SUPPLY (VPWR)

This pin connects to the positive power supply and is the source input of operational power for the device. The VPWR pin is a backside surface mount tab of the package.

OUTPUT (OUT)

Protected high side power output to the load. Output pins must be connected in parallel for operation.

FUNCTIONAL DEVICE OPERATION

OPERATIONAL MODES

The 33981 has 2 operating modes: Sleep and Normal depending on EN input.

SLEEP MODE

Sleep Mode is the state of the 33981 when the EN is logic [0]. In this mode, OUT, the gate driver for the external MOSFET, and all unused internal circuitry are off to minimize current draw.

NORMAL MODE

The 33981 will go to the Normal operating mode when the EN pin is logic [1]. The INHS and INLS commands will be disabled t_{ON} after the EN transitions to logic [1] to enable the charge of the bootstrap capacitor.

Table 6. Operating Modes

Condition	CONF	INHS	INLS	OUT	GLS	$\overline{FS}$	EN	Comments
Sleep	x	x	x	x	x	H	L	Device is in Sleep Mode. The OUT and low side gate are OFF.
Normal	L	H	H	H	H	H	H	Normal mode. High side and low side are controlled independently. The high side and the low side are both on.
Normal	L	L	L	L	L	H	H	Normal mode. High side and low side are controlled independently. The high side and the low side are both off.
Normal	L	L	H	L	H	H	H	Normal mode. Half-bridge configuration. The high side is off and the low side is on.
Normal	L	H	L	H	L	H	H	Normal mode. Half-bridge configuration. The high side is on and the low side is off.
Normal	H	PWM	H	PWM	PWM_bar	H	H	Normal mode. Cross-conduction management is activated. Half-bridge configuration.

H = High level
L = Low level
x = Don't care
PWM_bar = Opposite of pulse-width modulation signal.

PROTECTION AND DIAGNOSTIC FEATURES

UNDER-VOLTAGE

The 33981 incorporates under-voltage protection. In case of V_{PWR}<$V_{PWR(UV)}$, the OUT is switched OFF until the power supply rises to $V_{PWR(UV)}$+$V_{PWR(UVHYS)}$. The latched fault are reset below $V_{PWR(UV)}$. The FS output pin reports the under-voltage fault in real time.

OVER-TEMPERATURE FAULT

The 33981 incorporates over-temperature detection and shutdown circuitry on OUT. Over-temperature detection also protects the low side gate driver (GLS pin). Over-temperature detection occurs when OUT is in the ON or OFF state and GLS is at high or low level.

For OUT, an over-temperature fault condition results in OUT turning OFF until the temperature falls below T_{SD}. This cycle will continue indefinitely until the offending load is removed. Figure 12 and Figure 18 show an over-temperature on OUT.

An over-temperature fault on the low side gate drive results in OUT turning OFF and the GLS going to 0V until the temperature falls below T_{SD}. This cycle will continue until the offending load is removed. FS pin transition to logic [1] will be disabled typically t_{ON} after to enable the charge of the bootstrap capacitor.

Over-temperature faults force the TEMP pin to 0 V.

OVER-CURRENT FAULT ON HIGH SIDE

The OUT pin has an over-current high-detection level called I_{OCH} for maximum device protection. If at any time the current reaches this level, OUT will stay OFF and the CSNS pin will go to 0V. The OUT pin is reset (and the fault is delatched) by a logic [0] at the INHS pin for at least $t_{RST(DIAG)}$. When INHS goes to 0 V, CSNS goes to 5.0 V.

In Figure 15, the OUT pin is short-circuited to 0V. When the current reaches I_{OCH}, OUT is turned OFF within t_{OCH} owing to internal logic circuit.

OVER-LOAD FAULT ON LOW SIDE

This fault detection is active when INLS is logic [1]. Low side overload protection does not measure the current

directly but rather its effects on the low side MOSFET. When $V_{DLS} > V_{OCLS}$, the GLS pin goes to 0 V and the OCLS internal current source is disconnected and OCLS goes to 0 V. The GLS pin and the OCLS pin are reset (and the fault is delatched) by a logic [0] at the INLS pin for at least $t_{RST(DIAG)}$. Figure 13 and Figure 14 illustrate the behavior in case of overload on the low side gate driver.

When connected to an external resistor, the OCLS pin with its internal current source sets the V_{OCLS} level. By changing the external resistance, the protection level can be adjusted depending on low side characteristics. A 33 kΩ resistor gives a V_{DS} level of 3.3 V typical.

This protection circuitry measures the voltage between the drain of the low side (DLS pin) and the 33981 ground (GND pin). For this reason it is key that the low side source, the 33981 ground, and the external resistance ground connection are connected together in order to prevent false error detection due to ground shifts.

The maximum OCLS voltage being 4.0 V, a resistor bridge on DLS must be used to detect a higher voltage across the low side.

CONFIGURATION

The CONF pin manages the cross-conduction between the internal MOSFET and the external low side MOSFET. With the CONF pin at 0 V, the two MOSFETs can be independently controlled. A load can be placed between the high side and the low side.

With the CONF pin at 5.0 V, the two MOSFETs cannot be on at the same time. They are in half-bridge configuration as shown in the 33981 Simplified Application Diagram. If INHS and INLS are at 5.0 V at the same time, INHS has priority and OUT will be at V_{PWR}. If INHS changes from 5.0 V to 0 V with INLS at 5.0 V, GLS will go to high state as soon as the V_{GS} of the internal MOSFET is lower than 2.0 V typically. A half-bridge application could consist in sending PWM signal to the INHS pin and 5.0 V to the INLS pin with the CONF pin at 5.0 V.

Figure 20, illustrates the simplified application diagram in the 33981 Simplified Application Diagram with a DC motor and external low side. The CONF and INLS pins are at 5.0 V. When INHS is at 5.0 V, current is flowing in the motor. When INHS goes to 0 V, the load current recirculates in the external low side.

BOOTSTRAP SUPPLY

Bootstrap supply provides current to charge the bootstrap capacitor through the VPWR pin. A short time is required after the application of power to the device to charge the bootstrap capacitor. A typical value for this capacitor is 100 nF. An internal charge pump allows continuous MOSFET drive.

When the device is in the sleep mode, this bootstrap supply is off to minimize current consumption.

HIGH SIDE GATE DRIVER

The high side gate driver switches the bootstrap capacitor voltage to the gate of the MOSFET. The driver circuit has a low-impedance drive to ensure that the MOSFET remains OFF in the presence of fast falling dV/dt transients on the OUT pin.

This bootstrap capacitor connected between the power supply and the C_{BOOT} pin provides the high pulse current to drive the device. The voltage across this capacitor is limited to about 13 V typical.

An external capacitor connected between pins SR and GND is used to control the slew rate at the OUT pin. Figure 9 and Figure 10 give V_{OUT} rise and fall time versus different SR capacitors.

LOW SIDE GATE DRIVER

The low side control circuitry is PWM capable. It can drive a standard MOSFET with an $R_{DS(ON)}$ as low as 10.0 mΩ at a frequency up to 60 kHz. The V_{GS} is internally clamped at 12 V typically to protect the gate of the MOSFET. The GLS pin is protected against short by a local over-temperature sensor.

THERMAL FEEDBACK

The 33981 has an analog feedback output (TEMP pin) that provides a value in inverse proportion to the temperature of the GND flag (pin 13). The controlling microcontroller can “read” the temperature proportional voltage with its analog-to-digital converter (ADC). This can be used to provide real-time monitoring of the PC board temperature to optimize the motor speed and to protect the whole electronic system. TEMP pin value is V_{TFEED} with a negative temperature coefficient of DT_{FEED}.

REVERSE BATTERY

The 33981 survives the application of reverse battery voltage as low as -16 V. Under these conditions, the output’s gate is enhanced to decrease device power dissipation. No additional passive components are required. The 33981 survives these conditions until the maximum junction rating is reached.

In the case of reverse battery in a half-bridge application, a direct current passes through the external freewheeling diode and the internal high side.

As Figure 11 shows, it is essential to protect this power line. The proposed solution is an external N-channel low side with its gate tied to battery voltage through a resistor. A high side in the V_{PWR} line could be another solution.

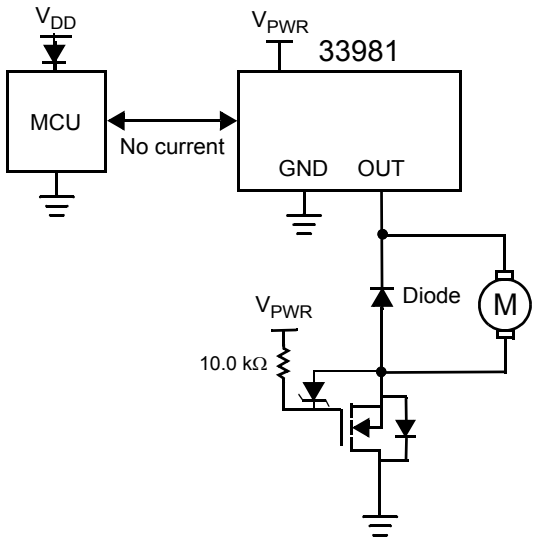


Figure 11. Reverse Battery Protection

GROUND (GND) DISCONNECT PROTECTION

If the DC motor module ground is disconnected from load ground, the device protects itself and safely turns OFF the output regardless of the output state at the time of disconnection. A 10 k resistor needs to be added between the EN pin and the rest of the circuitry in order to ensure the device turns off in case of ground disconnect and to prevent exceeding this pin's maximum ratings.

FAULT REPORTING

This 33981 indicates the faults below as they occur by driving the $\overline{FS}$ pin to logic [0]:

- Over-temperature fault
- Over-current fault on OUT
- Overload fault on the external low side MOSFET

The $\overline{FS}$ pin will return to logic [1] when the over temperature fault condition is removed. The two other faults are latched.

Table 7. Functional Truth Table in Fault Mode

Conditions	CONF	INHS	INLS	OUT	GLS	$\overline{FS}$	EN	TEMP	CSNS	OCLS	Comments
Over-temperature on OUT	x	x	x	L	H	L	H	L	x	x	The 33981 is currently in Fault mode. The OUT is OFF. TEMP at 0V indicates this fault. Once the fault is removed 33981 recovers its normal mode.
Over-temperature on GLS	x	x	x	L	L	L	H	L	x	x	The 33981 is currently in Fault mode. The OUT is OFF and GLS is at 0V. TEMP at 0V indicates this fault. Once the fault is removed 33981 recovers its Normal Mode.
Over-current on OUT	x	H	L	L	x	L	H	x	L	x	The 33981 is currently in Fault mode. The OUT is OFF. It is reset by a logic [0] at INHS for at least $t_{RST(DIAG)}$. When INHS goes to 0V, CSNS goes to 5.0 V.
Overload on External Low Side MOSFET	L	L	H	x	L	L	H	x	x	L	The 33981 is currently in Fault mode. GLS is at 0 V and OCLS internal current source is off. The external resistance connected between OCLS and GND pin will pull OCLS pin to 0V. The fault is reset by a logic [0] at INLS for at least $t_{RST(DIAG)}$.

H = High level
L = Low level
x = Don’t care

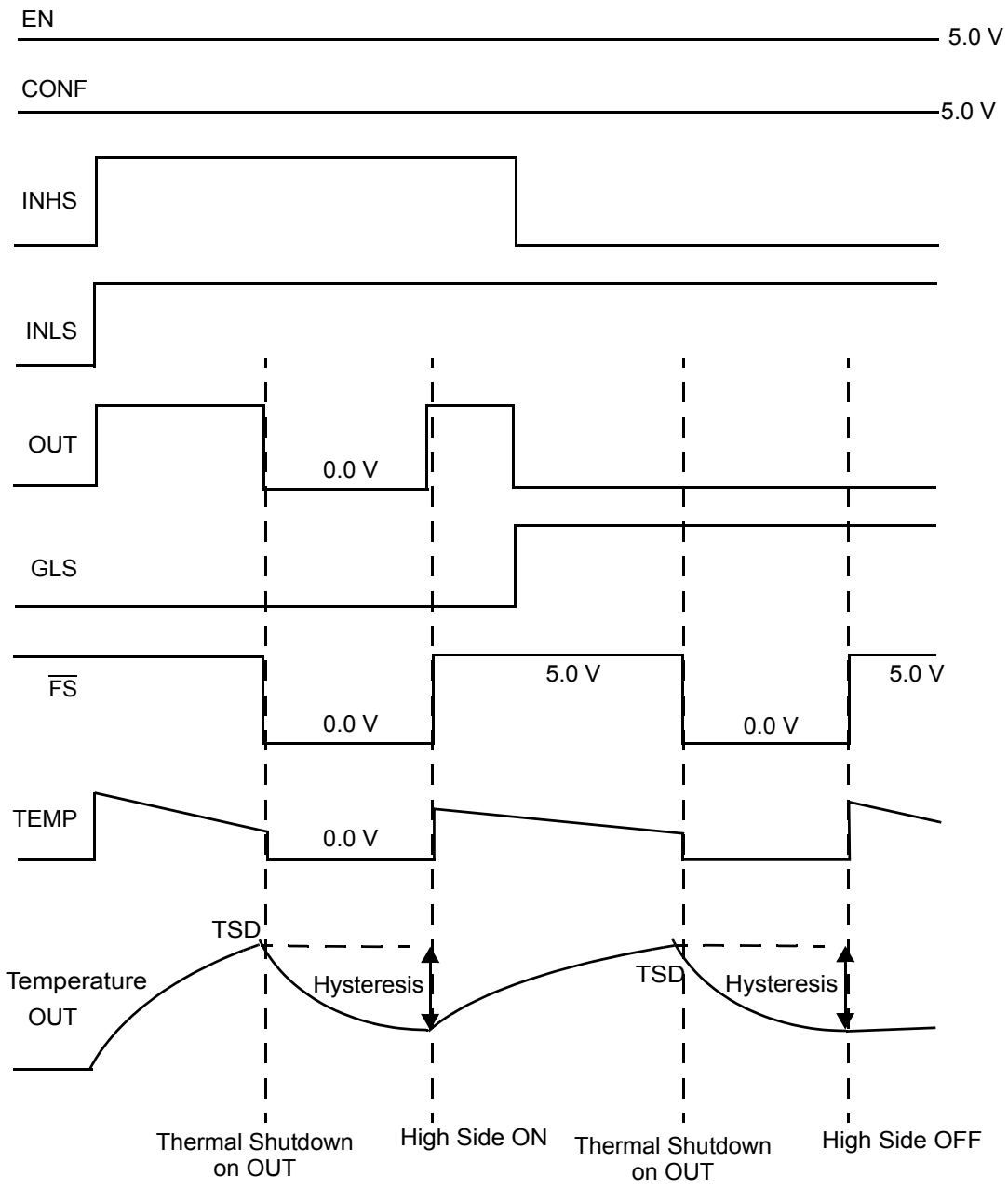


Figure 12. Over-temperature on Output

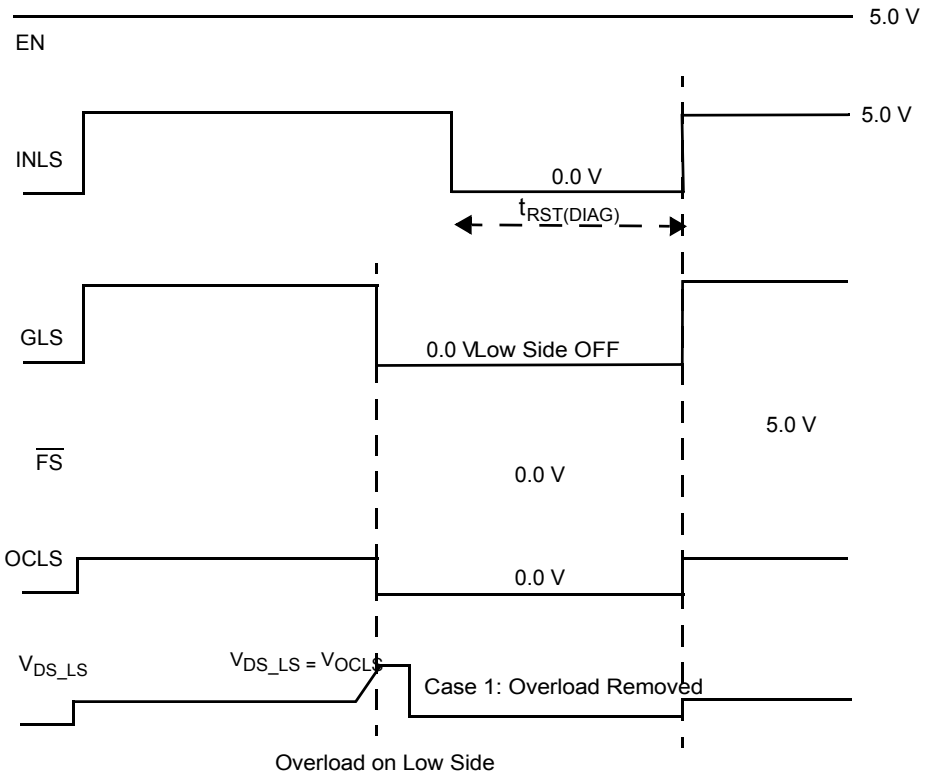


Figure 13. Overload on Low Side Gate Drive, Case 1

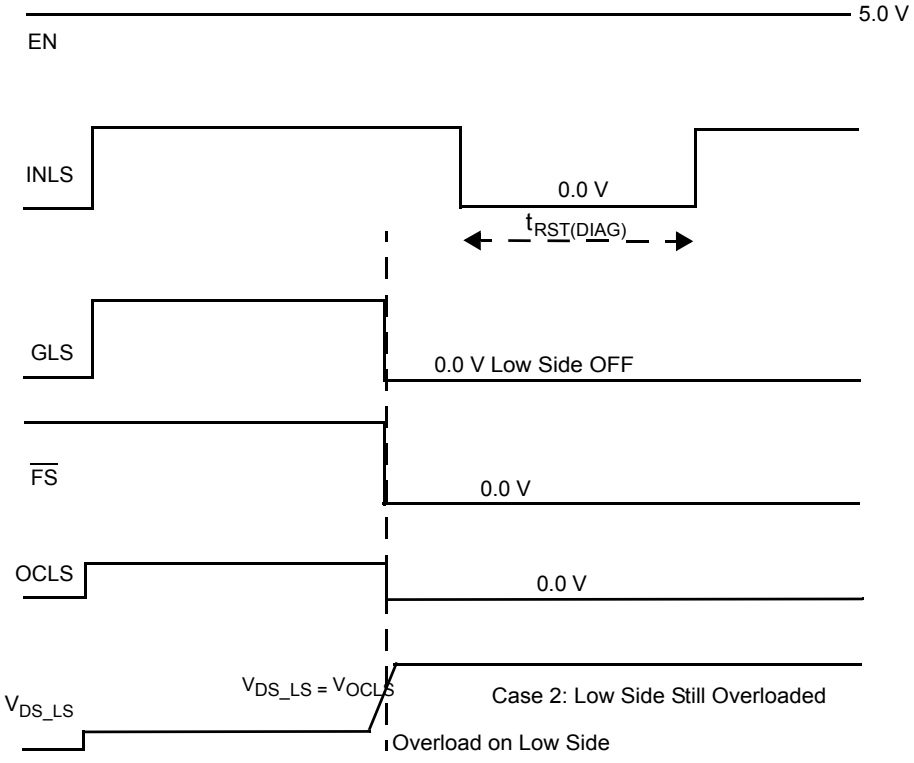


Figure 14. Overload on Low Side Gate Drive, Case 2

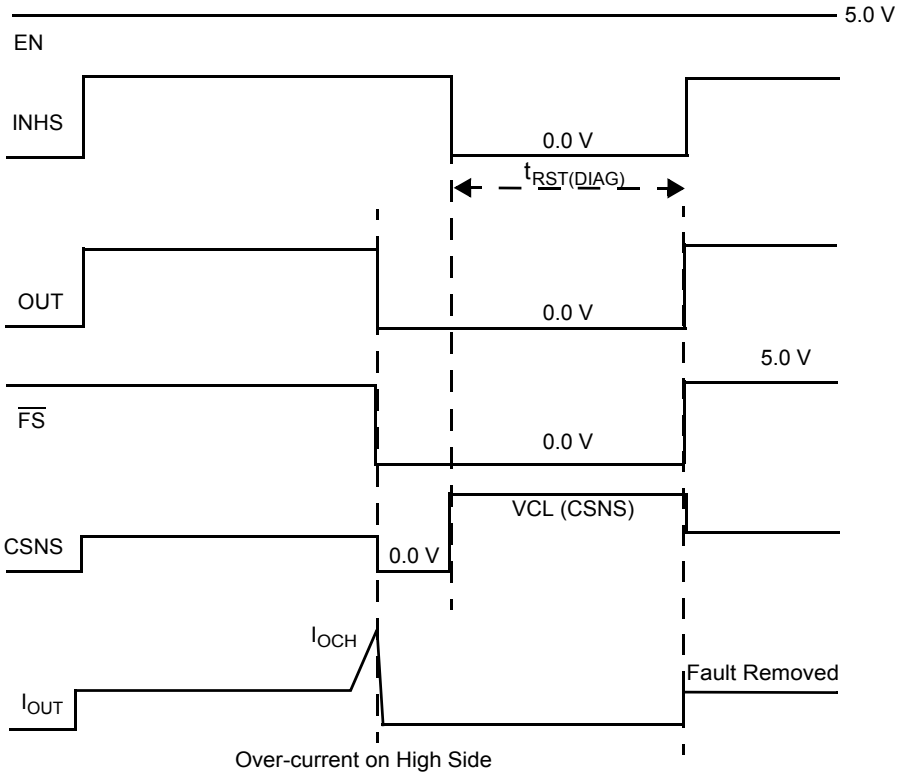


Figure 15. Over-current on Output

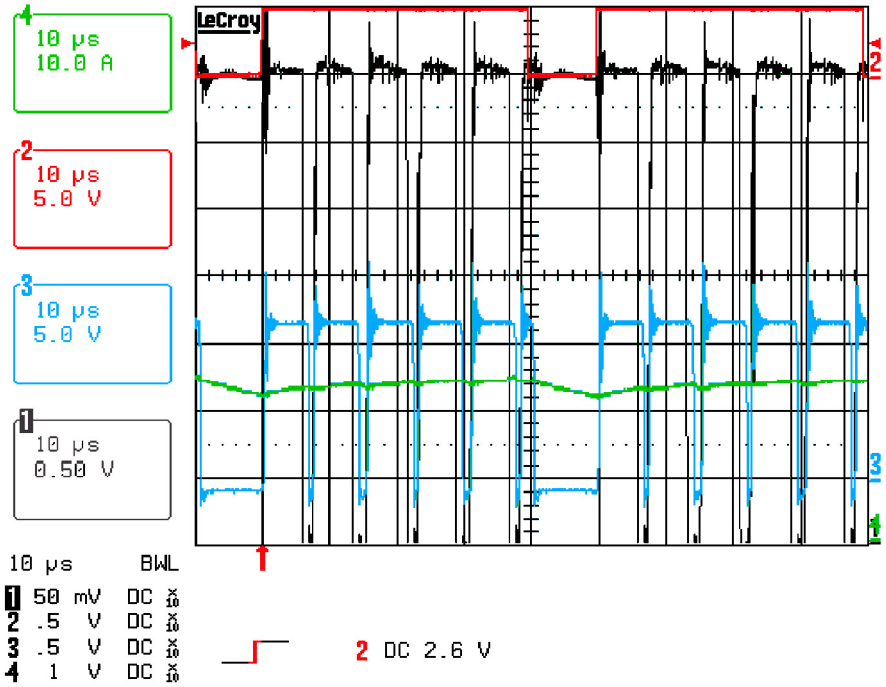


Figure 16. High Side Over-current

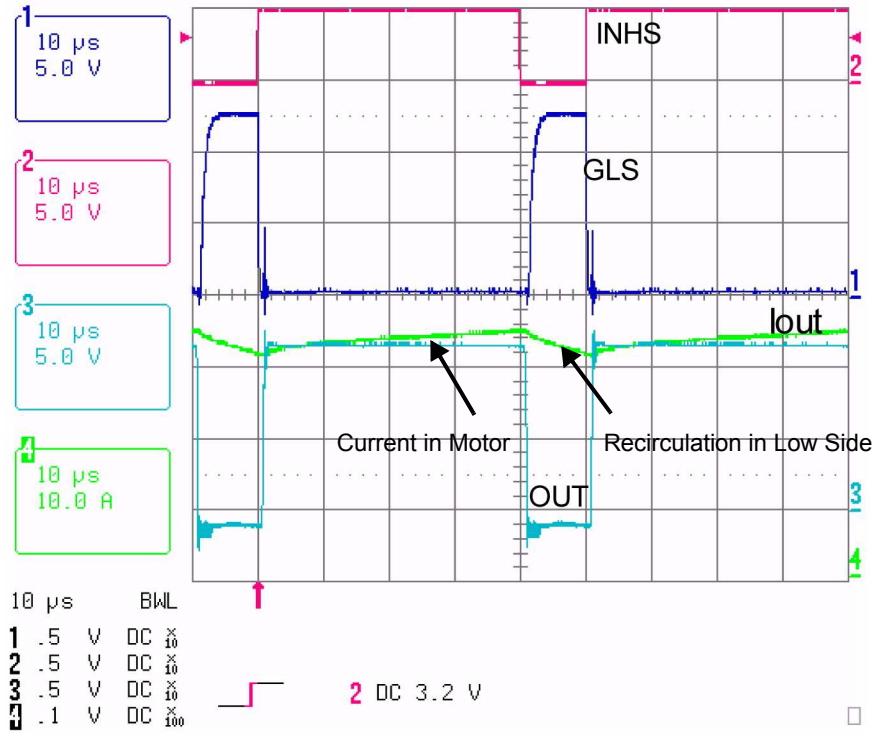


Figure 17. Cross-Conduction with Low Side

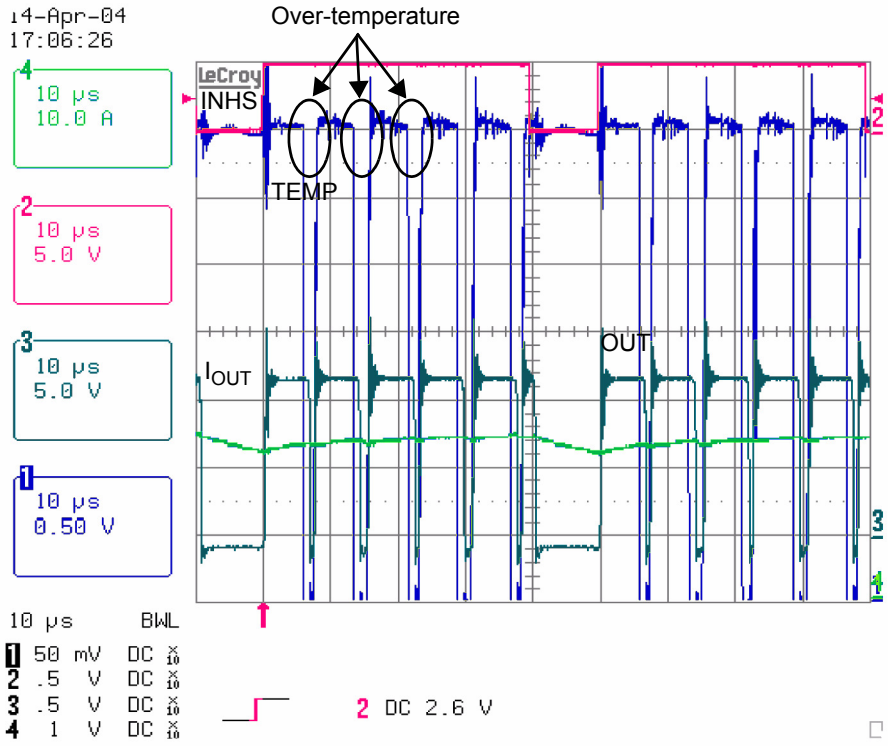


Figure 18. Over-temperature on OUT

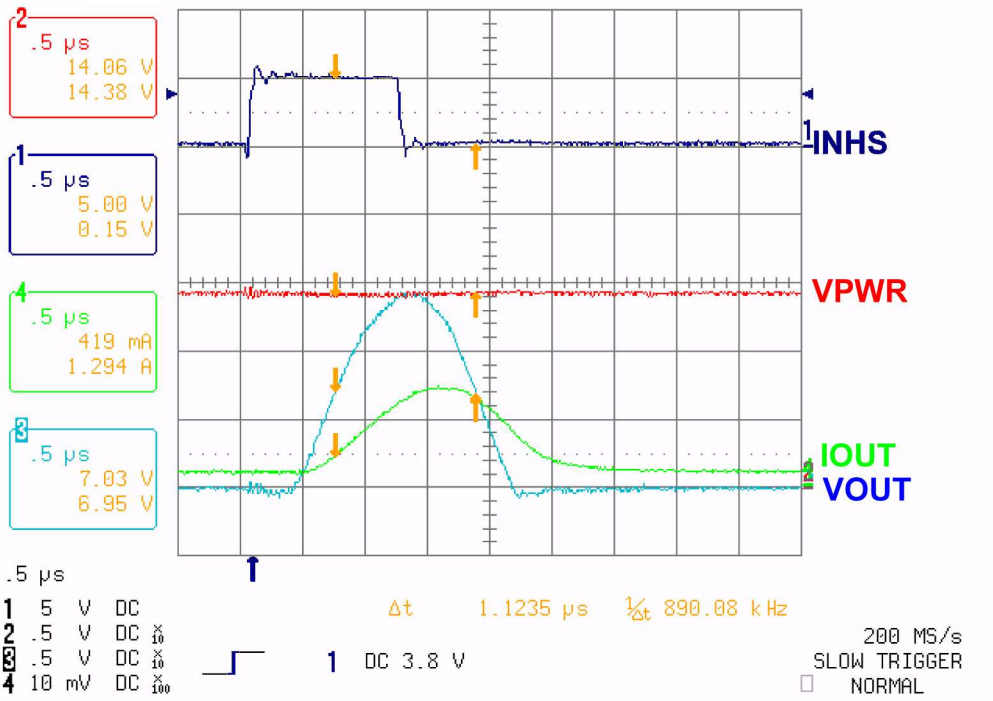


Figure 19. Maximum Operating Frequency for SR Capacitor of 4.7 nF

TYPICAL APPLICATIONS

INTRODUCTION

Figure 20 shows a typical application for the 33981. A brush DC motor is connected to the output. A low side gate driver is used for the freewheeling phase. Typical values for external capacitors and resistors are given.

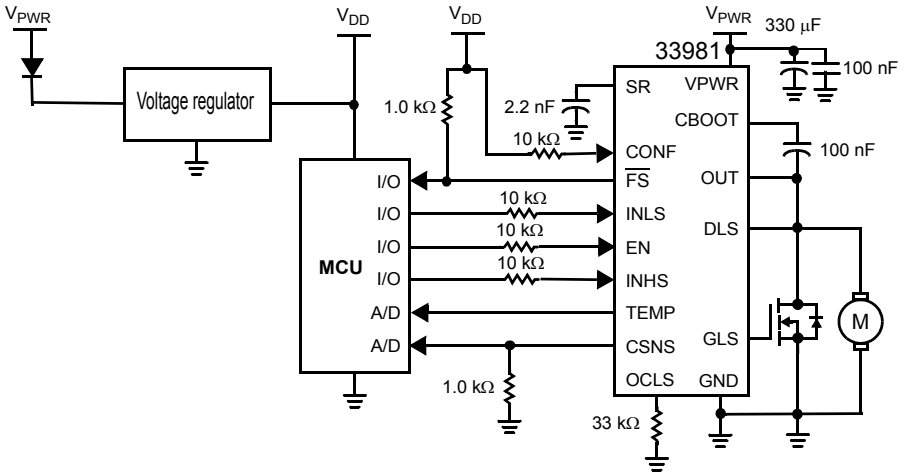


Figure 20. 33981 Typical Application Diagram

EMC AND EMI RECOMMENDATIONS

INTRODUCTION

This section relates the EMC capability for 33981, high frequency high-current high side switch. This device is a self-protected silicon switch used to replace electromechanical relays, fuses, and discrete circuits in power management applications.

This section presents the key features of the device and its targeted applications. The automotive standard to measure conducted and radiated emissions is provided. Concrete measurements on the 33981 and improvements to reduce electromagnetic emission are described.

DEVICE FEATURES

This 33981 is a 4.0 mΩ self-protected, high side switch digitally controlled from a microcontroller (MCU) with extended diagnostics, able to drive DC motors up to 60 kHz.

A bootstrap architecture has been used to provide fast transient gate voltage in order to reach 4.0 mΩ $R_{DS(ON)}$ maximum at room temperature. In parallel, a charge pump is implemented to offer continuous on-state capability. This dual current supply of the high side MOSFET allows a duty cycle from 5% to 100%. An external capacitor connected between pins SR and GND is used to control the slew rate at the output and, therefore, reduce electromagnetic perturbations.

In standard configuration, the motor current recirculation is handled by an external freewheeling diode. To reduce global power dissipation, the freewheeling diode can be replaced by an external discrete MOSFET in low side configuration. The IC integrates a gate driver that controls and protects this external MOSFET in the event of short-circuit to battery. The product manages the cross conduction between the internal high side and the external low side when used in a half-bridge configuration. The two MOSFETs can be controlled independently when the CONF pin is at 0 V. To eliminates fuses, the device is self-protected from severe short-circuits (100 A typical) with an innovative over-current strategy.

The 33981 has a current feedback for real-time monitoring of the load current through an MCU analog/digital converter to facilitate closed-loop operation for motor speed control.

The 33981 has an analog thermal feedback that can be used by the MCU to monitor PC board temperature to optimize the motor control and to protect the entire electronic system. Therefore, an over-temperature shutdown feature protects the IC against high overload condition.

Figure 21 illustrates the typical application diagram.