MF2007SW
Application Note
Revision 1.1

The product and product specifications are subject to change without notice.

Usage Precautions

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Note the following warnings and precautions to ensure safety when using this IC:

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	⚠	Check the polarity of the input and output pins to ensure that they are properly connected before supplying power. ***Failure to do so may trip protective devices or lead to smoke generation or fire.***
	⚠	Use only the specified input voltage. Be sure to incorporate protective devices on the input line. ***Failure to do so may result in smoke generation or fire under abnormal conditions.***
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Special uses	Transportation equipment (e.g. vehicle-mounted, marine), core communications equipment, traffic signal equipment, disaster prevention/security equipment, various safety equipment, medical equipment, etc.
Specified uses	Nuclear power control systems, aviation equipment, aerospace equipment, undersea repeater equipment, life support equipment, etc.

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Contents

1. Overview

MF2007SW is **an IC designed to drive external N-channel MOSFETs**. This section presents two typical examples of its use.

■ **Ideal diode (always on) type**

ECU uses the output from a battery or DC/DC converter as an input source. Typically, diodes are used as input reverse connection and reverse current prevention elements. However, as electronic devices have become multifunctional, thereby requiring larger currents, concerns have emerged about increased voltage drops (V_F) and heat buildup of diodes. **Replacing these conventional diodes, a configuration of “one N-channel MOSFET + MF2007SW” can serve as an ideal diode that achieves low V_F and low heat buildup**.

■ **Solid state relay (bidirectionally conducting on-off switch) type**

Mechanical relays have conventionally been used as bidirectional on-off switches. Bidirectional switches are now required to be small and lightweight. **A configuration of “two N-channel MOSFETs + MF2007SW,” smaller and more lightweight than a mechanical relay, can serve as a solid state relay that provides reliable on-off switching and quick response.**

1.1 Features

- The reverse current prevention function is enabled or disabled by the high-low control of the REV pin.
- Maximum input rating: 70 V
- Standby current: 5 μA (* This is the current flowing into the IC when shutdown is initiated by turning the EN pin low.)
- Gate voltage (charge pump voltage): 12.5 V
- Gate charging current: 75 μA
- Gate discharge current at fast charging initiated by reverse current detection: 0.7 A (typ)
- Gate discharge current at fast charging with EN = low: 0.12 A (typ)
- Incorporates a built-in capacitor for charge pump; requires no external capacitor.
- Monitors potential differences between the drain and the source of an external N-channel MOSFET (VDS monitoring function); enables shutdown in the event of an abnormality using the IDET pin, which outputs analog signals based on the monitored potential differences.
- Protected against input reverse connection up to 40 V
- Enables smaller device dimensions by adopting a small SMD package (TSSOP10: 3 mm × 4.9 mm).
- AEC-Q100 compliant

■ **Ideal diode type**

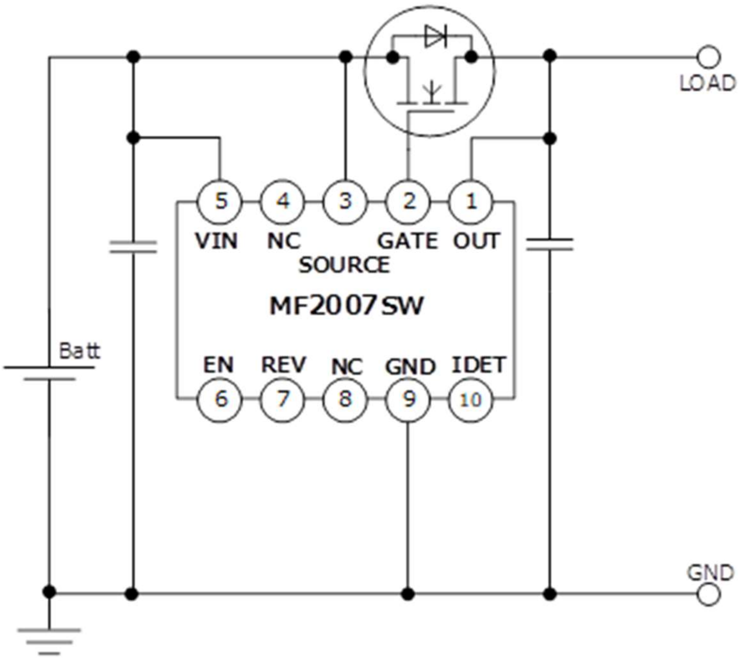
- V_F (voltage drop), loss and heat buildup are significantly reduced compared to a Schottky barrier diode.
- If the reverse current comparator detects a reverse current, Gate fast discharge function (0.7 A) is activated to turn off the external N-channel MOSFET.

■ **Solid state relay type**

- Smaller in size, more lightweight and quicker in response as well as enabling on-off operation with less chattering than mechanical relays
- If an abnormal operation is detected, the EN pin is driven low, which activates Gate fast discharge function (0.12 A) and immediately stops operation.

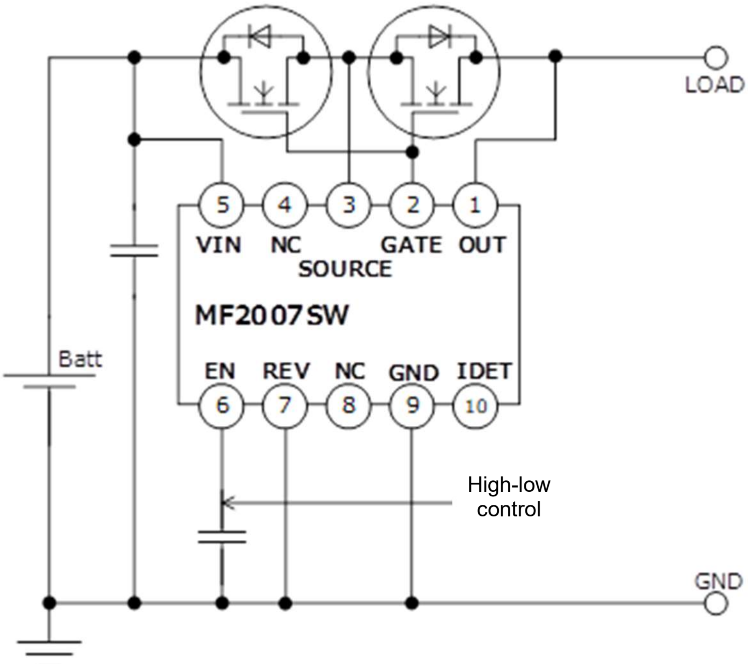
1.2 Basic connection examples

■ **Ideal diode type**



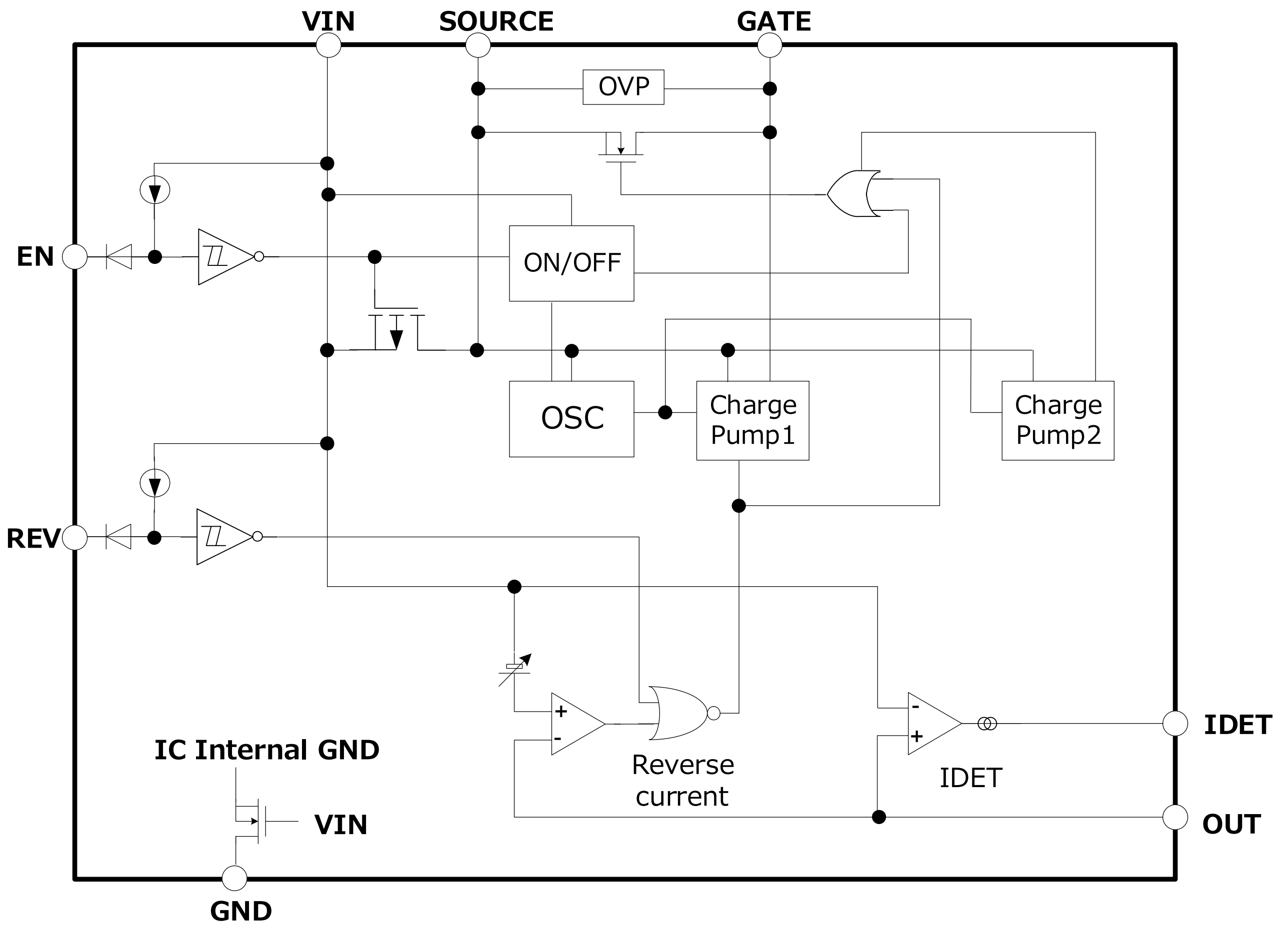
The external N-channel MOSFET is always on during normal operation (no protection activated). This means an ideal diode type can be used with the EN pin/REV pin left open.

■ **Solid state relay type**

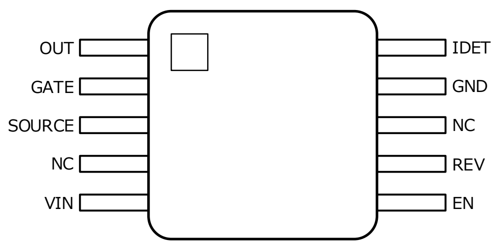


To use as a solid state relay type, connect two external N-channel MOSFETs back-to-back in a common source configuration. On-off switching of the external N-channel MOSFETs is driven with high-low control of the EN pin. Short-circuit the REV pin to GND.

1.3 Block diagram



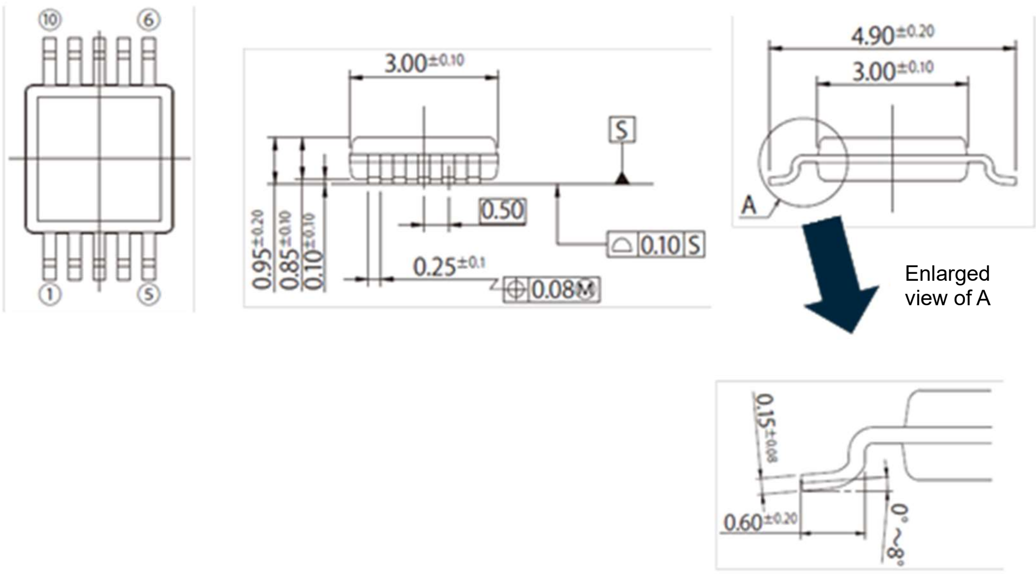
1.4 Pin assignment and functions



Package (House Name): TSSOP10

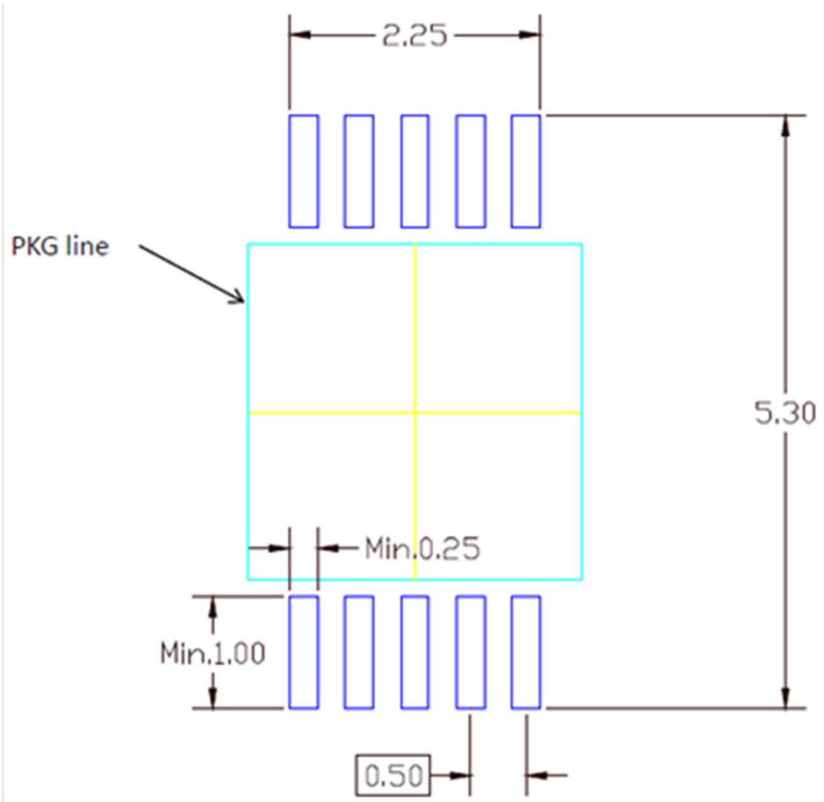
Pin number	Symbol	Function
1	OUT	Output pin
2	GATE	External MOSFET gate connection pin
3	SOURCE	External MOSFET source connection pin
4	NC	No connection
5	VIN	Power supply pin
6	EN	Standby signal input pin
7	REV	Reverse current protection selector pin
8	NC	No connection
9	GND	Ground pin
10	IDET	External MOSFET potential difference output pin

1.5 Appearance and dimensions (package: TSSOP10)



① to ⑩: Pin numbers, unit: mm

1.6 Land pattern example



Unit: mm

2. Specifications

2.1 Absolute maximum ratings

Unless otherwise specified, Tj = 25 °C

Item	Symbol	Standard value	Unit
Input/output ratings			
VIN / SOURCE - GND	VIN / SOURCE	-40 to 70	V
EN / REV - GND	EN / REV	-0.3 to 70	V
VIN - OUT	VIN_OUT	-70 to 70	V
VIN - SOURCE	VIN_SOURCE	-0.3 to 70	V
OUT - GND	OUT / GATE	-2 to 70	V
GATE - SOURCE	GATE_SOURCE	-0.3 to 15	V
IDET - GND (*1)	IDET	-0.3 to 5.5	V
Thermal ratings			
Permissible loss	Pd	1.08	W
Junction temperature	Tj	-40 to 150	°C
Storage temperature	Tstg	-55 to 150	°C
Thermal rating (thermal resistance)			
Thermal resistance (*2)	Rth(j-a)	115	°C/W
	Rth(j-c)	30	°C/W

*1 ... Except when a negative voltage is applied to VIN

*2 ... Values measured when the dimensions of the glass-epoxy substrate are 114.3 × 76.2 mm with a thickness of 1.6 mm and the dimensions of the inner-layer copper foil are 74.2 × 74.2 mm with a thickness of 35 μm

Avoid exceeding the absolute maximum ratings when using this IC. Exceeding these ratings may damage the IC. The failure mode (open-circuit or short-circuit fault) will not be identifiable if an IC is damaged. Take the appropriate physical safety measures, including adding a fuse.

2.2 Recommended operating conditions

Item	Symbol	Recommended value	Unit
VIN / SOURCE – GND (*3)	VIN / SOURCE	4.5 to 65	V
OUT - GND (*3)	OUT	-0.3 to 65	V
Junction temperature	Tj	-40 to 125	°C

*3 ... Except when a negative voltage is applied to VIN

CAUTION: Use outside the range of recommended operating conditions can affect reliability.
Contact the Shindengen sales department in advance for any applications that require constant use at temperatures above 105 °C.

2.3 Electrical characteristics

Unless otherwise specified, VIN = 12 V and Tj = 25 °C

Item	Symbol	Condition	Standard value			Unit
			MIN	TYP	MAX	
VIN pin						
Charge pump supply start voltage	Vcp_stt		–	3.0	4.5	V
Charge pump supply stop voltage	Vcp_stp		–	2.5	4	V
Operating current at shutdown	Iq	EN = 0 V	1	5	10	μA
Current consumption in normal operation	Iop		100	200	280	μA
EN pin						
Booster circuit start threshold	Venst		0.9	1.5	2.1	V
Booster circuit stop threshold	Vensp		0.6	1.0	1.4	V
EN pin discharge current	IEN	EN = 0 V	0.1	0.4	1.0	μA
Gate pin						
Boosting voltage	Vgate		10	12.5	15	V
Source current 1	Igso1	Δvgate = 0 V	45	75	105	μA
Source current 2	Igso2	Δvgate = 5 V	30	50	70	μA
Sink current at reverse current protection	Igsi1	ΔVSD = 0.5 V ⇒ -0.1 V	0.4	0.7	1.0	A
Off time at reverse current protection	Trevoff	VIN = 12 V, VIN-OUT = 0.5 V ⇒ -1 V, Δvgate < 2 V, Cgate = 0 pF	–	200	300	ns
Sink current at EN stop	Igsi2	EN = 5 V ⇒ 0 V	0.06	0.12	0.18	A
Off time at EN stop	Tenoff	VIN = 12 V, EN = 3 V ⇒ 0 V, Δvgate < 2 V, Cgate = 0 pF	–	50	100	ns
On time at EN start	Tenon	VIN = 12 V, OUT = 0 V, EN = 0 V ⇒ 3 V, Δvgate > 0.5 V, Cgate = 0 pF	–	12	25	μs

Unless otherwise specified, VIN = 12 V and Tj = 25 °C

Item	Symbol	Condition	Standard value			Unit
			MIN	TYP	MAX	
Source pin						
Shutdown current	Isq	VIN = SOURCE = 12 V, EN = 0 V	–	0	1	μA
Out pin						
Shutdown current	Ioq	VIN = OUT = 12 V, EN = 0 V	–	0	1	μA
Current at reverse connection	Ir	VIN = -12 V, OUT = 12 V	–	0	1	μA
Reverse current protection threshold	Vrev	VIN－OUT	-25	-13	-2	mV
IDET pin						
Sink current 1 at forward voltage	Idet_Si1	VIN = 12 V, OUT = 11.5 V, IDET = 4 V	80	110	140	μA
Sink current 2 at forward voltage	Idet_Si2	VIN = 12 V, OUT = 11.9 V, IDET = 4 V	5	25	45	μA
Source current 1 at reverse voltage	Idet_So1	VIN = 12 V, OUT = 12.1 V, IDET = 0 V	5	25	45	μA
Source current 2 at reverse voltage	Idet_So2	VIN = 12 V, OUT = 12.5 V, IDET = 0 V	70	100	130	μA
Current amplification factor	gm	VIN-OUT = -0.1 V to 0.1 V	180	220	260	μA/V
REV pin						
Reverse current protection start voltage	Vrevst		0.9	1.5	2.1	V
Reverse current protection stop voltage	Vrevsp		0.6	1.0	1.4	V
REV pin discharge current	Irev	EN = 0 V	0.1	0.4	1.0	μA

3. Functions and electrical characteristics of individual pins

3.1 VIN pin

The VIN pin is used to supply power to the IC (MF2007SW). Connect the pin to the positive (+) line of the battery (power source). Connect the VIN and Source pins to a common line in an ideal diode type and to different lines in a solid state relay type.

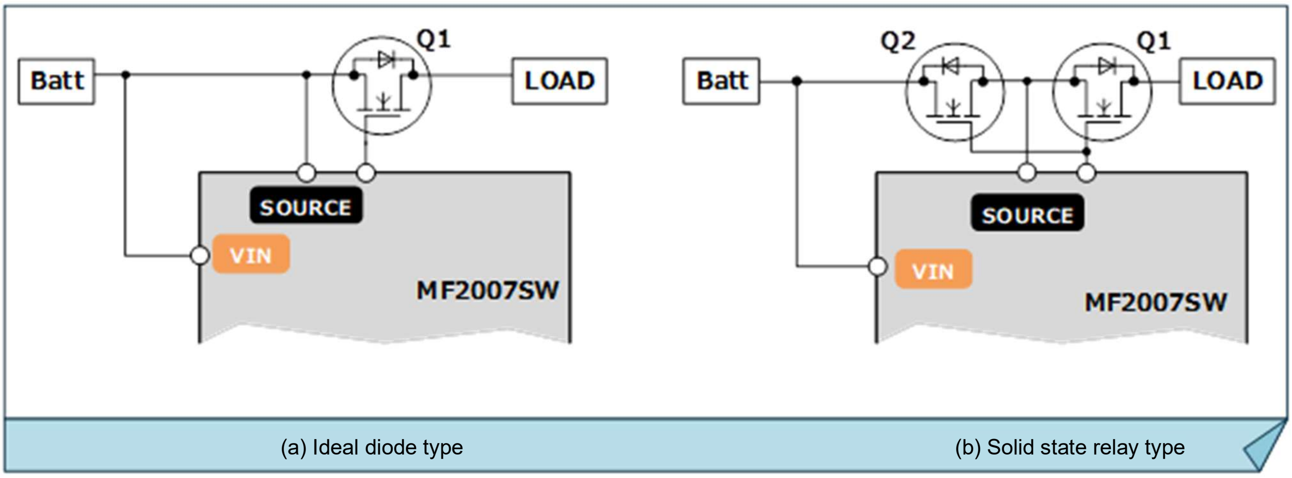


Figure 1 VIN pin connection example

Explanations of electrical characteristics of the VIN pin		
Charge pump supply start voltage	Vcp_stt	Power supply voltage at which the charge pump in the IC begins to operate
Charge pump supply stop voltage	Vcp_stp	Power supply voltage at which the charge pump in the IC stops
Current consumption in normal operation	Iop	Current flowing into the IC from the VIN pin, which is the power source to the IC, during normal operation
Operating current at shutdown	Iq	Current flowing into the IC from the VIN pin at shutdown; shutdown is performed by switching the EN pin voltage to low (see Section 3.2).

3.2 EN pin

The EN pin functions as the standby signal pin. The built-in charge pump begins to operate when EN = high and shuts down when EN = low. When the current consumption at the VIN pin during normal operation Iop (typ) is 200 μA, the current at shutdown Iq (typ) falls to 5 μA, reducing IC current consumption when the external N-channel MOSFET is off. A solid state relay type, when EN = high, outputs the Gate pin voltage and turns on the external N-channel MOSFET. Use this as a relay drive pin. Since EN = high is generated by the application of a voltage via the constant current source from the VIN pin in the IC, if shutdown by the EN pin is not required, no external voltage application is required.

Explanations of electrical characteristics of the EN pin		
Booster circuit start threshold	Venst	This is the threshold used to determine that EN = high. For EN = high, this must be set so that V_EN ≥ Venst.
Booster circuit stop threshold	Vensp	This is the threshold used to determine that EN = low. For EN = low, this must be set so that V_EN ≤ Vensp.
EN pin discharge current	IEN	Current flowing from the EN pin. This is the current of the constant current source from VIN to EN in the IC. To minimize current consumption at the VIN pin, IEN is a very low current. We recommend adding an external capacitor to the EN pin if ambient noise impairs operational stability.

3.3 Gate pin

The Gate pin functions as the gate connection pin for an external N-channel MOSFET. Output from the Gate pin is used to turn the external N-channel MOSFET on and off. During normal operation (EN = high), the voltage between Gate and Source Vgate (typ) is 12.5 V. The capacity required to turn off (sink current) upon reverse current detection or with the EN pin (switched from high to low) is significantly greater than that required to turn on (source current). This enables safe shutdown operation. During normal operation, the voltage between Gate and GND equals the sum of VIN (source) and Vgate (see Section 3.4).

Explanations of electrical characteristics of the Gate pin		
Boosting voltage	Vgate	The gate-source voltage when EN = high. This is an output voltage of the charge pump in the IC.
Source current 1	Igso1	Current value for charging Gate pin voltage via charge pump output. This is the capacity at the rising edge of the Gate pin.
Source current 2	Igso2	Current value for charging Gate pin voltage when the gate-source voltage = 5 V.
Sink current at reverse current protection	Igsi1	Current value for discharging Gate pin voltage to turn off the external N-channel MOSFET when a reverse current is detected in an ideal diode type (see Section 3.5).
Off time at reverse current protection	Trevoff	Delay time from when a reverse current is detected in an ideal diode type until Gate pin voltage begins to discharge (see Section 3.5).
Sink current at EN stop	Igsi2	Current value for discharging Gate pin voltage to turn off the external N-channel MOSFET when the EN pin is switched from high to low.
Off time at EN stop	Tenoff	Delay time from when the EN pin is switched from high to low until Gate pin voltage begins to discharge.
On time at EN start	Tenon	Delay time from when the EN pin is switched from low to high until charging of Gate pin voltage begins.

3.4 Source pin

The Source pin functions as the source connection pin for an external N-channel MOSFET. The Source pin serves as the reference potential for the charge pump in the IC. Thus, this pin is connected to the source of an external N-channel MOSFET to ensure the external N-channel MOSFET can reliably be turned on and off. (For wiring, see Figure 1.)

Explanations of electrical characteristics of the Source pin		
Shutdown current	Isq	Source leakage current value when EN = low. When EN = low, the current is minimized by turning off the MOSFET between VIN and Source in the IC.

3.5 Out pin

The Out pin functions as the connection pin on the output (load) side. This pin is used to monitor the state on the load side. Use of this pin is effective when the reverse current detection function or the potential difference monitoring between the drain and the source of the external N-channel MOSFET (VDS monitoring function) is used. If these functions are not required, the pin can be left unused (open). Whether the Out pin is connected or unconnected does not affect the IC operations, except for the IDET pin.

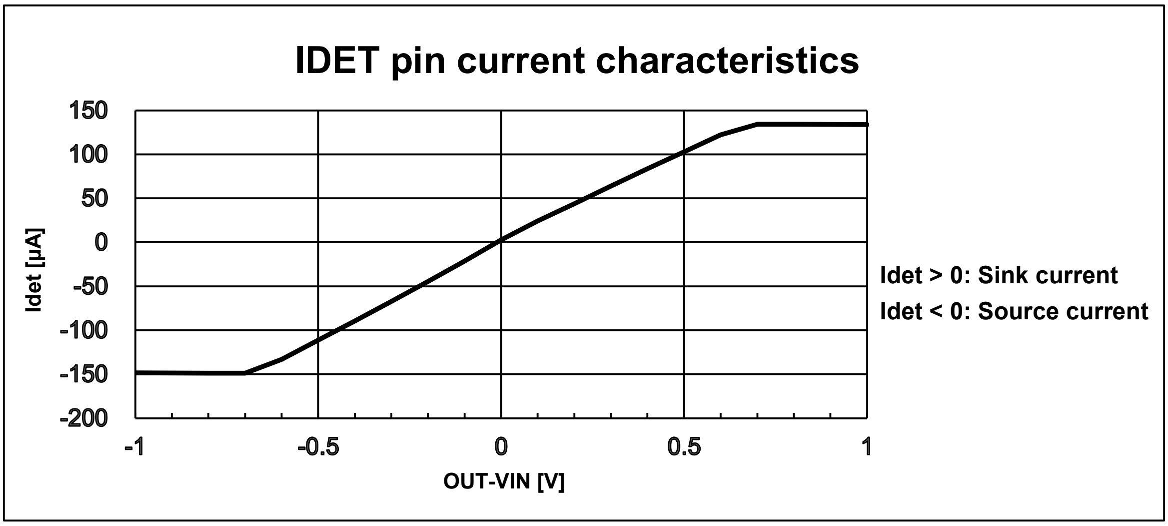
Explanations of electrical characteristics of the Out pin		
Shutdown current	Ioq	Leakage current at the Out pin at shutdown (EN = low).
Current at reverse connection	Ir	Leakage current at the Out pin in the case of input reverse connection.
Reverse current protection threshold	Vrev	VIN-Out potential difference when a reverse current is detected. The reverse current prevention function is activated when VIN-Out < Vrev to rapidly discharge gate-source voltage (see Section 4.5).

3.6 IDET pin

The IDET pin outputs the state of the potential between the drain and source of an external N-channel MOSFET. In the IC, this pin outputs a linear current signal corresponding to the potential difference between the VIN and Out pins (see “4.6 VDS monitoring function”). Since the signal changes linearly based on the state on the Out (load) side, it can effectively be used to monitor load conditions. If it is not necessary to output the state of the drain-source potential of an external N-channel MOSFET or to monitor load conditions, the pin can be left unused (open). Even if the IDET pin is left unused, it does not affect the IC operations.

Explanations of electrical characteristics of the IDET pin		
Sink current 1 at forward voltage	Idet_Si1	Sink current (inflow current) at the IDET pin when VIN-Out = 0.5 V.
Sink current 2 at forward voltage	Idet_Si2	Sink current (inflow current) at the IDET pin when VIN-Out = 0.1 V.
Source current 1 at reverse voltage	Idet_So1	Source current (outflow current) at the IDET pin when Out-VIN = 0.1 V.
Source current 2 at reverse voltage	Idet_So2	Source current (outflow current) at the IDET pin when Out-VIN = 0.5 V.
Current amplification factor	gm	Amplification factor of the IDET current against the VIN-Out potential difference.

The chart below shows the characteristics of sink and source currents as actual values.



3.7 REV pin

The REV pin enables and disables the reverse current prevention function. The function is enabled when REV = high and disabled when REV = low. Since REV = high is brought by voltage application via the constant current source from the VIN pin in the IC, even if reverse current prevention is required, no external voltage application is required; this pin is unused (open, no external signal needed). If the reverse current prevention function itself is not required, short-circuit the pin to the IC GND pin.

Explanations of electrical characteristics of the REV pin		
Reverse current protection start voltage	Vrevst	Threshold used to determine that REV = high. REV = high when V_REV ≥ Vrevst.
Reverse current protection stop voltage	Vrevsp	Threshold used to determine that REV = low. REV = low when V_REV ≤ Vrevst.
REV pin discharge current	Irev	Current flowing from the REV pin; this is the current value of the constant current source from VIN to REV in the IC. To minimize current consumption at the VIN pin, Irev is a very low current. If ambient noise impairs stable operation, we recommend adding an external capacitor to the EN pin.

3.8 GND pin

Connect the GND pin to GND of the power supply circuit. As a countermeasure against input reverse connection, an N-channel MOSFET for reverse connection protection is placed between GND in the IC and the GND pin (see “4.7 Countermeasures against input reverse connection up to 40 V”). In normal operation (VIN > GND), the MOSFET for reverse connection protection is on, while GND in the IC and the GND pin have the same potential.

4. Circuit operations and functions

4.1 Basic operations

The MF2007SW is a control IC used to turn a high side external N-channel MOSFET on and off. An N-channel MOSFET is turned on or off when the gate voltage Vgs, using the source potential as the reference, equals or exceeds the gate threshold voltage Vth. Thus, **in the IC (MF2007SW), the charge pump (Charge Pump 1) uses the Source pin potential as the reference potential**. The charge pump outputs the Gate drive signal (Vgate) to turn on or off an external N-channel MOSFET.

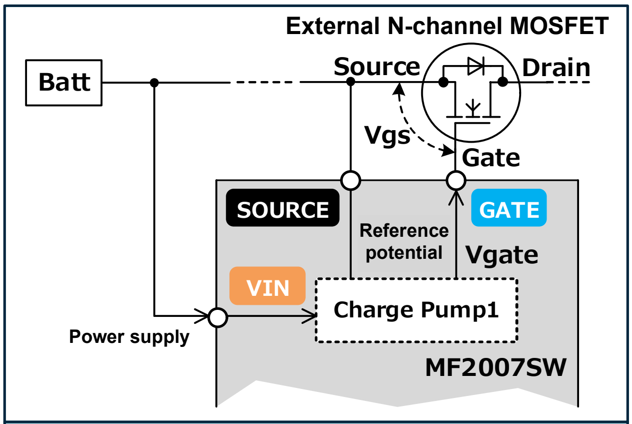


Figure 2 Connection with external N-channel MOSFET

■ Ideal diode type

Combined with one N-channel MOSFET, the MF2007SW can serve as a low loss diode (ideal diode). As shown at right, it allows current flow in the forward direction, Batt to LOAD, but does not allow current flow in the reverse direction, LOAD to Batt. In the IC, VIN and Out voltages are compared to determine whether to allow Gate output. Depending on Gate output, the external N-channel MOSFET is turned on or off to conduct or shut off electricity between Batt and LOAD.

- Batt > LOAD: The N-channel MOSFET is turned on by Gate output to conduct electricity between Batt and LOAD.
- Batt < LOAD: Gate output stops so that the N-channel MOSFET is turned off to shut off electricity between Batt and LOAD.

For details, see “4.5 Reverse current prevention function.”

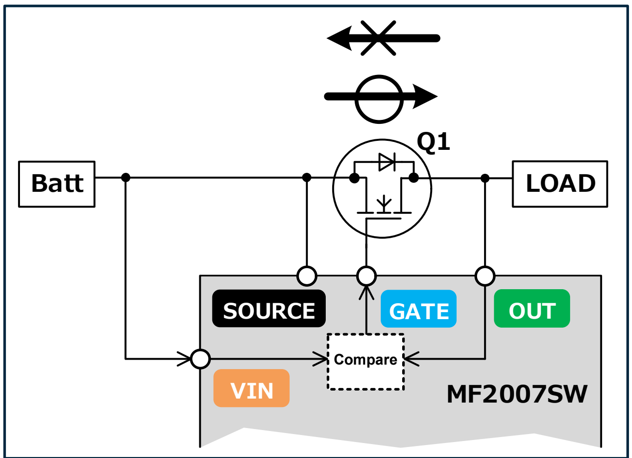


Figure 3 Schematic diagram of ideal diode type

■ Solid state relay type

Combined with two N-channel MOSFETs, the MF2007SW can serve as a solid state relay (bidirectional switch). As shown in Figure 4, connecting two external N-channel MOSFET in a common source configuration makes it possible to conduct and shut off electricity between input and output (Batt and LOAD) using an EN signal.

- EN = high: Gate output turns on the two N-channel MOSFETs to conduct electricity between Batt and LOAD.
- EN = low: Gate output stops so that the N-channel MOSFETs is turned off to shut off electricity between Batt and LOAD.

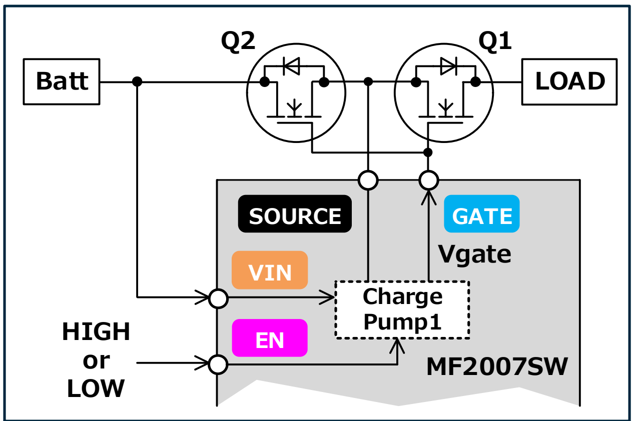


Figure 4 Schematic diagram of solid state relay type

4.2 Normal start and stop

In the MF2007SW, the startup circuit is turned on when the VIN voltage equals or exceeds the charge pump supply start voltage Vcp_stt = 3.0 V (typ) and when the EN voltage equals or exceeds the booster circuit start threshold Venst = 1.5 V (typ). The OSC in the IC begins to oscillate and Charge Pump 1 outputs Vgate to the Gate pin. The startup circuit is turned off when the VIN voltage equals or drops below the charge pump supply stop voltage Vcp_stp = 2.5 V (typ) or when the EN voltage equals or drops below the booster circuit stop threshold Vensp = 1.0 V (typ). The OSC in the IC and Charge Pump 1 output stop.

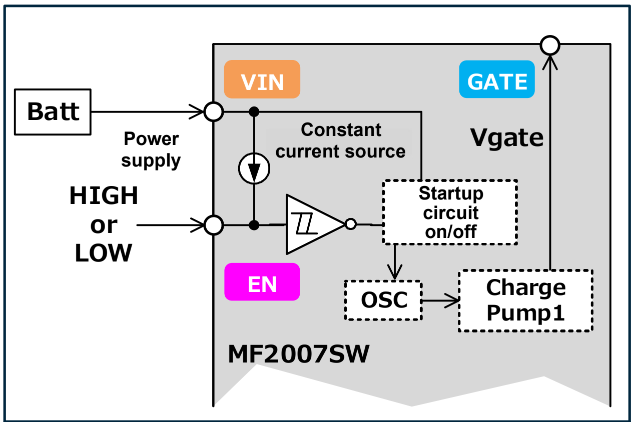


Figure 5 Block diagram of normal start and stop

■ Ideal diode type (start and stop by VIN)

Since an ideal diode type does not perform on/off driving of an external N-channel MOSFET using the EN pin, the EN pin is left unused, while the external N-channel MOSFET is always on during normal operation. In the IC, a constant current source is provided from the VIN pin to the EN pin so that the EN pin voltage rises as the VIN pin voltage rises. Thus, the start-stop control is implemented with the VIN pin charge pump supply start/stop voltage.

Charge pump supply start voltage Vcp_stt = 3.0 V

Charge pump supply stop voltage Vcp_stp = 2.5 V

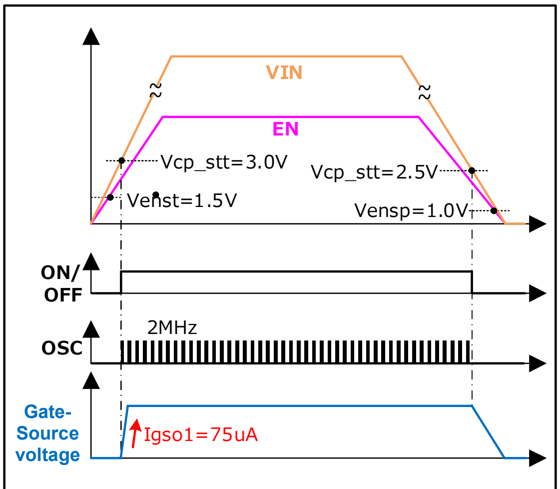


Figure 6 Start and stop of ideal diode type

■ Solid state relay type (start and stop by EN)

Unlike the ideal diode above, a solid state relay drives the on-off switching of an external N-channel MOSFET by the high-low control of the EN pin. It starts up when the EN pin rises to Venst = 1.5 V (typ) or more and stops when it falls to Vensp = 1.0 V (typ) or less. When it stops with the EN pin falling to Vensp = 1.0 V or less, the Gate fast discharge function is activated (see "4.4 Gate fast discharge function"). In this case, the delay time in the IC is Tenon = 12 μs for turning on and Tenoff = 50 ns for turning off. If Batt connection is turned on or off with EN = high/low, the start and stop operations are controlled by the VIN pin.

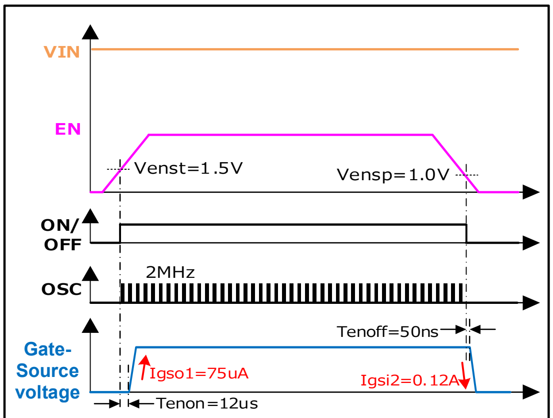


Figure 7 Start and stop of solid state relay type

4.3 On-off driving of external N-channel MOSFET

The external N-channel MOSFET is turned on by the source current Igso1 = 75 μA (typ) output from the Gate pin of the MF2007SW. After the MOSFET is turned on, the Gate voltage is kept at 12.5 V (typ) by the OVP circuit between Gate and Source in the IC.
For switching off via VIN shut-off, the supply of Igso stops to turn off the MOSFET. In this case, the external N-channel MOSFET turns off as its gate voltage falls by self-discharge. The stop timing and behavior depend on the parasitic capacitance and other characteristics of the external N-channel MOSFET and capacity components added on the battery and load sides.
For switching off by any method other than the above, a discharge current Igsi flows due to Gate fast discharge. The external MOSFET is turned off by the fast discharge of Gate voltage with the fast discharge MOSFET between Gate and Source in the IC (Section 4.4 Gate fast discharge function). While the fast discharge MOSFET is on, Gate voltage will not rise.

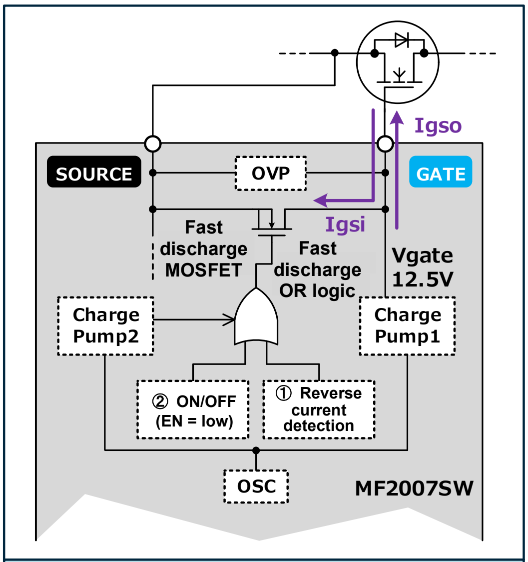


Figure 8 Block diagram of the vicinity of the Gate pin

4.4 Gate fast discharge function

The MF2007SW incorporates the Gate fast discharge function. This function is activated upon ① reverse current detection or ② switching on/off when EN = low. If ① or ② is detected at the OR logic input for fast discharge, the fast discharge MOSFET between Gate and Source in the IC is turned on and rapidly discharges the Gate voltage (see Figure 8). The OR logic for fast discharge is driven by the output of Charge Pump 2 in the IC. Charge Pump 2 begins to operate simultaneously with Charge Pump 1 when the OSC in the IC begins to oscillate. The Gate fast discharge capacities by ① and ② as shown in Figure 8 are as follows:

① Gate fast discharge by reverse current detection * See Section 4.5 (next page) for detailed information on preventing reverse currents.
- The Gate discharge current is a sink current Igsi1 = 0.7 A (typ).
- The off time (delay time in the IC) from reverse current detection until Gate fast discharge starts Trevoff = 200 ns (typ)

② Gate fast discharge by EN = low *See "Solid state relay type (start and stop by EN)" in Section 4.2 on previous page.
- The Gate discharge current is a sink current Igsi2 = 0.12 A (typ).
- The off time (delay time in the IC) from when EN = low is detected until Gate fast discharge starts Tenoff = 50 ns (typ)

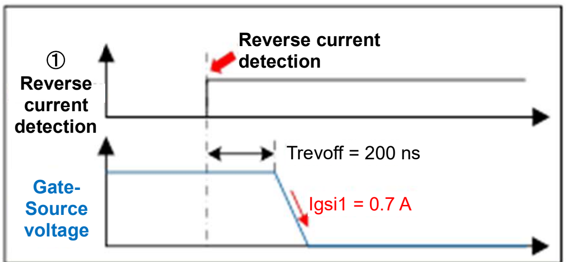


Figure 9 Gate fast discharge by ① Reverse current detection

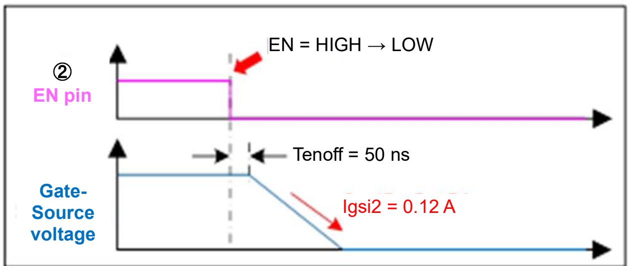


Figure 10 Gate fast discharge by ② EN = low

4.5 Reverse current prevention function

The MF2007SW enables the reverse current prevention function when the REV pin is high (reverse current protection start voltage Vrevst = 1.5 V (typ) or more). In the IC, a constant current source is provided from the VIN pin to the REV pin, and the reverse current prevention function is enabled if there is no external signal to the REV pin (REV pin unused). The reverse current prevention function can be disabled when the REV pin is low (reverse current protection stop voltage Vrevsp = 1.0 V (typ) or less). If the reverse current prevention function is not required, simply short-circuit the REV pin to the GND pin.

The MF2007SW reverse current prevention function works as follows: if the VIN and Out voltages fulfill the requirement of “VIN - Out < -13 mV (reverse current protection threshold),” the reverse current prevention comparator (COMP & Reverse Current) is activated to initiate Gate fast discharge. The Gate voltage is rapidly discharged, and the external N-channel MOSFET is turned off to prevent reverse current (see Figure 11).
If VIN (Batt side) falls, resulting in “Out - VIN > 13 mV (typ),” Gate voltage fast discharge begins after the off time (delay time in the IC) Trevoff = 200 ns (typ). The current (Isd) of the external N-channel MOSFET flows until the Gate voltage reaches the gate threshold voltage Vth. If the Gate voltage falls to Vth or less, the external N-channel MOSFET is turned off to prevent reverse current. If VIN (Batt side) rises, resulting in “Out - VIN < 9 mV (typ),” Gate voltage fast discharge stops after the delay time in the IC of approximately 2 μs, and the Gate rises. The gate voltage for the external N-channel MOSFET is charged, and the MOSFET is turned on (see Figure 12).

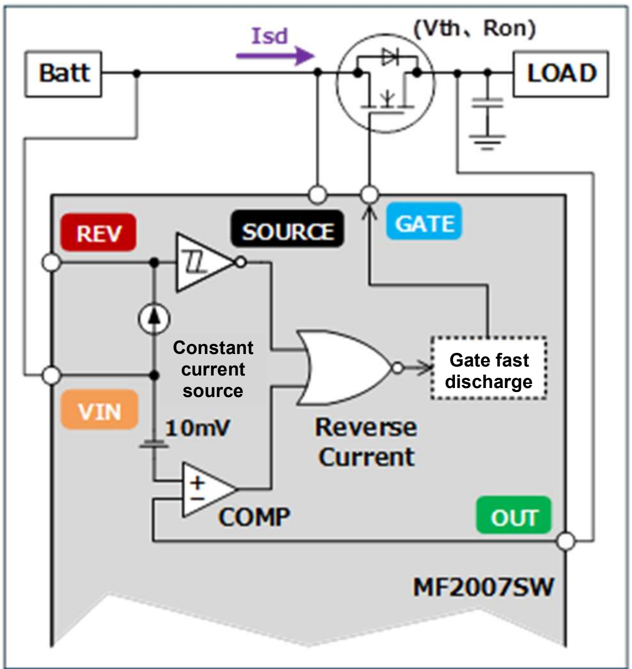


Figure 11 Reverse current prevention circuit

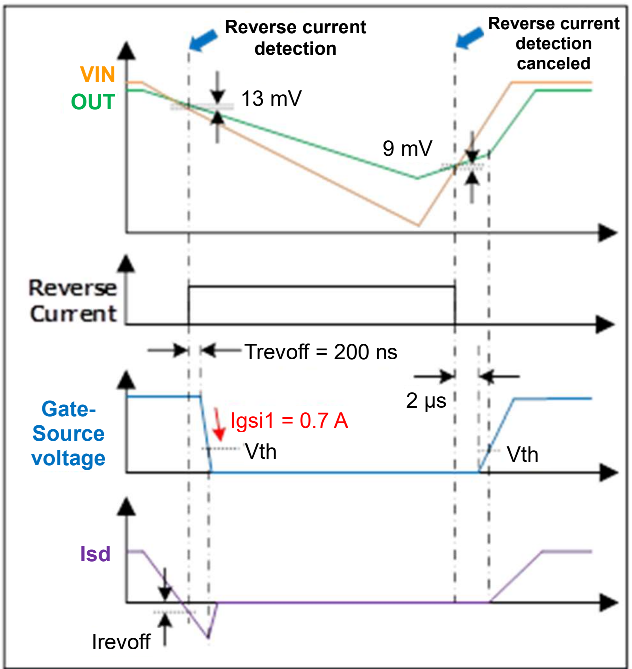


Figure 12 Reverse current prevention function

Due to concerns about instability during normal operation, the reverse current detection point of the MF2007SW is set at “Out - VIN = 13 mV (typ).” This means the negative current value for detecting reverse current prevention Irevoff is 13 mV/Ron. Until the reverse current reaches Irevoff, reverse current prevention cannot be detected, and electricity continues to flow to the external N-channel MOSFET. If the on-resistance Ron of a MOSFET is low, the absolute value of the negative current Irevoff for detecting reverse current prevention is large.

4.6 VDS monitoring function

The MF2007SW features a VDS monitoring function, which monitors the state of the VIN and Out pins, converts the VIN-Out potential difference to a current using the current amplification factor gm = 220 μA/V (typ), and generates a current at the IDET pin (see Figure 13).
The following currents are generated:

VIN > Out ⇒ Inflow current to IDET pin Idet_Si
VIN < Out ⇒ Outflow current from IDET pin Idet_So

Figure 14 shows an operation example as the load current increases. Monitoring the VDS state of the external N-channel MOSFET allows monitoring of the load state as IDET signal detection.

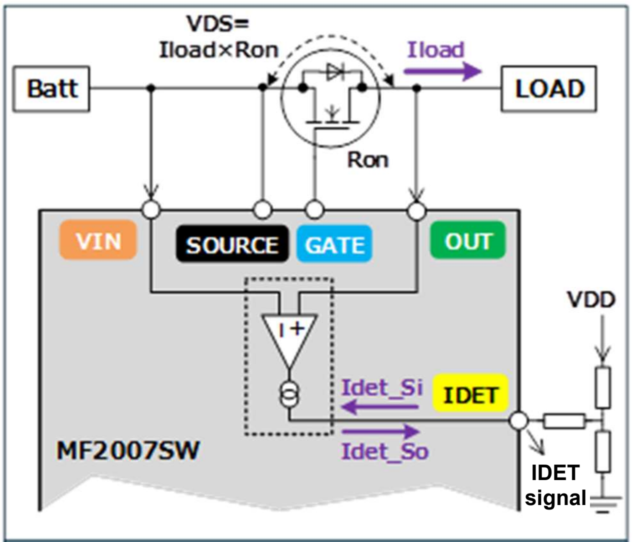


Figure 13 Block diagram of the VDS monitoring function

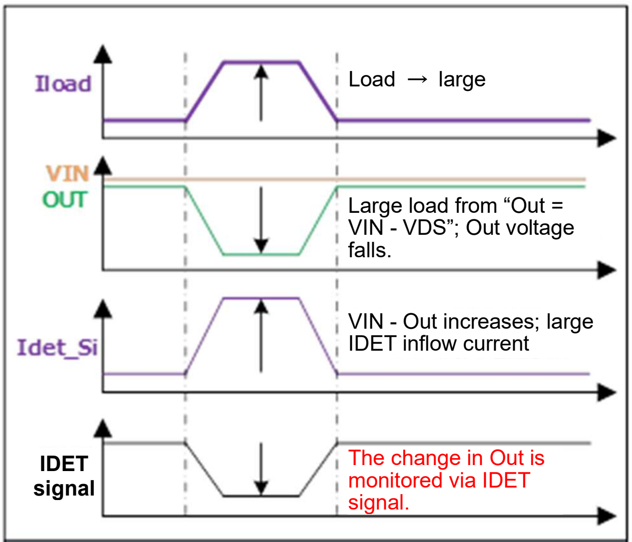


Figure 14 Use of IDET signal by the VDS monitoring function

Figure 15 shows a design example of the VDS monitoring function. The design example shown in Figure 15 uses 43k-1k-1k resistors. Figure 16 shows an example of characteristics with VDD fixed at 5 VDC and with different voltage dividing resistor conditions. The IDET signal changes based on Out-VIN voltage conditions, Thus, the 0- to 5-V IDET signals can be used as analog signals, allowing operations (protection) in accordance with the load state.

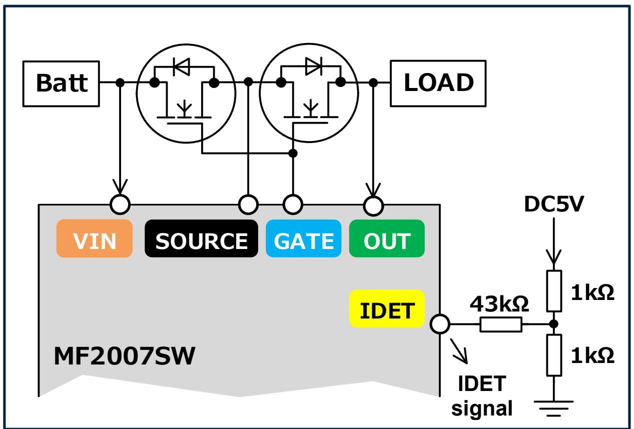


Figure 15 Design example of the VDS monitoring function (43k-1k-1k)

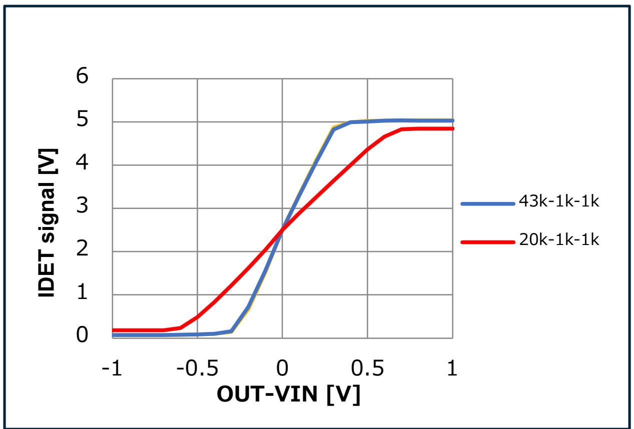


Figure 16 IDET signal characteristics

4.7 Countermeasures against input reverse connection up to 40 V

In the case of an input reverse connection (application of negative voltage), a current flows from the GND pin into the IC along the route indicated by a purple arrow in Figure 17 and turns on the fast discharge MOSFET in the IC, which turns off the external N-channel MOSFET. This prevents Out (output) from becoming a negative voltage. Since a 12- or 24-V battery is assumed, the withstand voltage between VIN and GND is limited to -40 V. No reverse connection exceeding the withstand voltage is assumed to be possible. To prevent damage to the IC due to an input reverse connection, the MF2007SW incorporates an N-channel MOSFET for reverse connection protection between the GND pin and GND in the IC (see Figure 18). If an input reverse connection occurs (VIN < 0 V), the MOSFET for reverse connection protection is not turned on, and no current flows from the GND pin to the VIN pin. Power is not supplied to the IC, the charge pump does not operate, and the Gate pin voltage does not rise, which prevents an incorrect turn-on of the external N-channel MOSFET.

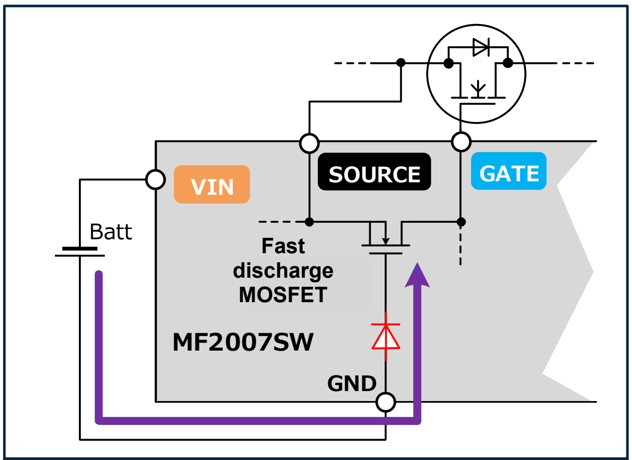


Figure 17 Input reverse connection protection circuit 1

In the case of an input reverse connection, a negative voltage is applied to the VIN pin. The MF2007SW features built-in diodes for ESD protection near the EN and REV pins inside the IC to prevent inflow currents from these pins to the VIN pin (see Figure 19).

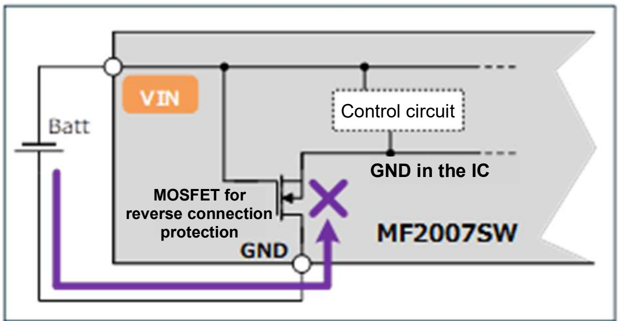


Figure 18 Input reverse connection protection circuit 2

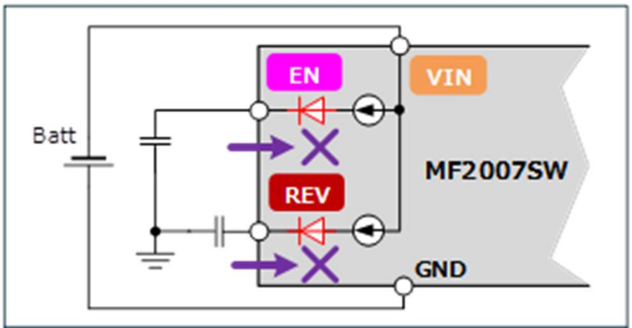


Figure 19 Input reverse connection protection circuit 3

4.8 IC current consumption

When the EN pin = low (shutdown mode), the MF2007SW stops IC operations (e.g., the charge pump) to minimize current consumption.
When the IC is operating, the current consumption Iop is 200 µA (typ). When EN = 0 V, IC current consumption equals the operating current at shutdown Iq = 5 µA (typ).

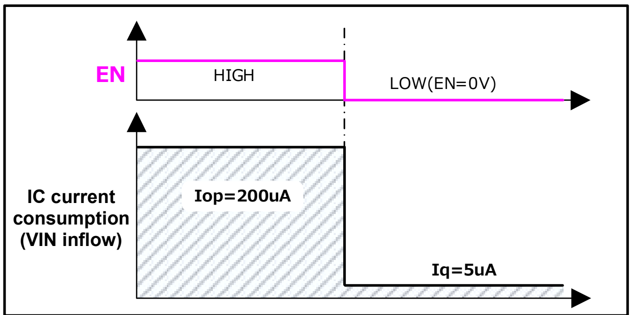


Figure 20 IC current consumption

5. Method for selecting peripheral component constants

Typical circuit examples are shown below.

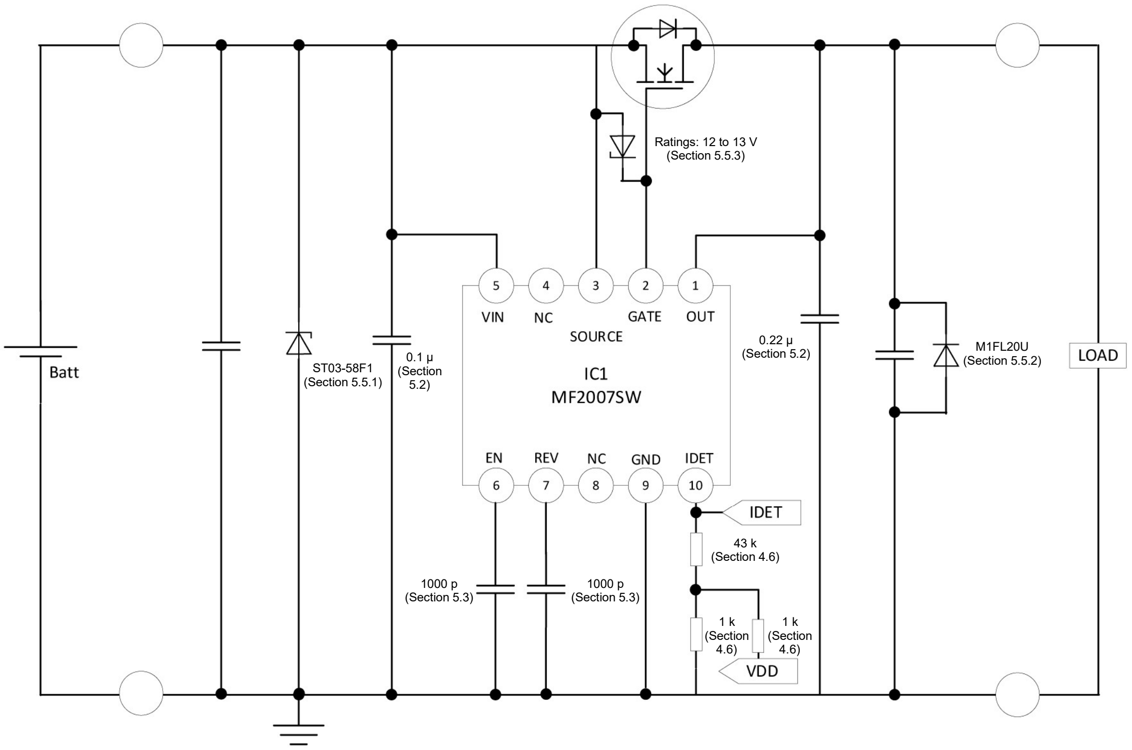


Figure 21 Example of ideal diode circuit

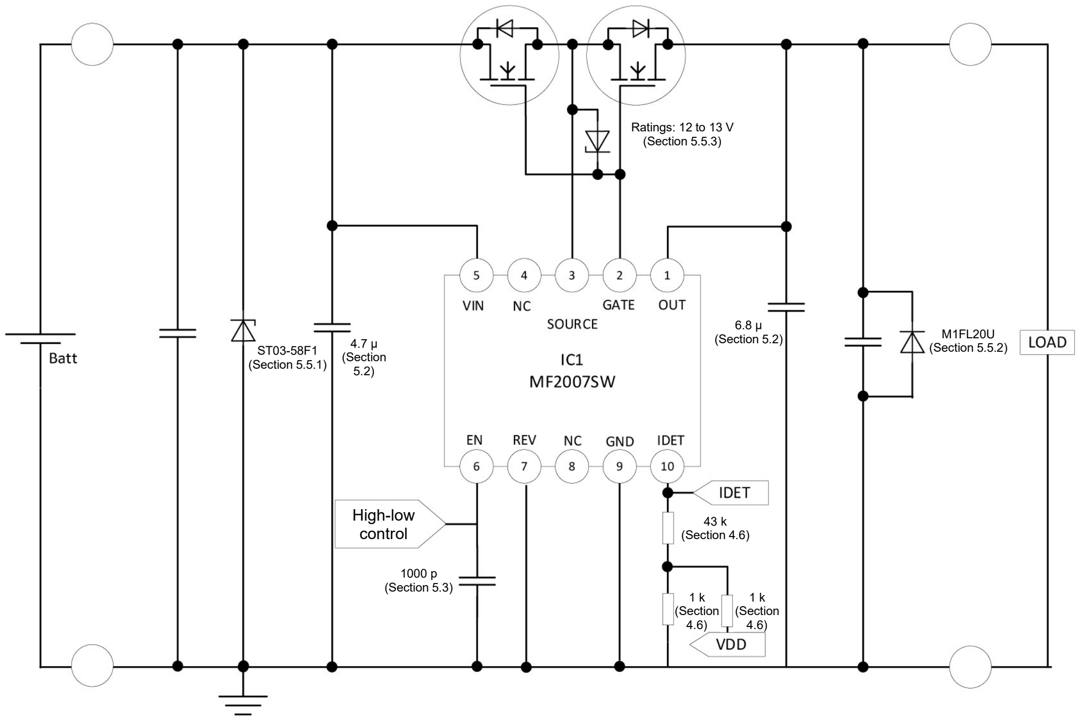


Figure 22 Example of solid state relay circuit

5.1 N-channel MOSFET

The withstand voltage between the drain and source must be high enough for the maximum input voltage that can be applied to the circuit.
When the input capacitance Ciss of an external N-channel MOSFET increases, the turn-on time and turn-off time tend to lengthen. As a rough guide, if Ciss is 40 nF or more, the rise time will be 100 μs or more.
Since all load currents flow through an external N-channel MOSFET, select a product with sufficiently low drain-to-source on-state resistance RDS (ON) to minimize loss of the external N-channel MOSFET.

5.2 VIN pin capacitor and Out pin capacitor

Capacitors for the VIN and Out pins are used to alleviate stress. Add these components if it is necessary to limit the effects of external noise and ripple voltage.
Particularly in a solid state relay type, ringing will occur at the pins during turn-off by the EN pin. Add high-capacitance capacitors to avoid exceeding the element withstand voltage.
High capacitor capacitance, however, may have adverse effects, including a larger inrush current at startup. Using the recommended range as a guide, check the operation with the actual device and adjust the capacitance accordingly. To reduce ringing at the source, make sure the VIN pin capacitor capacitance is less than the Out pin capacitor capacitance.
When they are used in an ideal diode type, they may not activate if the reverse current prevention is turned on at startup. To prevent this, make sure the capacitor capacitance ratio between VIN and Out pins is 1:2 so that the activation of the Out side is delayed.

<Recommended values>

	VIN pin capacitor	Out pin capacitor
Ideal diode type	0.1 to 1.0 [μF]	0.22 to 2.2 [μF]
Solid state relay type	4.7 to 10 [μF]	6.8 to 22 [μF]

*** Even if no ringing reduction measures are required, a 0.1 to 1 μF capacitor is needed to protect the IC.**

5.3 EN pin capacitor and REV pin capacitor

Capacitors for the EN and REV pins are used to reduce noise. Add these components if it is necessary to limit the effects of external noise and ripple voltage.
Note that high capacitor capacitance may have adverse effects, including longer times to switch operations. The recommended capacitor capacitance is around 1,000 pF. Check the operation with the actual device and adjust the capacitance accordingly.

5.4 IDET circuit

The IDET circuit converts a potential difference between the VIN and Out pins to a current, generates an IDET signal using external resistors, and transmits the signal to an external circuit.
The IDET signal is obtained by dividing an external power supply VDD using resistors R1 and R2, which produces a voltage Va, and adding a voltage generated at resistor R3 to Va. The current below flows to R3:

VIN > Out ⇒ Inflow current at IDET pin Idet_Si
Out > VIN ⇒ Outflow current at IDET pin Idet_So

Thus, IDET signal V_IDET is calculated as follows:

VIN > Out ⇒ V_IDET [V] = Va - R3 × Idet_Si
= VDD × R2/(R1 + R2) - R3 × Idet_Si
Out > VIN ⇒ V_IDET [V] = Va + R3 × Idet_So
= VDD × R2/(R1 + R2) - R3 × Idet_So

Make sure R1 and R2 have a resistance value that allows a current more than 10 times as large as the Idet current.

<Recommended values>

VDD voltage	R1, R2	R3
5 V	1 kΩ	20 kΩ to 43 kΩ

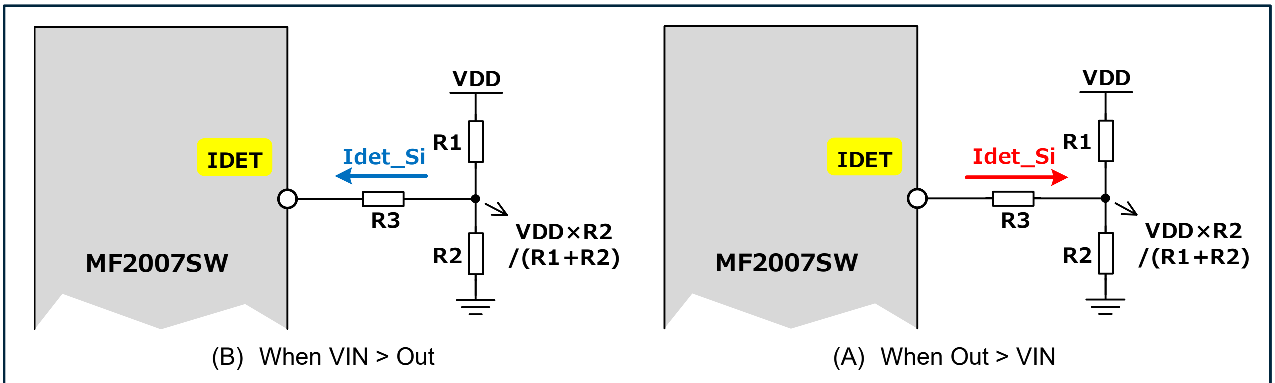


Figure 23 IDET circuit

5.5 External protection components

5.5.1 Input surge protection

The absolute maximum voltage for the VIN pin of the MF2007SW ranges from -40 V to 70 V. If a voltage exceeding this range is likely to be applied due to a positive or negative surge voltage, use a transient voltage suppression (TVS) diode or other protective element.
Make sure the TVS voltage does not exceed the standard value of the MF2007SW even in the worst-case scenario. Additionally, check with the actual device that the selected TVS diode is capable of absorbing the input transient energy.

5.5.2 Countermeasure against negative output voltages

As a countermeasure against negative output voltages caused by ringing on the load side when an inductive load is connected or by an output leakage current due to input reverse connection, the negative output voltage can be limited by adding a fast recovery diode (FRD) to the output pin.
If you choose to add a Schottky barrier diode (SBD), select an SBD with a small reverse current IR to reduce current consumption at no load.

5.5.3 Gate protection

Take appropriate measures to ensure that the gate-source withstand voltage for the IC: 15 V is not exceeded when a voltage changes significantly: for instance, if the input voltage falls sharply. As gate protection, add a Zener diode between Gate and Source of the IC. Be sure to select a Zener diode with a Zener voltage not exceeding the gate-source withstand voltage for the IC.

6. Application circuit examples

6.1 Ideal diode connected in parallel

When the MF2007SW is used for large currents, heat buildup caused by external N-channel MOSFETs can be minimized by connecting external N-channel MOSFETs in parallel to disperse the current. Because the on-resistance (Ron) of MOSFET has positive temperature characteristics, the current sharing imbalance is small with parallel connection of MOSFETs compared to that of diodes.

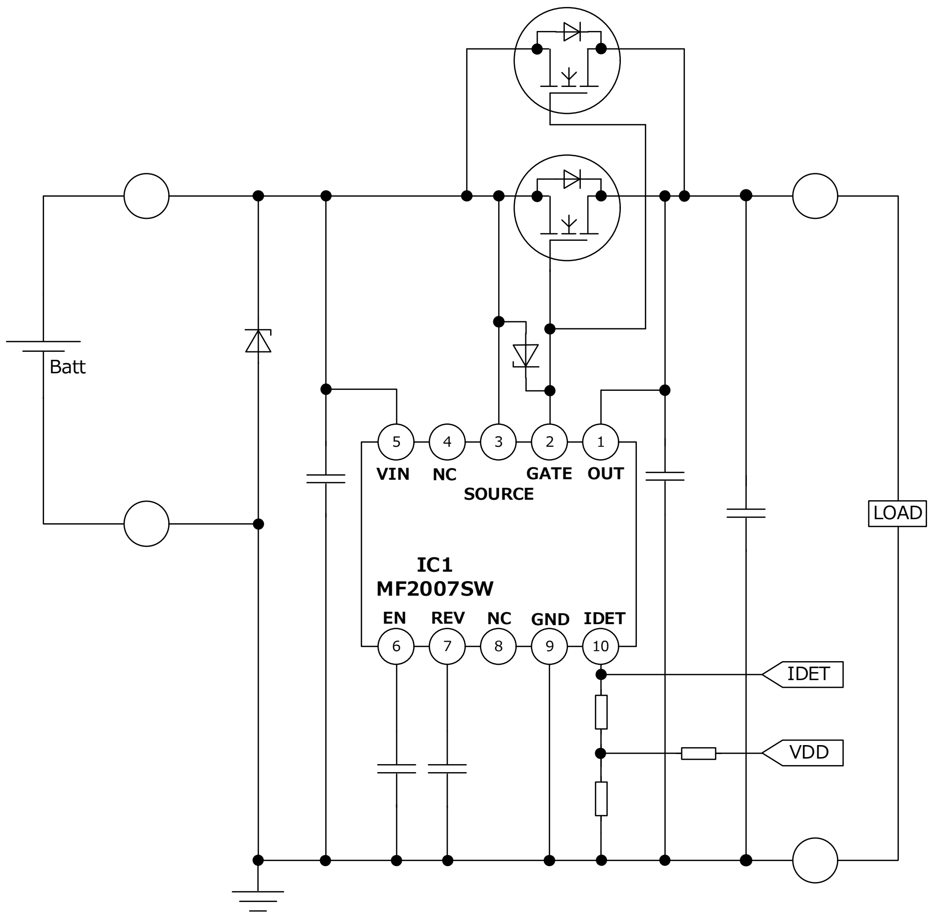


Figure 24 Ideal diode connected in parallel

6.2 Bidirectionally conducting solid state relay

The MF2007SW can be used as a solid state relay that conducts electricity bidirectionally by turning REV low. If power is supplied to the VIN pin from both Batt and LOAD shown in the diagram below via diodes, the MF2007SW can be turned on by either the Batt or LOAD voltage. To fulfill the maximum rating of the MF2007SW, select an ultra-low Vf diode that meets the working condition of Vf < 0.3 V. To supply power to the VIN pin by Batt voltage at all times, see “1.2 Basic connection examples.”

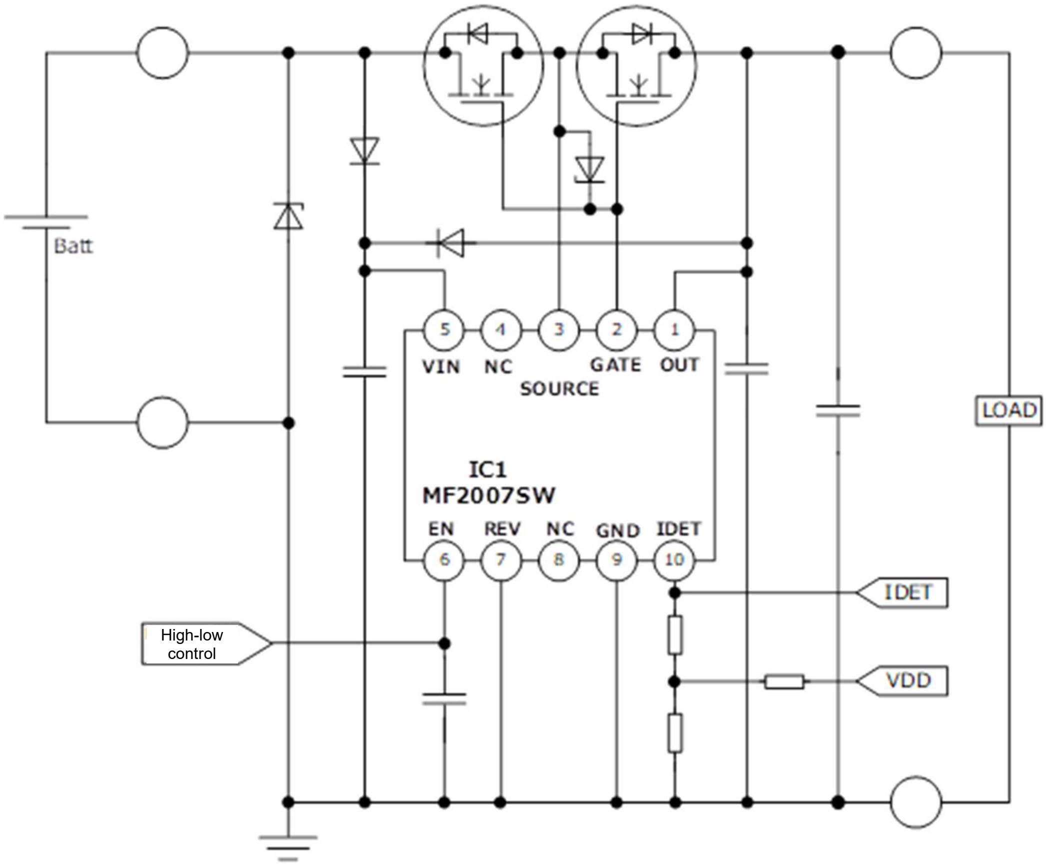


Figure 25 Bidirectionally conducting solid state relay

7. Pattern layout

This section provides pattern design precautions. Be sure to check the operation with the actual device before deciding on the layout.
In general, consider the following three points during pattern design:

1. A power line in which large currents flow should be as short and thick as possible. Separate the power GND line from the IC GND line. Connect the IC GND line to a stable potential with minimal current variations.
2. Make sure the line between the Gate pin and the gate of an external N-channel MOSFET is as short as possible. Place the IC as close as possible to the MOSFET.
3. Place a noise reduction capacitor as close as possible to each pin.

7.1 Pattern layout examples

Examples of double-sided PCB are provided as pattern layout reference examples.

■ **Ideal diode type**

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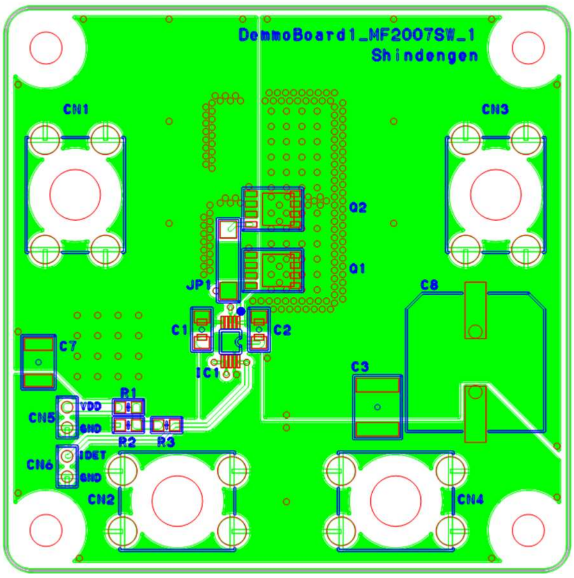

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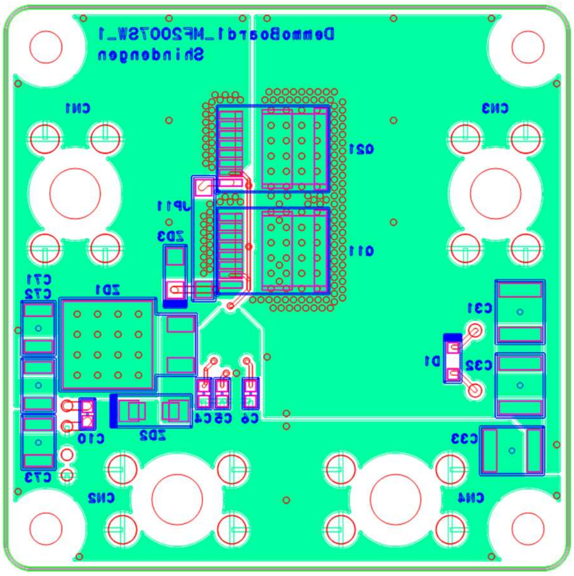

■ **Solid state relay type**

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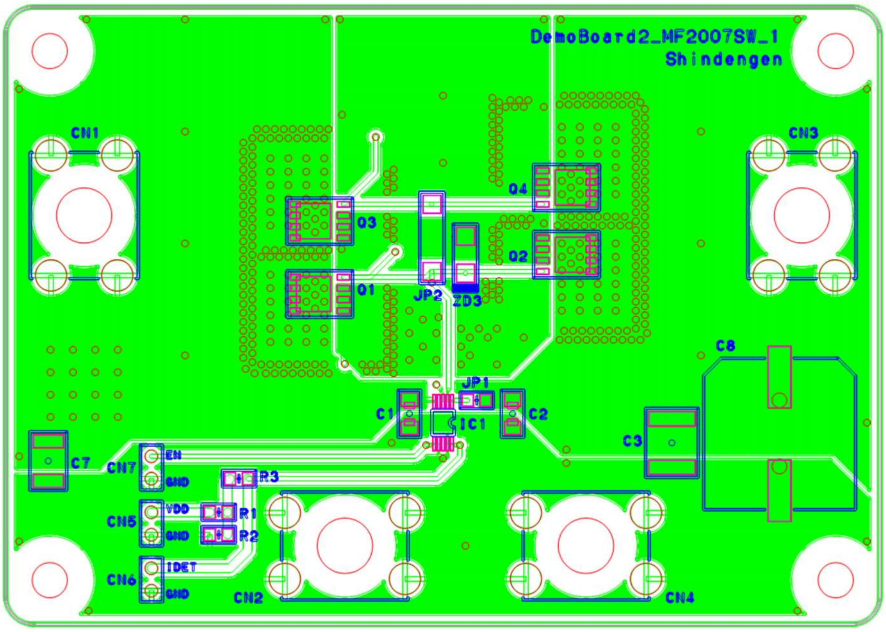

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