RV4146
Low Power Ground Fault Interrupter

Description

The RV4146 is a low power controller for AC receptacle ground fault circuit interrupters. These devices detect hazardous current paths to ground and ground to neutral faults. The circuit interrupter then disconnects the load from the line before a harmful or lethal shock occurs.

Internally, the RV4146 contains an oscillator, shunt regulator, precision sense amplifier, current reference, time delay circuit, and SCR driver.

Two sense transformers, SCR, solenoid, four diodes, three resistors and four capacitors complete the design of the basic circuit interrupter. The simple layout and minimum component count insure ease of application and long term reliability.

Features not found in other GFCI controllers include a low offset voltage sense amplifier, eliminating the need for a coupling capacitor between the sense transformer and sense amplifier, and an internal oscillator to eliminate the sensitivities of the dormant oscillator

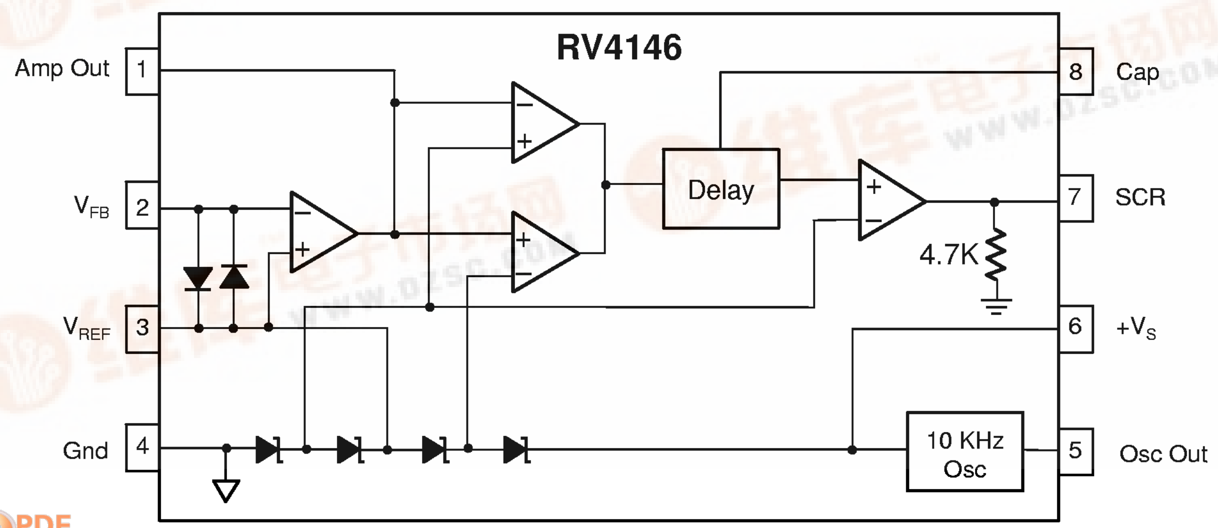
Features

- Built-in grounded neutral oscillator
- Direct interface to SCR
- 1 mA quiescent current
- Precision sense amplifier
- Adjustable time delay
- Minimum external components
- Meets UL 943 requirements
- For use with 110V or 220V systems
- Available in 8 pin DIP or SOIC package
- Differential circuitry for noise immunity
- Trip time dependent on fault magnitude

The RV4146 senses current faults independent of its phase relative to the line voltage. The gate of the SCR is driven during both cycles of the line voltage.

Noise immunity is maximized on the RVxxxx, but the use of differential circuitry with 3 times the discharge current as charge, and low output impedance on the SCR driver.

Functional Block Diagram



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Absolute Maximum Ratings

Supply Current .... 10 mA
Internal Power Dissipation .... 500 mW
Storage Temperature
  Range .... -65°C to +150°C
Operating Temperature
  Range .... -35°C to +80°C
Lead Soldering Temperature
  (60 Sec., DIP) .... +300°C
  (10 Sec., SO) .... +260°C

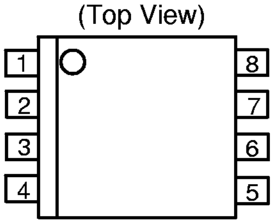
Ordering Information

Part Number	Package	Operating Temperature Range
RV4146N	N	-35°C to +80°C
RV4146M	M	-35°C to +80°C

Notes:
N = 8-lead plastic DIP
M = 8-lead plastic SOIC

Connection Information

8-Lead Plastic Dual In-Line SO-8
(Top View)



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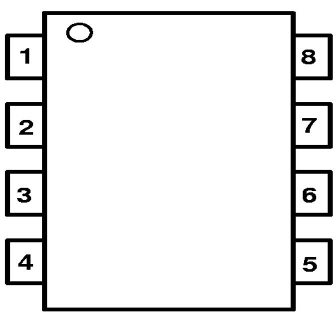
8-Lead Plastic Dial In-Line Package
(Top View)



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Pin	Function
1	Amp Out
2	V_{FB}
3	V_{REF} (+13V)
4	Ground
5	Line
6	$+V_S$
7	SCR Trigger
8	Delay Cap

Thermal Characteristics

	8-Lead Plastic SOIC	8-Lead Plastic DIP
Max. Junction Temp.	+125°C	+125°C
Max. P_D T_A <50°C	300 mW	468 mW
Therm. Res θ_{JC}	—	—
Therm. Res. θ_{JA}	240°C/W	160°C/W
For T_A >50°C Derate at	4.1 mW per °C	6.25 mW per °C

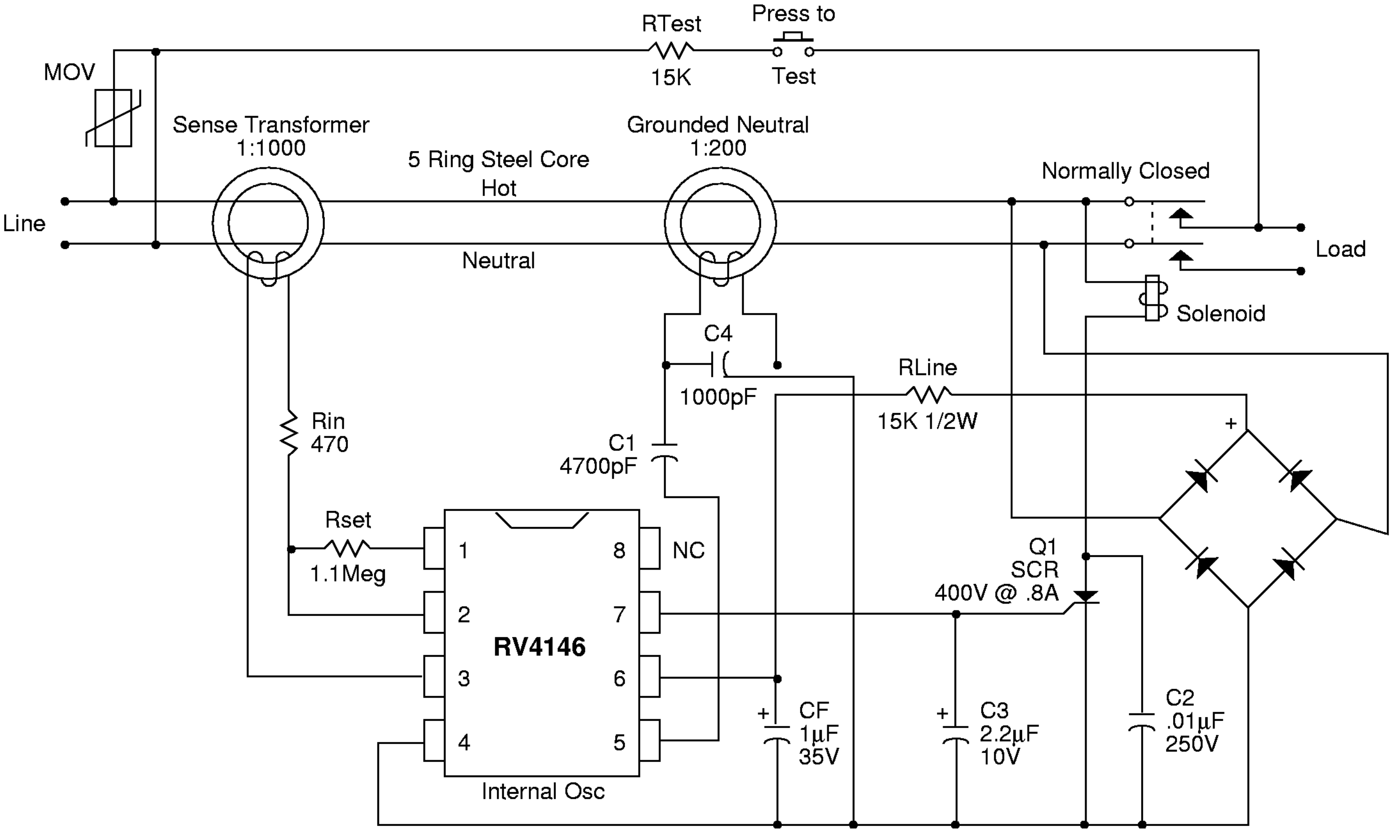

Figure 1. GFI Application Circuit (Full-Wave)

Electrical Characteristics

(I_{LINE} = 2.5 mA and T_A = +25°C, R_{SET} = 650 kΩ)

Parameters	Test Conditions	Min	Typ	Max	Units
Shunt Regulator (Pins 6 to 4)					
Regulated Voltage	I_{2-3} = 11 µA	25.0	27.0	29.0	Volts
Regulated Voltage	I_{LINE} = 750 µA, I_{2-3} = 9 µA	25.0	27.0	29.0	Volts
Quiescent Current	V_{5-4} = 24V	—	51	—	mA
Sense Amplifier (Pins 2 to 3)					
Offset Voltage		250	0	250	µV
Gain Bandwidth	(Design Value)	—	1.5	—	MHz
Input Bias Current	(Design Value)		30	100	nA
SCR Trigger (Pins 7 to 4)					
Output Voltage	I_{2-3} = 9 µA	0	0.1	.2	V
Output Voltage	I_{2-3} = 11 µA	2.4	3.0	3.6	Volts
Output Current	V_{7-4} = 0V, I_{2-3} = 11 µA	500	1000	2500	µA
Reference Voltage (Pins 3 to 4)					
Reference Voltage	I_{LINE} = 750 µA	12.0	13.0	14.0	Volts
Delay Timer (Pins 8 to 4)					
Delay Time (Note 1)	C_{8-4} = 12 nF	—	2.0	—	ms
Delay Current	I_{2-3} = 11 µA	30	40	50	µA
Oscillator					
Frequency		5	10	15	KHz
Voltage			1.5		V
Output Current		2	4		mA

Note:

1. Delay time is defined as starting when the instantaneous sense current (I_{2-3}) exceeds 6.5 V/R_{SET} and ending when the SCR trigger voltage V_{7-6} goes high.

Circuit Operation

(Refer to Block Diagram and Figure 1)

The precision op amp connected to Pins 1 through 3 senses the fault current flowing in the secondary of the sense transformer, converting it to a voltage at Pin 1. The ratio of secondary current to output voltage is directly proportional to feedback resistor, R_{SET}.

R_{SET} converts the sense transformer secondary current to a voltage at Pin 1. Due to the virtual ground created at the sense amplifier input by its negative feedback loop, the sense transformer's burden is equal to the value of R_{IN}. From the transformer's point of view, the ideal value for R_{IN} is 0Ω. This will cause it to operate as a true current transformer with minimal error. However, making R_{IN} equal to zero creates a large offset voltage at Pin 1 due to the sense amplifier's very high DC gain. R_{IN} should be selected as high as possible consistent with preserving the transformer's operation as a true current mode transformer. A typical value for R_{IN} is between 200 and 1000Ω.

As seen by the equation below, maximizing R_{IN} minimizes the DC offset error at the sense amplifiers output. The DC offset voltage at Pin 1 contributes directly to the trip current error. The offset voltage at Pin 1 is:

$$V_{OS} \times R_{SET}/(R_{IN} + R_{SEC})$$

Where:
V_{OS} = Input offset voltage of sense amplifier
R_{SET} = Feedback resistor
R_{IN} = Input resistor
R_{SEC}= Transformer secondary winding resistance

The sense amplifier has a specified maximum offset voltage of 200 µV to minimize trip current errors.

Two comparators connected to the sense amplifier output are configured as a window detector, whose references are -6.5 volts and +6.5 volts referred to Pin 3. When the sense transformer secondary RMS current exceeds $4.6/R_{SET}$ the output of the window detector starts the delay circuit. If the secondary current exceeds the predetermined trip current for longer than the delay time a current pulse appears at Pin 7, triggering the SCR.

The SCR anode is directly connected to a solenoid or relay coil. The SCR can be tripped only when its anode is more positive than its cathode.

Supply Current Requirements

The RV4146 is powered directly from the line through a series limiting resistor called R_{LINE}, of 15 kΩ. The controller IC requires and external full wave bridge diode.

The recommended value for R_{LINE} is 15 kΩ for 110V systems and 36 kΩ for 220V systems. When R_{LINE} is 30 kΩ the shunt regulator current is limited to 5 mA. The recommended maximum peak line current through R_{LINE} is 15 mA.

GFCI Application

(Refer to Figure 1)

The GFCI detects a ground fault by sensing a difference current in the line and neutral wires. The difference current is assumed to be a fault current creating a potentially hazardous path from line to ground. Since the line and neutral wires pass through the center of the sense transformer, only the differential primary current is transferred to the secondary. Assuming the turns ratio is 1:1000 the secondary current is 1/1000th the fault current. The RV4146's sense amplifier converts the secondary current to a voltage which is compared with either of the two window detector reference voltages. If the fault current exceeds the design value for the duration of the programmed time delay, the RV4146 will send a current pulse to the gate of the SCR.

Detecting ground to neutral faults is more difficult. R_B represents a normal ground fault resistance, R_N is the wire resistance of the electrical circuit between load/ neutral and earth ground. R_G represents the ground to neutral fault condition. According to UL 943, the GFCI must trip when R_N = 0.4Ω, R_G = 1.6Ω and the normal ground fault is 6 mA.

Assuming the ground fault to be 5 mA, 1 mA and 4 mA will go through R_G and R_N, respectively, causing an effective 1 mA fault current. This current is detected by the sense transformer and amplified by the sense amplifier. The ground/neutral and sense transformers are mutually coupled by R_G, R_N and the neutral wire ground loop, through the use of an on-board 10KHz oscillator.

C2 is used to program the time required for the fault to be present before the SCR is triggered. Refer to the equation below for calculating the value of C2. Its typical value is 12 nF for a 2 ms delay.

R_{SET} is used to set the fault current at which the GFCI trips. When used with a 1:1000 sense transformer, its typical value is 1 MΩ for a GFCI designed to trip at 5 mA.

R_{IN} should be the highest value possible which insures a predictable secondary current from the sense transformer. If R_{IN} is set too high, normal production variations in the transformer permeability will cause unit to unit variations in the secondary current. If it is too low, a large offset voltage error at Pin 1 will be present. This error voltage in turn creates a trip current error proportional to the input offset voltage of the sense amplifier. As an example, if R_{IN} is 500Ω, R_{SET} is 1 MΩ, R_{SEC} is 45Ω and the V_{OS} of the sense amplifier is its maximum of 200 µV, the trip current error is ±5.6%.

The SCR anode is directly connected to a solenoid or relay coil. It can be tripped only when its anode is more positive than its cathode. It must have a high dV/dt rating to ensure that line noise (generated by electrically noisy appliances) does not falsely trigger it. Also the SCR must have a gate drive requirement less than 200 µA. C3 is a noise filter that prevents high frequency line pulses from triggering the SCR.

The relay solenoid used should have a response time of 3 ms or less to meet the UL 943 timing requirement.

Sense Transformers and Cores

The sense and ground/neutral transformer cores are usually fabricated using high permeability laminated steel rings. Their single turn primary is created by passing the line and neutral wires through the center of its core. The secondary is usually from 200 to 1500 turns.

Magnetic Metals Corporation, Camden, NJ 08101, (609) 964-7842 and Magnetics, 900 E. Butler Road, P.O. Box 391, Butler, PA 16003, (412) 282-8282 are full-line suppliers of ring cores and transformers designed specifically for GFCI and related applications.

Calculating The Values of R_{SET} and C2

Determine the nominal ground fault trip current requirement. This will be typically 5 mA in North America (117V AC) and 22 mA in the UK and Europe (220V AC).

Determine the minimum delay time required to prevent nuisance tripping. This will typically be 1 to 2 ms.

The value of C2 required to provide the desired delay time is:

$$C2 = 6 \times T$$

where:

C2 is in nF

T is the desired delay time in ms.

The value of R_{SET} to meet the nominal ground fault trip current specification is:

$$R_{SET} = \frac{4.6 \times N}{I_{FAULT} \times \cos 180(T/P)}$$

Where:

R_{SET} is in kΩ

T is the time delay in ms

P is the period of the line frequency in ms

I_{FAULT} is the desired ground fault trip current in mA RMS

N is the number of sense transformer secondary turns.

This formula assumes an ideal sense transformer is used. The calculated value of R_{SET} may have to be changed up to 30% to when using a non-ideal transformer.