MORNSUN®

TLB1506-P

Type B Residual Current Detection Module

Features

- Suitable for Type B residual current protection
- Ultra-small: 10mm×13mm×3.1mm
- Wide operating temperature range: -40℃~85℃
- Integrated magnetic modulation and demodulation chip
- Trigger current threshold is adjustable
- Output drives trip unit directly
- Lends for AC and DC current sensors
- ADC sampling circuit can be connected externally
- Adjustable current sensing coefficient
- Adjustable current detection range

Package

Applications

- Type B residual current protection device
- AC/DC small current current detection current sensor
- Fluxgate control

Functional Description

TLB1506-P is a chip dedicated to current detection based on fluxgate, and integrates current processing circuit to achieve Type B residual current protection function.

Used for detecting dc residual current, Type A residual current and high frequency residual current above 1kHz. TLB1506-P outputs a trip signal when the remaining current exceeds the threshold. TLB1506-P is a complete Type B residual current protection scheme, users only need a small number of peripheral devices to achieve.

Used for current sensor, TLB1506-P has few peripheral components and adjustable sensing coefficient, suitable for current detection applications ranging from 6mA to 300mA. Double current sampling and detection mechanism is adopted in the chip, which can effectively offset the errors caused by magnetic bias of the magnetic ring, so the measurement accuracy is high. At the same time, the output adopts dynamic zero-pole feedback fine-tuning technology to ensure that the output voltage smoothly follows the change of residual current, and further reduce the output error.

Typical application circuit

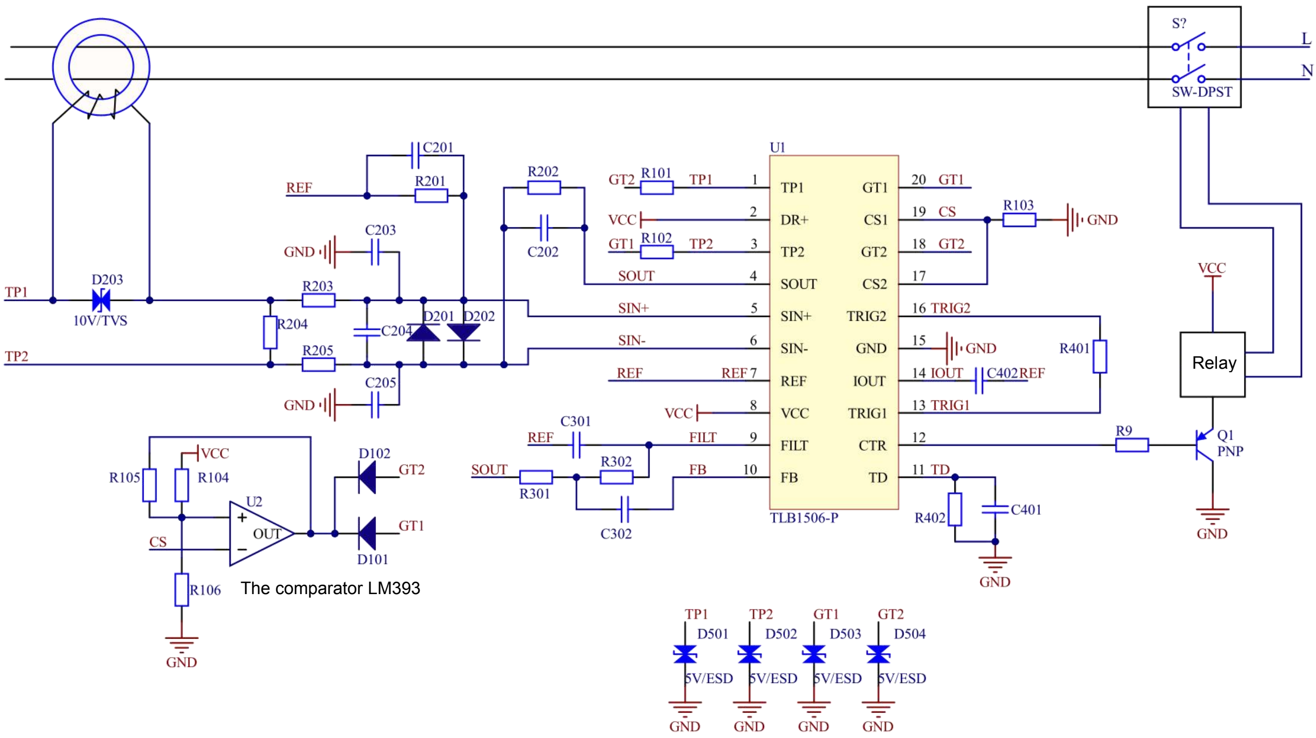


Figure 1 TLB1506-P Typical application circuit(For typical application parameters, see 2.7 DEMO Performance Specifications)

Absolute Maximum Ratings

General test conditions: Free-air, normal operating temperature range (Unless otherwise specified).

Symbol	Parameters		Min.	Max.	Unit
V_{max}	Maximum pin pressure tolerance		-0.3	5.5	V
	Electrostatic discharge (ESD) rating Human body model (HBM)	TP1,DR+,TP2,GT1,CS1, GT2,CS2 pins (ESD peripheral ①)		4000	V
		Other pins		3000	
	Reflow Soldering Temperature		Peak temp. ≤245℃, maximum duration ≤60s at 217℃. Please also refer to IPC/JEDEC J-STD-020D. 3.		

① : the pin is electrostatic sensitive pin, in the extreme electrostatic application environment need to increase the application circuit in D501,D502,D503,D504 four 5V clamp voltage TVS -ESD protection tube to the ground.

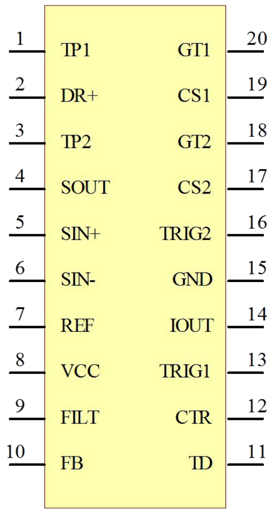
Important: Exposure to absolute maximum rated conditions for an extended period may severely affect the device reliability, and stress levels exceeding the “Absolute Maximum Ratings” may result in permanent damage.

Electrical Characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{CC}	VCC pin supply voltage	Normal system operating voltage	4.9	5	5.1	V
V_{out}	Sensor output voltage	/	GND		V_{CC}	V
V_{ref}	Reference bias voltage	V_{CC}=5V		V_{CC}/2		V
I_{CTR}	Trip output current	V_{CTR}=0.4V	10	20		mA
T_J	Operating temperature range		-40		85	℃
T_{STG}	Storage temperature		-40		105	℃
	Static power consumption	No peripheral circuits are added			2	mA

Pin Description

Pin	Name	Description	Type	Min.	Typ.	Max.	Unit	Pin Diagram
1	TP1	H bridge output pin 1	O	0	0 or DR+	DR+	V	
2	DR+	Magnetic modulation voltage	I	4.9	5	5.1	V	
3	TP2	H bridge output pin 2	O	0	0 or DR+	DR+	V	
4	SOUT	Fluxgate current sensor output pin 1	O	0	VCC/2	VCC	V	
5	SIN+	Fluxgate sensor differential amplification sampling pin +	I	0	VCC/2	VCC	V	
6	SIN-	Fluxgate sensor differential amplification sampling pin -	I	0	VCC/2	VCC	V	
7	REF	Voltage reference, VCC/2	O	2.45	VCC/2	2.55	V	
8	VCC	The power supply voltage	I	4.9	5	5.1	V	
9	FILT	High frequency attenuation pin 1	I	0	VCC/2	VCC	V	
10	FB	High frequency attenuation pin 2	O	0	VCC/2	VCC	V	
11	TD	Duty cycle setting pin	O/I	0	0	VCC	V	
12	CTR	Tripping action signal output pin	O	0	VCC	VCC	V	
13	TRIG1	Window comparator pin 1	O/I	VCC/2	-	VCC	V	
14	IOUT	Fluxgate current sensor output pin 2	O	0	VCC/2	VCC	V	
15	GND	Ground	I	0	0	0	V	
16	TRIG2	Window comparator pin 2	O/I	0	-	VCC/2	V	
17	CS2	Peak flip sampling pin 2	O	0	0.5	-	V	
18	GT2	Peak flip action pin 2	I	0	0 or DR+	DR+	V	
19	CS1	Peak flip sampling pin 1	O	0	0.5	-	V	
20	GT1	Peak flip action pin 1	I	0	0 or DR+	DR+	V	



Note: O is the output pin, I is the input pin, O/I is the output pin of the product, which is the external output signal, but the signal on the pin can be affected by peripheral devices and at the same time as the input of the next level of the product.
Typical value represents the typical value of the pin when there is no residual current input.

Circuit Diagram

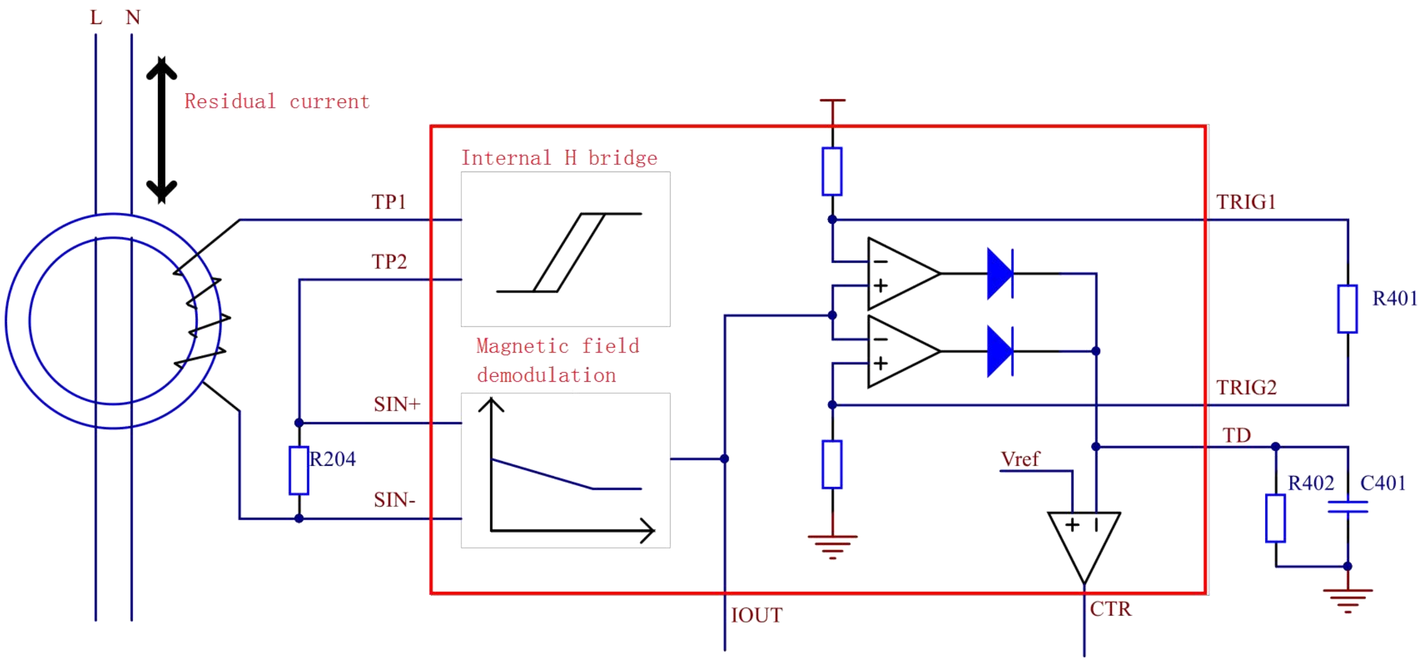


Figure 2 TLB1506-P Internal circuit diagram

Product sequence

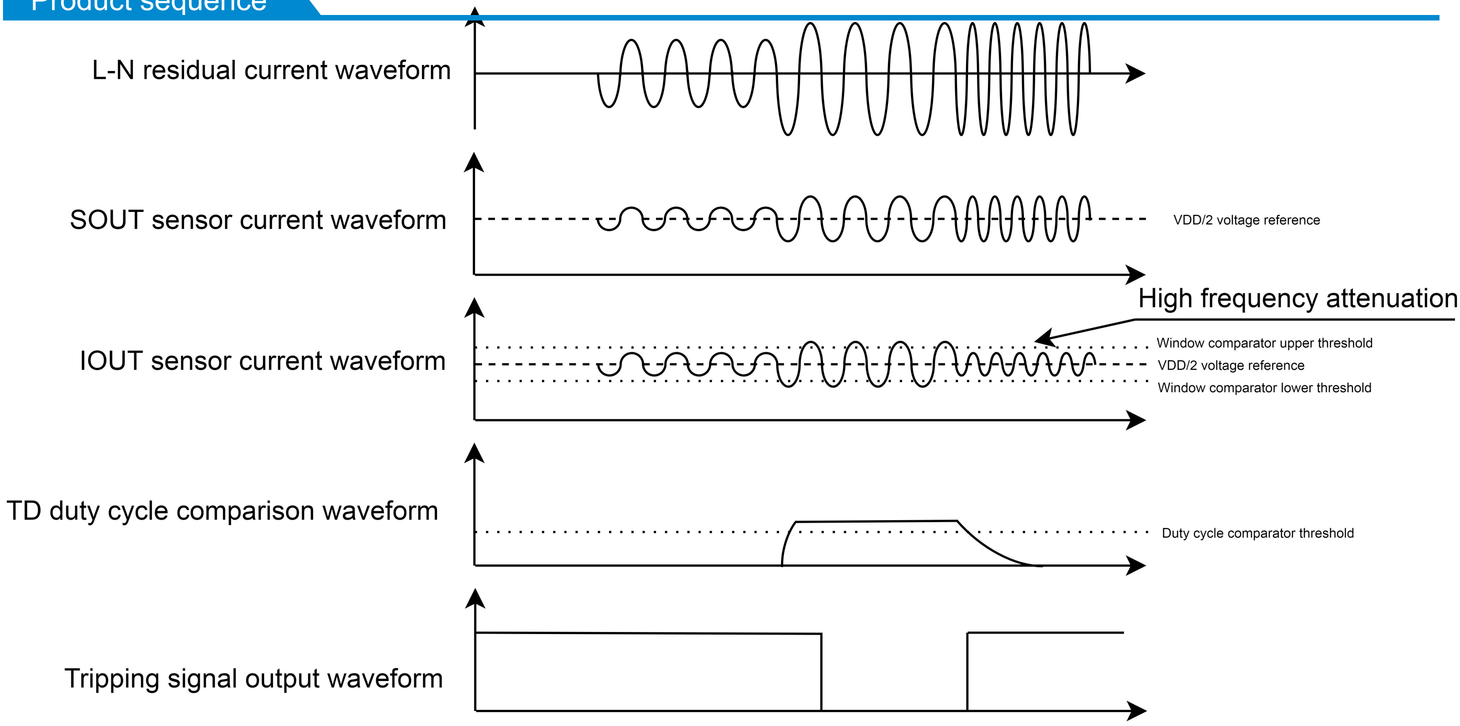


Figure 3 TLB1506-P Internal waveform block diagram

Design guidelines

1. Principle of circuit parameter design

To facilitate user design, users need to determine the following input parameters before design.
Design input parameters:

The input parameters	Parameters of the symbol	Parameters are defined
Trigger leakage current	/	Indicates the effective value of the current that triggers the residual current protection
High frequency detection frequency	f_C	High frequency leakage current response characteristics

According to the requirements of GBT6829-2017, taking 30mA system as an example, trip current and trip delay shall meet the following specifications

project	symbol	parameter	The test conditions	The lower threshold	Upper threshold	unit
50 Hz AC	I_{TrAC50}	Leakage trip current	50Hz AC leakage rises slowly, and the corresponding current when tripping signal is output is tripping current	15	30	mA
	$T_{Tr1AC50}$	Leakage trip time	The time interval between the time when the leakage current is powered on and the output of the trip signal when the AC leakage current is suddenly powered on at 30mA	0	300	ms
	$T_{Tr2AC50}$	Leakage trip time	The interval between the time when the 60mA AC leakage current is suddenly powered on and the time when the leakage current is powered on	0	150	ms
	$T_{Tr4AC50}$	Leakage trip time	When the AC leakage current is suddenly powered on at 300mA, the interval between the time when the leakage current is powered on and the output of the trip signal	0	40	ms
	I_{Tr1_DC+AC}	Leakage trip current	The AC with +12mA dc bias rises slowly, and the corresponding current when the tripping signal is output is the tripping current	15	30	mA

	I_{Tr2_DC+AC}	Leakage trip current	The AC with -12mA DC bias rises slowly, and the corresponding current when the tripping signal is output is the tripping current	15	30	mA
DC pulsating leakage current	I_{Tr1AC2}	Leakage trip current	50Hz positive half-wave leakage rises slowly, and the corresponding current when tripping signal is output is tripping current	10.5	42	mA
	I_{Tr1AC3}	Leakage trip current	At 50Hz, positive half-wave leakage at 90° phase Angle rises slowly, and the corresponding current when tripping signal is output is tripping current	7.5	42	mA
	I_{Tr1AC4}	Leakage trip current	The positive half-wave leakage at a phase Angle of 135° at 50Hz rises slowly, and the corresponding current when tripping signal is output is tripping current	4.5	42	mA
	I_{Tr1AC5}	Leakage trip current	50Hz negative half-wave leakage rises slowly, and the corresponding current when tripping signal is output is tripping current	10.5	42	mA
	I_{Tr1AC6}	Leakage trip current	At 50Hz, the negative half wave leakage at 90° phase Angle rises slowly, and the corresponding current when tripping signal is output is tripping current	7.5	42	mA
	I_{Tr1AC7}	Leakage trip current	At 50Hz, the negative half wave leakage at 135° phase Angle rises slowly, and the corresponding current when tripping signal is output is tripping current	4.5	42	mA
High frequency AC	$I_{Tr1AC150}$	Leakage trip current	The 150Hz AC leakage rises slowly, and the corresponding current when the tripping signal is output is the tripping current	15	72	mA
	$I_{Tr1AC400}$	Leakage trip current	The 400Hz AC leakage rises slowly, and the corresponding current when the tripping signal is output is the tripping current	15	180	mA
	$I_{Tr1AC1000}$	Leakage trip current	The 1000Hz AC leakage rises slowly, and the corresponding current when the tripping signal is output is the tripping current	30	420	mA
	$T_{Tr1AC150}$	Leakage trip time	When the AC leakage current of 72mA 150Hz is suddenly powered on, set the interval between the time when the leakage current is powered on and the time when the tripping signal is output	0	300	ms
	$T_{Tr1AC400}$	Leakage trip time	When the AC leakage current of 180mA 400Hz is suddenly powered on, the interval between the time when the leakage current is powered on and the output of the tripping signal is set	0	300	ms
	$T_{Tr1AC1000}$	Leakage trip time	When the AC leakage current of 420mA 1000Hz is suddenly powered on, the interval between the time when the leakage current is powered on and the output of the tripping signal is set	0	300	ms
DC current	I_{Tr1DC1}	Leakage trip current	The straight current leakage current rises slowly, and the corresponding current when tripping signal is output is tripping current	15	60	mA
	I_{Tr1DC2}	Leakage trip current	The negative DC leakage current rises slowly, and the corresponding current when tripping signal is output is tripping current	15	60	mA
	T_{Tr1DC}	Leakage trip time	+60mA DC leakage current is suddenly powered on. The interval between the time when the leakage current is powered on and the time when the tripping signal is output	0	300	ms
	T_{Tr2DC}	Leakage trip time	-60mA DC leakage current Indicates the interval between the time when the leakage current is powered on suddenly and the time when the tripping signal is output	0	300	ms
	T_{Tr3DC}	Leakage trip time	+120mA DC leakage current is suddenly powered on. The interval between the time when the leakage current is powered on and the time when the tripping signal is output	0	150	ms
	T_{Tr4DC}	Leakage trip time	-120mA DC leakage current Is suddenly powered on. The interval between the time when the leakage current is powered on and the time when the tripping signal is output	0	150	ms
	T_{Tr5DC}	Leakage trip time	+300mA DC leakage current is suddenly powered on. The interval between the time when the leakage current is powered on and the output of the tripping signal	0	40	ms

	T_{Tr6DC}	Leakage trip time	-300mA DC leakage current Is suddenly powered on. This parameter specifies the interval between the time when the leakage current is powered on and the output of tripping signal	0	40	ms

1.1. Design of fluxgate magnetic ring

The first choice of magnetic ring is the selection of magnetic materials, must choose iron based amorphous alloy, cobalt based amorphous alloy, permalloy such magnetic materials, because this magnetic ring high and low temperature permeability stability, high permeability, magnetic ring curve presents a long and thin rectangular. Based on cost considerations, iron - based amorphous alloys are preferred.

The next thing to consider is the assembly of magnetic rings. Because it is to detect residual current current, both mains LN lines need to pass through the magnetic ring, so the inner diameter of the magnetic ring should not be too small. However, different types of products with different specifications have different requirements on the inner diameter, which is also related to the production and assembly process. It cannot be determined qualitatively here, but can only explain the principle of selection. After meeting the assembly requirements of inner diameter, the smaller the volume of the magnetic ring is, the better (the smaller the difference of inner diameter and outer diameter, the smaller the cross-sectional area), which is determined by the production process and existing standard products of the supplier. Because in theory, the smaller the volume, the less coercivity, the smaller the loss, the higher the switching frequency.

The limitation between switching frequency and measuring range is considered in the design of the number of turns. The more turns, the greater the range, the greater the sense, the lower the switching frequency. Since the bandwidth of residual current detection is generally 1kHz, the minimum switching frequency can be set at about 5kHz.

Confirm size and material according to assembly requirement and supplier's condition. We can obtain the mean ring circumference l_C, cross-sectional area A_E, saturated magnetic density B_{SA}, recovered magnetic density B_{RE}, and relative permeability μ_E. The saturated inductance L_{SA} of a magnetic ring and the normal inductance L_N can be calculated as follows:

$$L_N = \frac{N_P^2 \cdot \mu_0 \cdot \mu_E \cdot A_E}{l_C}$$

$$L_{SA} = \frac{N_P^2 \cdot \mu_0 \cdot A_E}{l_C}$$

The calculation formula of saturation current I_{SA} and recovery current I_{RE} is

$$I_{SA} = \frac{B_{SA} \cdot l_c}{N_P \cdot \mu_0}$$

$$I_{RE} = \frac{B_{RE} \cdot l_c}{N_P \cdot \mu_0}$$

The conduction time of the unsaturated region is T_{ON_N}, the conduction time of the saturated region is T_{ON_SA}, and the excitation voltage of the full bridge oscillation is VCC. The calculation formula is as follows:

$$T_{ON\_N} = \frac{L_N \cdot (I_{SA} - I_{RE})}{V_{CC}}$$

$$T_{ON\_SA} = \frac{2 \cdot L_N \cdot I_{PEAK}}{V_{CC}}$$

Switching frequency is:

$$F_{SW} = \frac{1}{2 \cdot (T_{ON\_N} + T_{ON\_SA})}$$

When the input current I_{IN}>I_{IN_ERR}; When I_{IN_ERR} is set, the fluxgate works abnormally, resulting in the output voltage of the fluxgate current detection returning to zero. Its calculation formula is

$$I_{IN\_ERR} = N_P \cdot I_{PEAK}$$

The detection range of the fluxgate is denoted as I_{-RANGE}~I_{+RANGE}. Note that I_{RANGE} and I_{IN_ERR} are two different concepts. I_{RANGE} depends on the magnification of the sampling circuit. For example, if the input current exceeds the I_{RANGE}, the sampling circuit will saturate the output voltage of 0V or VCC, but the detection loop will work fine. Usually take

$$I_{IN\_ERR} = 10 \sim 20 \cdot I_{RANGE}$$

Generally, the parameters provided by domestic manufacturers are incomplete or inaccurate, and there is a certain transition zone from unsaturated to saturated, and the frequency parameters can not be obtained very accurately through calculation. The formulas above can be used as the direction of debugging. Generally, an I_{PEAK} can be determined first, and then N_P can be determined according to the range. The actual machine debugging can confirm the frequency. If the frequency is high, I_{PEAK} can be reduced and N_P can be increased to reduce the switching frequency. On the contrary, I_{PEAK} is increased and N_P is decreased.

1.2. Design principle of parameters related to oscillating circuit

The pins related to the oscillating circuit are TP1, DR+, TP1, TP2, GT1, GT2, CS1, CS2; Related devices for R101,R102,R103, R104, R105, R106, U2, D101, D102. TLB1506-P has a bridge oscillation circuit inside.

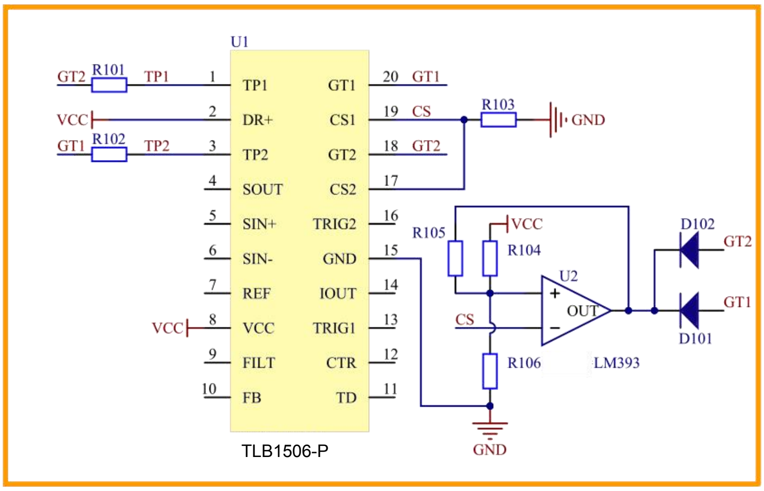


Figure 4 Oscillation circuit and its peripheral circuit

R101 and R102 take fixed resistors 2kΩ. R103 is the peak current sampling resistance of the oscillation circuit. R104 and R106 determine the peak current threshold, and R105 is used to set the peak current threshold error. The peak current itself is only used to reverse the feedback peak current, so the peak current setting requirements are not very high.

U3 uses the comparator LM393 whose output is OC gate, so the threshold V_{CSH} and return difference triggered by CS is V_{CSL}:

$$V_{CSH} = V_{VCC} \cdot \frac{R_{106}}{R_{104} + R_{106}} \text{ , } V_{CSL} = V_{VCC} \cdot \frac{R_{106} // R_{105}}{R_{104} + R_{106} // R_{105}}$$

Peak current is usually designed to be 3 times the normal operating current:

$$I_{PEAK} = \frac{V_{CSH}}{R_{103}} = 3 \times \frac{V_{CC}}{R_{103} + R_{204}}$$

For value design, see 2.1 Oscillation Circuit Design.If you want to further improve the accuracy characteristic, you can reduce the resistance of R103, but not so much that you cannot flip the fluxgate circuit.

The comparator U2 is used to flip the internal oscillator and is a must, diodes D101, D102 are not high requirements, can be 20V/100mA Schottky diode.

Function module	The pin	Related peripherals	Recommended selection instructions
Oscillation circuit	TP1、DR+、TP1、TP2、GT1、GT2、CS1、CS2	R101、R102	2 k Ω resistance
		R103	Peak current sampling resistance, see design principle
		R104、R106	To determine the peak current threshold, see Design Principles
		R105	Used to set the peak threshold current return, see design principle
		D101、D102	20V/100mA Schottky diode
		U2	The LM393 comparator

1.3. Sampling circuit related parameters design principle

The pins related to the oscillating circuit are SOUT, SIN+ and SIN-. The related devices are detecting magnetic ring and its coil, D203, R203, R204, R205, C203, C204, C205, D201, D202, C201, R201, C202, R202. The purple box in the figure below is an external magnetic ring.

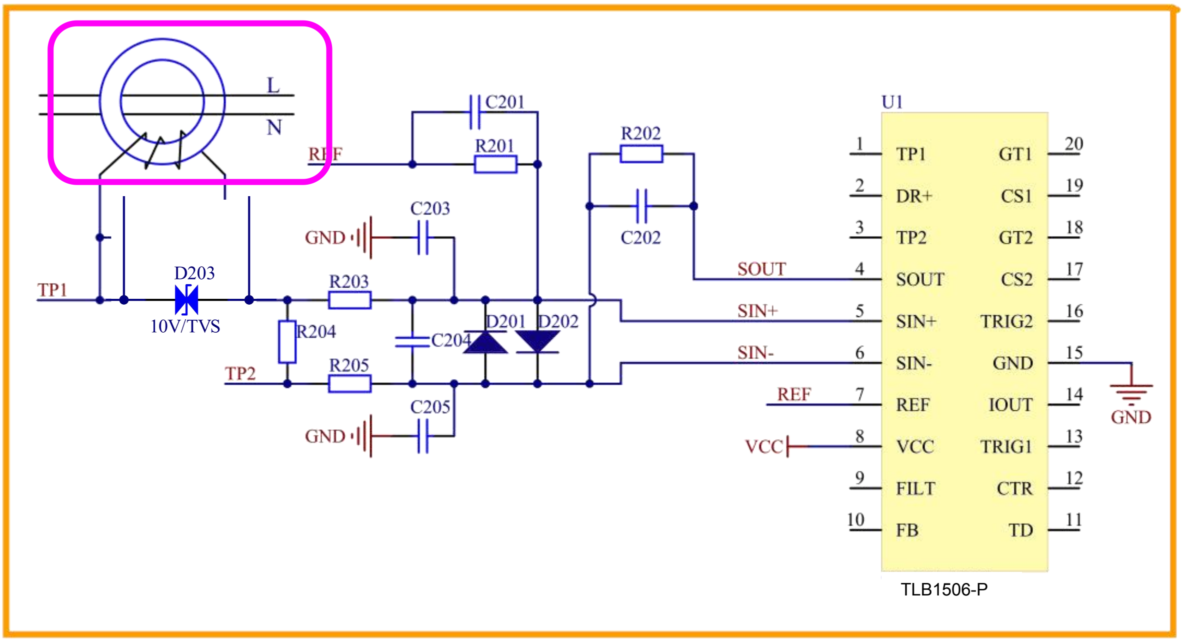


Figure 5 Sampling circuit and its peripheral circuit

D203 are surge protection TVS devices. When the input current has surge current, high voltage will be induced on the detection magnetic ring to absorb surge voltage. TVS tube with surge grade of 10V can be generally selected and adjusted according to the actual situation.

D201 and D202 are used to prevent high voltage between SIN+ and SIN- pins. 60V/1A Schottky diode is generally preferred.

R204 is the sampling resistance for detecting magnetic ring current, and the average voltage of R204 can reflect the measured current. The inside of SIN+ and SIN- pins is a differential sampling op-amp, whose magnification is:

$$G_{DE} = \frac{R_{202}}{R_{205}}$$

In order to improve the symmetry of op-amp, R203=R205 and R201=R202 are generally selected.

As can be seen from the above, the relationship between the voltage at both ends of resistance R204 and the measured current is:

$$V_{R204} = \frac{I_{IN}}{N_P} \cdot R_{204}$$

Where, NP is the number of turns of the magnetic ring.

The voltage of output pin SOUT of the final differential operational amplifier is:

$$S_{OUT} = V_{R204} \cdot G_{DE}$$

Due to differential sampling, the voltage to ground at both ends of resistance R204 is high-frequency square wave, so C203 and C205 are used to filter the high-frequency work-mode voltage to ground at both ends of resistance R204, and C204 is used to filter the differential mode voltage at both ends of resistance R204. Desirable C203=C205=C204=0.1uF, X7R ceramic capacitor.

Function module	The pin	Related peripherals	Recommended selection instructions
Sampling circuit	SOUT、SIN+、SIN-	Detection of the circular	Magnetic ring material selection of amorphous alloy, the number of turns design see the design principle.
		D203	Surge protection device, 30V TVS tube is generally optional.
		D201、D202	Surge protection devices, generally available in 60V/1A Schottky secondary.
		R204	Check the magnetic ring current sampling resistance, see design principle.
		C203、C205	Used to filter common mode voltage at both ends of R204, generally 0.1uF/25V capacitor is selected.
		C204	Used to filter the differential mode voltage at both ends of R204, generally 0.1uF/25V capacitor is selected.
		R201、R202、R203、R205	For adjusting the differential amplification ratio, see design principle.

1.4. Calculation of sensing coefficient

According to the relevant parameter design of 1.3 sampling circuit, the design formula of fluxgate sensor is as follows:

$$V_{out} = V_{ref} + \frac{I_{in} \cdot R_{204} \cdot R_{202}}{N \cdot R_{205}} = V_{ref} + k \cdot I_{in}$$

$$k = \frac{R_{204} \cdot R_{202}}{N \cdot R_{205}}$$

Where N is the number of turns of the coil, and the function relationship is shown as follows. The output voltage ranges from 0V to 5V in the range of $-I_{in}$ ~$+I_{in}$ of the remaining current. The slope of the curve is designed by the peripheral parameters:

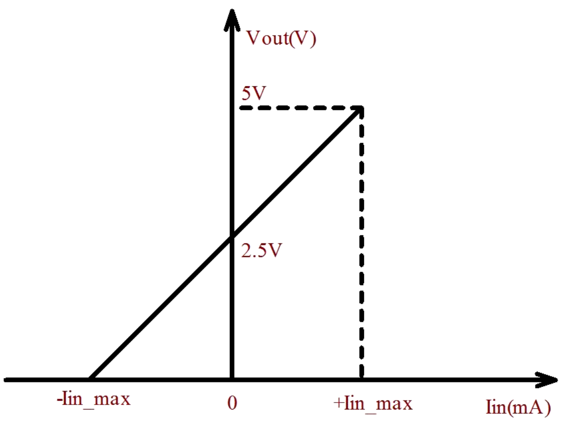
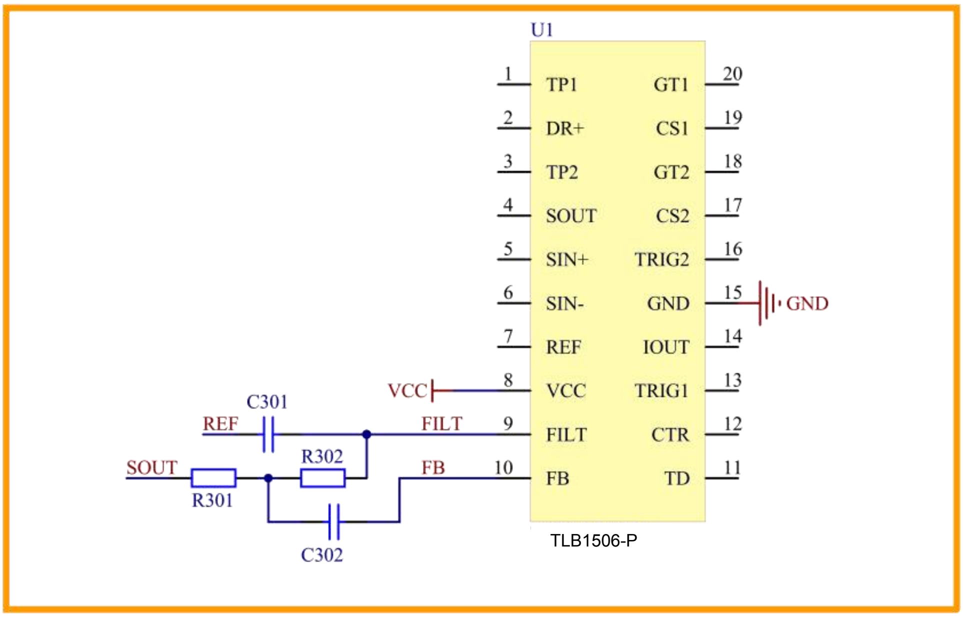


Figure 6 Input current and output voltage

1.5. Design principle of filter circuit parameters

The pins related to the filter circuit are FILT, FB and IOUT. The related devices are R301, R302, C302, C301 and C402.



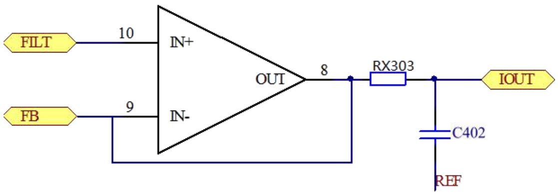


Figure 7 Schematic diagram of filter circuit

It forms a second-order low-pass filter. Generally, the cut-off frequency of the sensor used for residual current measurement is 1kHz. The typical selection value is R301=4.22 kΩ, R302=6.8 kΩ, C302=22nF, C301=10nF. The function of this second order filter circuit is to make the output voltage more smooth, not necessary, R301, R302, C302, C301 these devices can be suspended. Because the standard of type B residual current requires that the triggering threshold at 1000Hz is higher than 50Hz, the signal at 1000Hz should be attenuated. The cut-off frequency of the first-order and second-order low-pass filtering can be set to about 600Hz, and the parameter requirements of the cut-off frequency are not high. The cut-off frequency setting formula is as follows:

$$f_C = \frac{1}{2 \cdot \pi \cdot R_{302} \cdot C_{301}}$$

RX303 is the internal resistance of the module, and its value is 10k Ω.

The selection of filter parameters here will increase the values of trip current and 135° wave trip current at high frequency.

Function module	The pin	Related peripherals	Recommended selection instructions
Filter circuit (optional)	FILT、FB、IOUT	R301 (Levitable)	4.22 kΩ resistance
		R302 (Levitable)	6.8kΩ (f_C=14.7kHz) or 120kΩ (f_C=833Hz) resistance
		C302 (Levitable)	22 the nF capacitance
		C301 (Levitable)	10 the nF capacitance

1.6. Design principle of threshold judgment related parameters

The pins related to the threshold judgment circuit are TRIG1, TRIG2, TD and CTR, and the related devices are R12, C8 and R15. The function of this part of the circuit is mainly to compare the sampled amplified signal with the set threshold value, and finally the CTR pin outputs the corresponding high and low level. The user can read the level of CTR pin directly to get the system test value or drive the switching device directly through CTR pin.

Threshold judgment is mainly composed of two comparison parts. The first comparison part constitutes a window comparator. When the window comparator exceeds the forward or reverse trigger threshold, TD pin level begins to rise and the second duty cycle comparison part is judged.

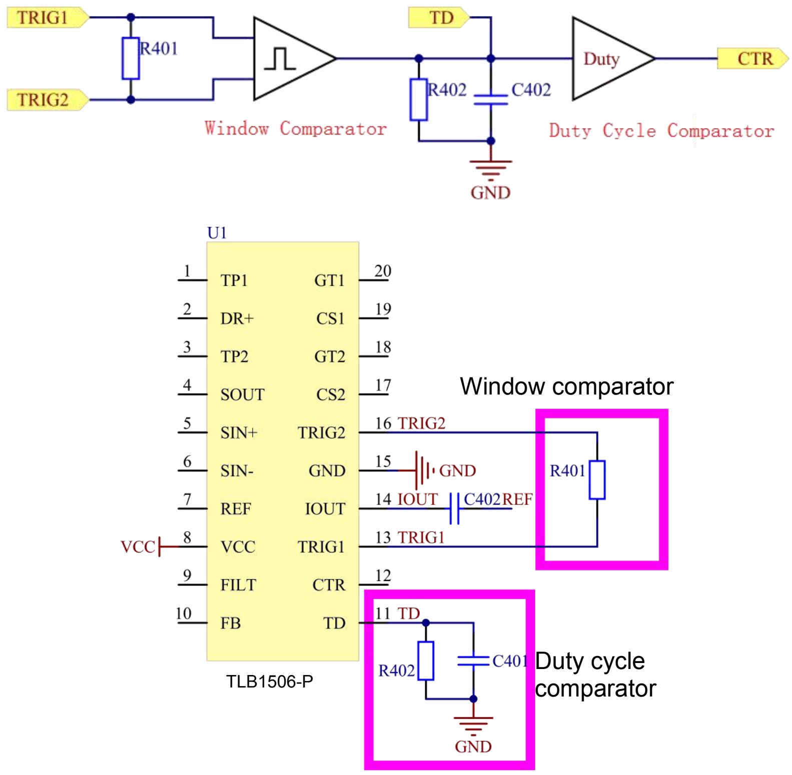


Figure 8 Schematic diagram of threshold judgment principle

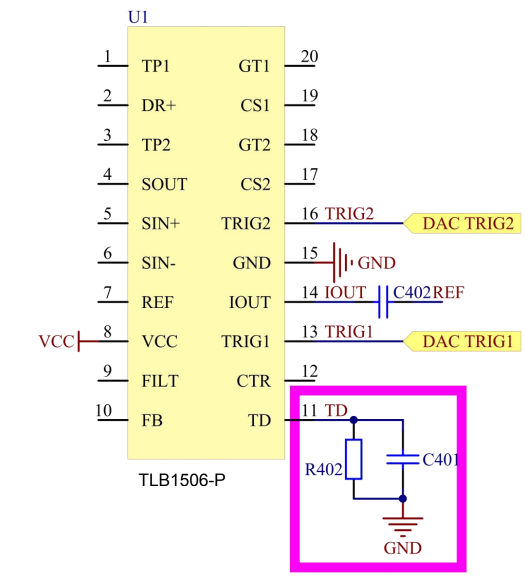


Figure 9 Threshold Adjustment scheme (DAC scheme)

The window comparator's forward threshold is controlled by TRIG1 pins: $V_{TRIG1}=\frac{V_{CC}}{2}+(\frac{V_{CC}}{2}\times\frac{\frac{R_{401}}{2}}{10000+\frac{R_{401}}{2}})$

The window comparator's reverse threshold is controlled by TRIG2 pins: $V_{TRIG2}=\frac{V_{CC}}{2}-(\frac{V_{CC}}{2}\times\frac{\frac{R_{401}}{2}}{10000+\frac{R_{401}}{2}})$

The voltage of these two pins can also be supplied by the external DAC pins, directly determining the remaining current of the action.

The second comparison part constitutes the duty comparator. When the duty comparator exceeds the duty threshold D_{TH}, The CTR will output low level.

The duty cycle comparator's comparison threshold is (internally set) : $V_{D\_H} = \frac{2}{3} V_{VCC}$, $V_{D\_L} = \frac{1}{3} V_{VCC}$

The design duty ratio threshold is determined by R402. When the duty ratio of the square wave output by the window comparator is small, the duty ratio comparator will not respond. Its duty cycle threshold is approximately:

$$D_{TH} \approx \frac{51000}{R_{402}}$$

51kΩ is the resistance between the internal window comparator and duty cycle comparator.

The residual current protection has two delay times. One is the maximum delay time of the full residual current of the non-delay RCD specified in GBT 6829-2017 5.4.12.1, which is 40ms to prevent the protection response from being too slow.In order to prevent accidental triggering caused by transient power-on, a half-wave residual current of 10 times the threshold is required. The system will not be triggered, so the triggering delay of the system is required to be greater than 10ms. C401 is used to set the response time of residual current protection. Generally, we can set the rise time of C401 to be slightly more than 10ms, and the delay of the system will not exceed 40ms. Therefore, when the window comparator continues to output high power, the basic formula of C401's rise time to V_{D_H} is as follows, and the rise time is denoted as T_{DL_MIN}:

$$V_{D\_H} = (V_{VCC} - 0.7V) \cdot \frac{R_{402}}{51000 + R_{402}} (1 - e^{-\frac{T_{DL\_MIN}}{\tau}})$$

$$\tau = (51000 // R_{402}) \cdot C_{401}$$

Then how to set the duty cycle threshold? We first look at several waveforms required to be tested in the standard, including half wave, half wave at 90° phase Angle and half wave at 135° phase Angle. The following figure shows waveforms of different half waves at the same RMS value. It can also be seen that the duty cycle output by the window comparator is also different. Assuming that the amplitude of each half-wave is infinite, the duty cycle of the square wave output by the window comparator also has the maximum value, where

The 135° half-wave limit duty cycle is 12.5%.

The limit duty cycle of 90° half wave is 25%.

The limit duty cycle of 0° half wave is 50%.

Therefore, the duty cycle threshold must be set to less than 12.5%, otherwise the system will not respond to half wave at 135° phase.

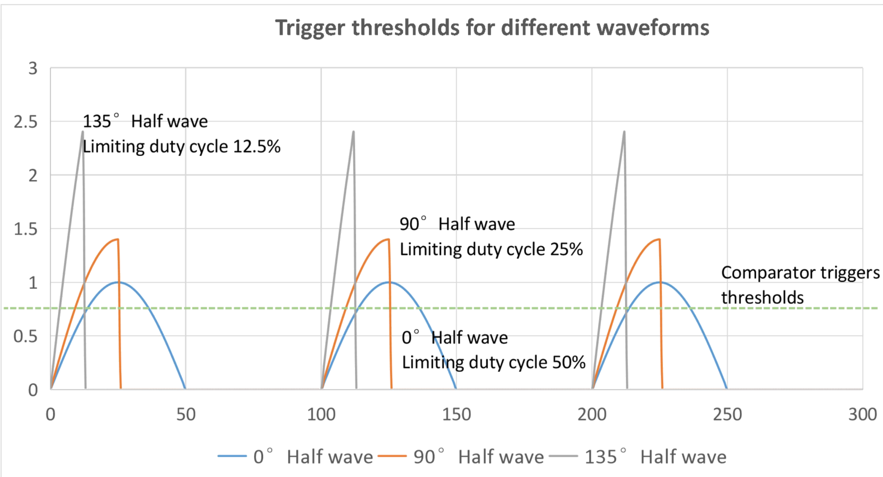


Figure 10 Schematic diagram of half wave with same effective value and different phase Angle

From the above analysis, we can know that the window comparator and duty ratio comparator detect different objects. Its conclusions are as follows:

1.Window comparator affects all 50Hz~1000Hz AC remaining current trigger thresholds, DC remaining current trigger thresholds, and pulsating DC remaining current trigger thresholds.

2.Duty cycle comparator further affects the triggering thresholds of residual current in 0° half wave, 90° half wave and 135° half wave.

Function module	The pin	Related peripherals	Recommended selection instructions
Threshold judgment circuit	TRIG1、TRIG2、TD	R401	TRIG1 and TRIG2 thresholds can be set through R401, see Design Principles
		C401、R402	Refers to the effective current value for detecting residual current trigger protection

2. Design example

Taking 30mA prototype (the current triggering residual current protection is 30mA) as an example, the design method is sorted out.

Design input parameters:

The input parameters	Parameters of the symbol	Parameters are defined	Actual input parameter
Bandwidth for residual current detection	/	Bandwidth for detecting residual current	1kHZ
Maximum detection current	I_{IN}	Refers to the detection range of residual current	900mA
Trigger residual current	/	It refers to the effective current value that detects residual current triggering residual current protection	20mA

In this product design, due to the correlation between parameters, this design report only analyzes the impact of DEMO parameters, and provides application examples for design and debugging. Some parameters are empirical values, which does not mean that only this value can achieve residual current detection function.

The magnetic ring selected by DEMO in this paper has an outer diameter of 18×11×10mm^3, N=15 turns, and the final switching frequency is 5.0kHz.

2.1. Oscillation circuit parameters design

Devices with fixed values are: R101=R102= 2KΩ, 0603 package; D101, D102 take 20V/100mA Schottky diode.

R103 is the peak current sampling resistance of the oscillation circuit, which is 7.5Ω. R104 and R106 determine the peak current threshold, which is 4.22kΩ and 300Ω. R105 is used to set the peak current threshold, which is 10kΩ. Comparator U2 adopts the comparator LM393 whose output is OC gate. D101,D102 select schottky diode above 10V. In order to give consideration to SNR and loss, the peak current voltage threshold is usually set at 0.6V~0.8V.

$$V_{CSH} = V_{VCC} \cdot \frac{R_{106}}{R_{104} + R_{106}} = 0.33V \qquad V_{CSL} = V_{VCC} \cdot \frac{R_{106} // R_{105}}{R_{104} + R_{106} // R_{105}} = 0.32V$$

When the drive loop is stable, the voltage divided on R103 should be greater than the threshold VCSH triggered by CS:

$$V_{R103\_S} = V_{VCC} \cdot \frac{R_{103}}{R_{103} + R_{204}} = 1.08V > V_{CSH} = V_{VCC} \cdot \frac{R_{106}}{R_{104} + R_{106}}$$

Peak current is:

$$I_{PEAK} = \frac{V_{CSH}}{R_{103}} = 44mA$$

The smaller the resistance value is, the smaller the saturation depth is and the smaller the coercivity is. 7.5Ω is recommended , The premise is that the voltage design of the flip comparator is satisfied.

2.2. Design related parameters of sampling circuit

According to the above introduction, the gain of the fluxgate current sensor is:

$$G_{ISEN} = \frac{1}{N_p} \cdot R_{204} \cdot \frac{R_{202}}{R_{205}}$$

Among them

I_{in} is the measured current.

N_p is the number of turns of the magnetic ring.

The unit of G_{ISEN} is Ω, which represents the conversion of input current signal into voltage signal.

If N_P=15, R204=27Ω, R201=R202=200kΩ, R205=R203=20kΩ, G_{ISEN} is about 18Ω. Take C204A=C204B=C204=0.1uF, withstand voltage 25V, 0603 package X7R ceramic capacitor.The output voltage is 2.5V±0.35V. Generally speaking, when the residual current protector is operating, the sensor voltage fluctuation range does not exceed ±1V.

The output voltage range is 0.5V~4.5V, and the midpoint voltage is 2.5V, so the measurement range is as follows:

$$I_{+RANGE} = \frac{4.5V - 2.5V}{G_{ISEN}} = 111.1mA$$

The range is greater than the trigger threshold for DC input. In the standard, the threshold range for power frequency ac is the narrowest. For a 30mA prototype, the range is 15mA~30mA. We set the ideal trigger threshold at the midpoint I_{AVR_50HZ}=20mA. The corresponding peak value is:

$$I_{PK\_50HZ} = \frac{I_{AVR\_50HZ}}{0.707} = 28.28mA$$

The voltage of output port I_{OUT} of fluxgate current sensor is

$$V_{PK\_50HZ} = I_{PK\_50HZ} \cdot G_{ISEN} + 2.5V = 3.0V$$

According to the above calculation, the 50Hz AC trigger threshold is 20mA, the AC peak value is about .28mA, and the range is about twice the AC peak value. According to the above design, the range is about 111mA, which meets the requirements.

If the voltage sampling accuracy is poor, the voltage range of the output port of the sensor can be appropriately increased by increasing the sampling resistance R204.

Due to the impedance mismatch of sampling, the fluxgate current sensor has an imbalance voltage problem, which requires a parallel resistor on R201 for zero adjustment, which needs to be determined by actual debugging.

2.3. Filter circuit parameters design

When the second-order filtering cutoff frequency is set to 1kHz, the values are R301=4.22kΩ, R302=6.8kΩ, C302=22nF, C301=10nF, C305=2.2nF. The filter is not necessary, only for residual current protection without the filter, the device is suspended.This parameter is designed according to the requirements of different frequencies in standard GBT 6829-2017 8.3.1.6. It is not recommended to adjust this parameter.

2.4. Duty cycle comparator parameter design

The duty cycle threshold D_{T_H} should be less than 12.5%. In order to prevent the triggering threshold of 135° phase Angle from being too large, 6% should be set.

The value of resistor R402 is:

$$R_{402} = \frac{51000}{D_{TH}} = 850k\Omega$$

The minimum delay can be:

$$T_{DL\_MIN} = 10ms$$

Equivalent high level voltage output by window comparator are:

$$V_{W\_OUT} = (V_{CC} - 0.7V) \cdot \frac{R_{402}}{R_{402} + 51000} = 4.05V$$

We set the rise time of C401 to be slightly greater than 10ms, C401=100nF.If the response is too fast and the 135° phase Angle operating current is small, the C401 capacitor value can be appropriately increased.

2.5. Parameter design of window comparator

The operation voltage of the fluxgate current sensor designed above is 2.5V±0.36V.

$$V_{TRIG1} = \frac{V_{CC}}{2} + \left(\frac{V_{CC}}{2} \times \frac{\frac{R_{401}}{2}}{10000 + \frac{R_{401}}{2}}\right) = 2.86V$$

$$V_{TRIG2} = \frac{V_{CC}}{2} - \left(\frac{V_{CC}}{2} \times \frac{\frac{R_{401}}{2}}{10000 + \frac{R_{401}}{2}}\right) = 2.14V$$

Can be selected R401=2.88kΩ.

2.6. Refer to BOM summary for DEMO design

Device location	30mA selection of residual current devices is recommended	300mA selection of residual current devices is recommended	The core function
R101,R102	2kΩ		Internal H bridge flip drive
R103	7.5Ω		Invert peak sampling resistance
R104	4.22kΩ		Flip threshold, return error
R105	10kΩ		
R106	300Ω		
D101,D102	Schottky diodes for voltages above 10V		Provides flip function for IC
R204	27Ω		Differential sampling resistance
D201,D202	TVS tube with voltage above 10V		Fluxgate protection device
D203	TVS tube with voltage above 10V		Fluxgate protection device
R201,R202	200kΩ	20kΩ	Coefficient of sensing resistance
R203,R205	20kΩ		
C203,C204,C205	100nF		Sampling signal filtering
R301	4.22kΩ		High frequency attenuation circuit parameters
R302	6.8kΩ		
C301	10nF		
C302	22nF		
R401	2.88kΩ		Window comparator threshold setting
R402	850kΩ		Duty cycle comparator minimum duty cycle design
C401	100nF		Minimum delay design
C402	2.2nF		High frequency attenuation circuit parameters
Amorphous magnetic ring	21 laps		Fluxgate sampling ring

2.7. DEMO Performance specifications

All index testing methods in this datasheet are based on company corporate standards;

Table: Basic residual current waveform VS typical trip current

Current unit: mA (Rms.)	25℃	105℃	-55℃
50Hz AC trigger current	24.4	23.8	23.6
AC +12mA residual current	21.1	19.8	20.2
AC -12mA residual current	20.5	21.5	20.7
0 degree pulsating DC stack +12mA residual current	22.9	21.1	21.1
0 degree pulsating DC stack -12mA residual current	21.6	21.7	21.7
+0 degree pulsating DC residual current	18.8	17.9	18.5
+90 degree pulsating DC residual current	20.8	18.5	19.9
+135 degree pulsating DC residual current	21.1	20.5	23.4
-0 degree pulsating DC residual current	19.3	18.8	19.1
-90 ° pulsating DC residual current	20.8	18.9	19.4

-135 ° pulsating DC residual current	20.8	20.7	22.2
150Hz residual AC current	24.4	24.3	24.1
400Hz residual AC current	27.6	27.3	27.7
1kHz residual AC current	59.4	58.1	60.3
DC residual leakage threshold	31.94	32.6	31.3
DC negative residual leakage threshold	32.5	31.5	31.5

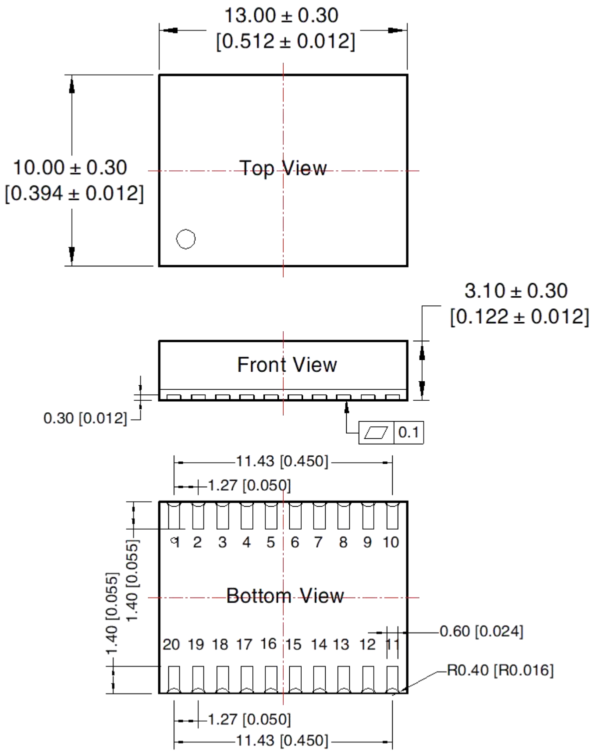
Table: Basic residual current waveform VS typical trip delay

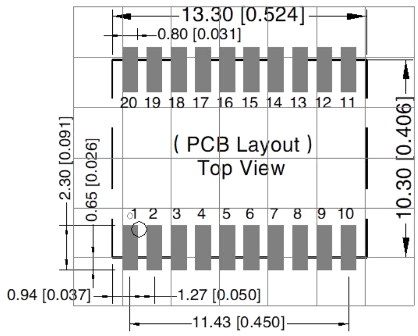
Delay unit: ms	25℃	105℃	-40℃
30mA residual current delay	77.0	66.2	79.8
60mA residual current delay	36.8	34.4	38.2
150mA residual current delay	31.2	27.4	32.2
300mA residual current delay	31.2	26.2	32.4
AC +12mA residual current delay	21.1	19.8	20.2
AC -12mA residual current delay	20.5	21.4	20.7
Delay of 72mA AC residual current at 150Hz	31.2	28.4	35.6
Delay of 180mA AC residual current at 400Hz	31.2	29.2	36.1
Delay of 420mA AC residual current at 1kHz	41.4	35.2	44.6
DC +60mA residual current delay	29.6	25.6	32.2
DC -60ma residual current delay	29.6	25.6	31.8
DC +120mA residual current delay	29.6	25.6	32.4
DC -120ma residual current delay	29.6	25.6	32.6
DC +300mA residual current delay	29.6	25.6	31.5
DC -300ma residual current delay	29.6	25.6	31.5

Weight Information

Parameter	The minimum value	Typical values	The maximum	Unit
Weight	0.6	0.9	1.2	g

THIRD ANGLE PROJECTION

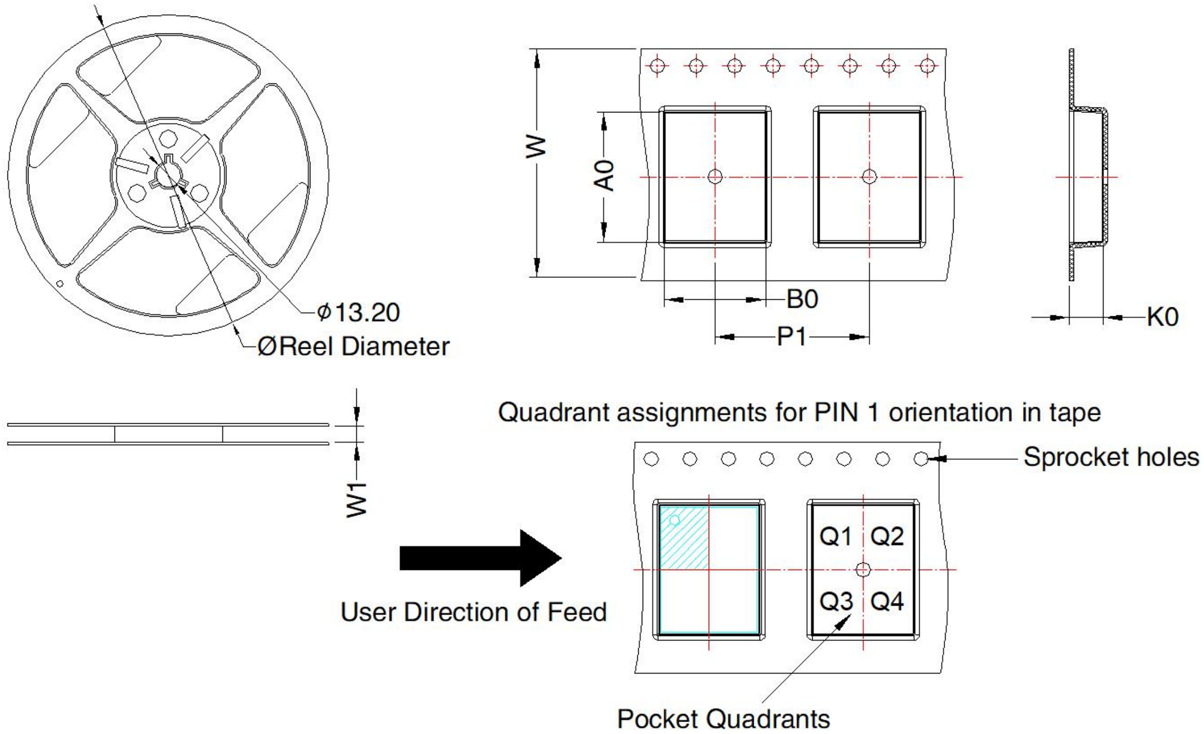




Note: Grid 2.54*2.54mm

Pin–Out			
Pin	Mark	Pin	Mark
1	TP1	11	TD
2	DR+	12	CTR
3	TP2	13	TRIG1
4	SOUT	14	OUT
5	SIN+	15	GND
6	SIN–	16	TRIG2
7	REF	17	CS2
8	VCC	18	GT2
9	FILT	19	CS1
10	FB	20	GT1

Note:
Unit: mm[inch]
General tolerances: ± 0.10[± 0.004]



Device	Package Type	Pin	MPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TLB1506-P	DFN 10x13	20	300	180.0	24.4	13.52	10.52	3.5	16.0	24.0	Q1

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