FAIRCHILD SEMICONDUCTOR®

August 2010

FAN4146 — Ground Fault Interrupter

Features

- For Two-Wire ALCI and RCD Applications
- Precision Sense Amplifier and Bandgap Reference
- Built-in AC Rectifier
- Direct DC Coupled to Sense Coil
- Built-in Noise Filter
- Low-Voltage SCR Disable
- SCR Gate Driver
- Adjustable Sensitivity
- Minimum External Components
- Meets UL 943B Requirements
- Ideal for 120V or 220V Systems
- Space-Saving SuperSOT™ 6-Pin Package

Applications

- Personal Care Products
- Two-Wire Electrical Outlets, Circuit Breakers, and Power Cords Requiring GFI Safety Features
- ALCI and RCCB Circuits

Description

The FAN4146 is a low-power controller for AC outlet Appliance Leakage Circuit Interrupters (ALCI) and two-wire Residual Current Devices (RCD). The FAN4146 detects hazardous grounding conditions and open circuits the line before a harmful shock occurs.

Internally, the FAN4146 contains a diode rectifier, precision bandgap 12V shunt regulator, precision low V_{OS} offset-sense amplifier, time delay noise filter, window-detection comparators, and a SCR driver. With the addition of a minimum number of external components, the FAN4146 detects and protects against a hot-wire-to-ground fault. The minimum number of components and the small SuperSOT™ package allow for a small-form-factor, low-cost application solution.

The FAN4146 circuitry has a built-in rectifier and shunt regulator that operates with a low quiescent current. This allows for a high-value, low-wattage-series supply resistor. The internal temperature compensated shunt regulator, sense amplifier, and bias circuitry provide for precision ground-fault detection. The low V_{OS} offset-sense amplifier allows direct coupling of the sense coil to the amplifier's feedback signal. This eliminates the large 50/60Hz AC-coupling capacitor. The internal delay filter rejects high-frequency noise spikes common with inductive loads. This decreases false nuisance tripping. The internal SCR driver is temperature compensated and designed to satisfy the current requirements for a wide selection of external SCRs.

The minimum number of external components and the 6-pin SuperSOT™ package enable for a low-cost, compact design and layout. The FAN4146ESX is an enhanced temperature range device.

Ordering Information

Part Number	Operating Temperature Range	Package	Packing Method
FAN4146SX	0°C to +70°C	6-Lead SUPERSOT6, JEDEC MO-193, 1.6mm	Tape and Reel
FAN4146ESX	-25°C to +80°C	6-Lead SUPERSOT6, JEDEC MO-193, 1.6mm	Tape and Reel

Typical Applications

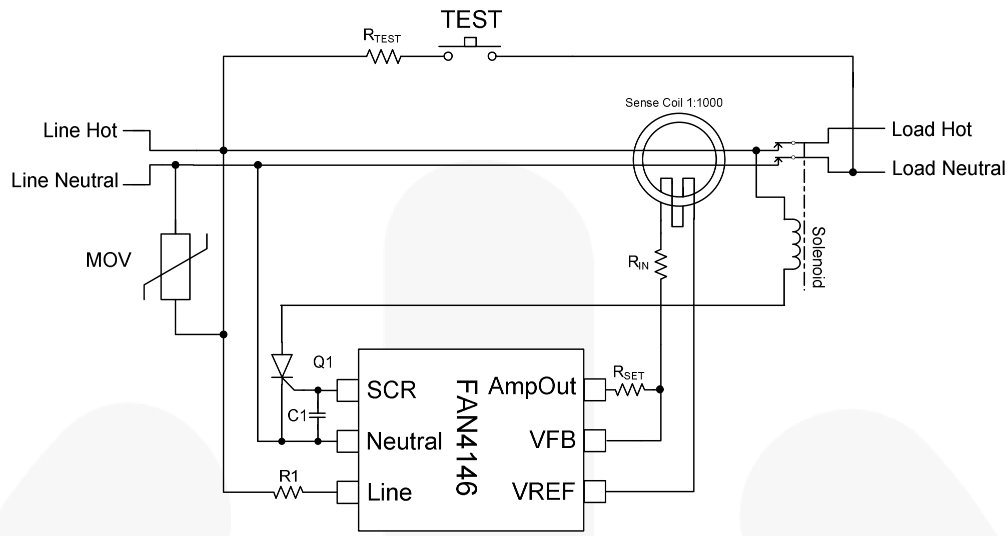


Figure 1. 120/220V_{AC} ALCI Application[2]

Typical Values

R1: 91KΩ (Wattage Determined by Maximum V_{AC})
R_{TEST}: 15KΩ
R_{SET}: 511KΩ[1]

R_{IN}: 470Ω
C1: 22nF

Note:

1. Value depends on sense-coil characteristics and application (value chosen for 5mA trip threshold).
2. Contact Fairchild for best application practices for nuisance tripping rejection.

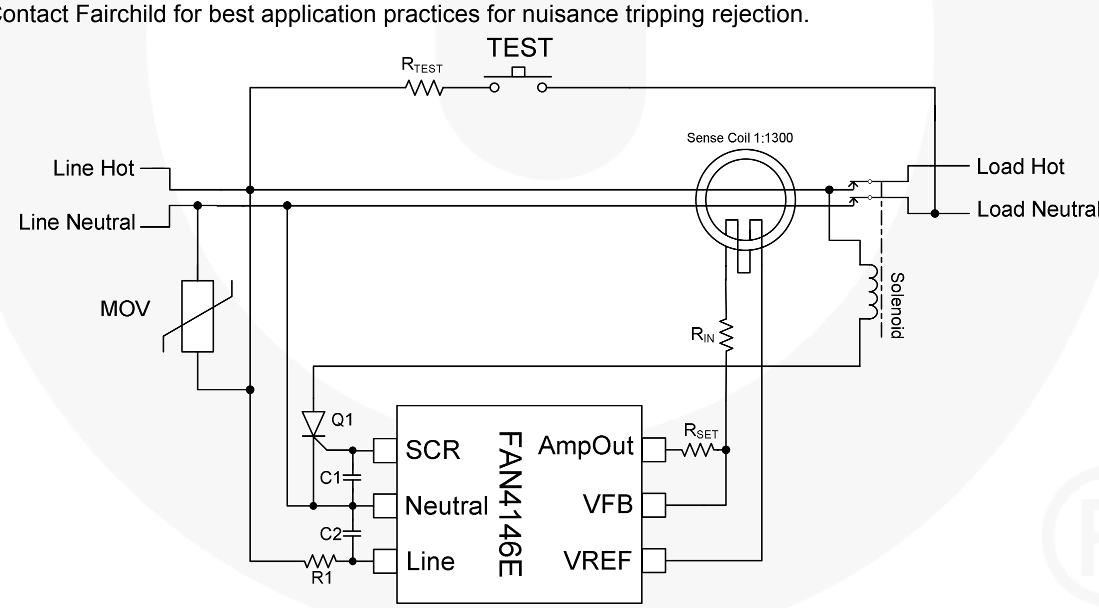


Figure 2. 220V_{AC} RCD Application[4]

Typical Values

R1: 174KΩ (Wattage Determined by Maximum V_{AC})
R_{TEST}: 15KΩ

R_{SET}: 324KΩ[3]
R_{IN}: 470Ω

C1: 22nF
C2: 10nF

Note:

3. Value depends on sense-coil characteristics and application (value chosen for 10mA trip threshold).
4. Contact Fairchild for best application practices for nuisance tripping rejection.

Block Diagram

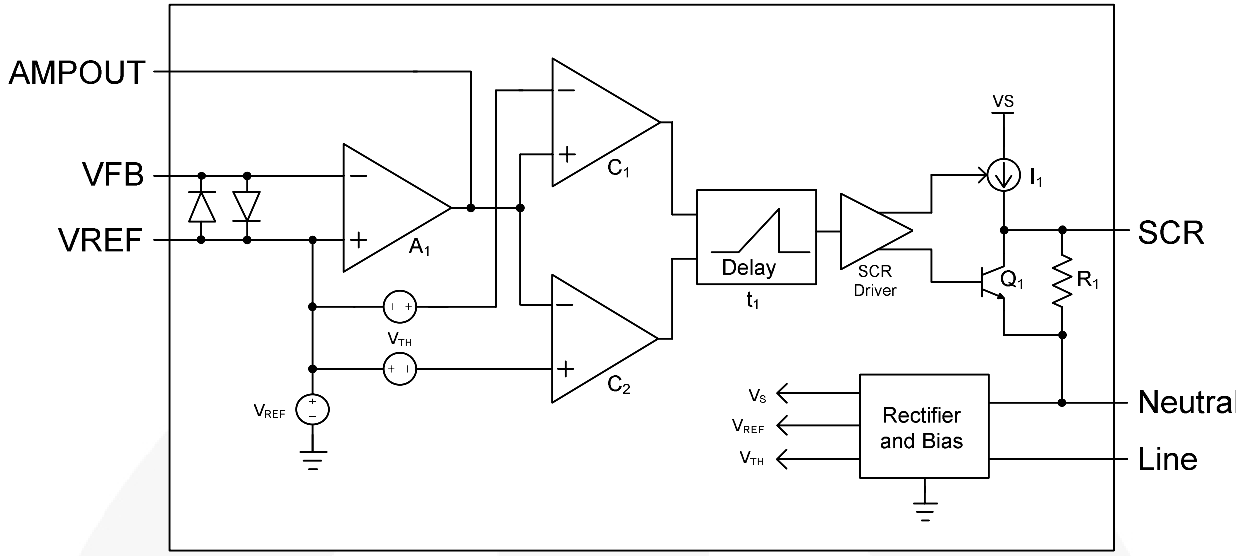


Figure 3. Block Diagram

Pin Configuration

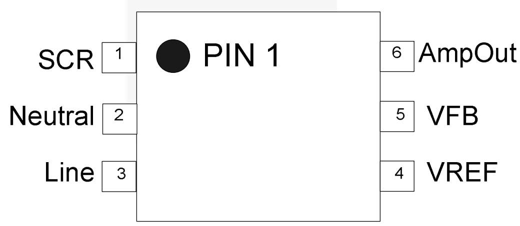


Figure 4. Pin Configuration

Pin Definitions

Pin #	Name	Description
1	SCR	Gate drive for external SCR
2	Neutral	Supply input for FAN4146 circuitry
3	Line	Supply input for FAN4146 circuitry
4	VREF	Non-inverting input for current-sense amplifier
5	VFB	Inverting input for current-sense amplifier
6	AmpOut	External resistor connected to VFB sets the I_{fault} sensitivity threshold

Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only.

Symbol	Parameter		Condition	Min.	Max.	Unit
I_{CC}	Supply Current		Continuous Current, Line to Neutral		15	mA
V_{CC}	Supply Voltage		Continuous Voltage, Line to Neutral	-1.5	16.0	V
		All other pins	Continuous Voltage to Neutral	-0.8	15.0	V
T_{STG}	Storage Temperature Range			-65	+150	°C
ESD	Electrostatic Discharge Capability		Human Body Model, JESD22-A114		2500	V
			Charged Device Model, JESD22-C101		1000	
			Machine Model, JESD22-A115		200	

DC Electrical Characteristics

Unless otherwise specified, T_A=25°C, I_{shunt}=1mA.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Units
V_{REG}	Power Supply Shunt Regulator Voltage	Line to Neutral	12.2	12.7	13.2	V
		Line to Neutral, I_{shunt}=-2mA	-0.9	-0.7		
I_Q	Quiescent Current	Line to Neutral=10V	350	400	450	μA
V_{REF}	Reference Voltage	V_{REF} to Neutral	5.8	6.0	6.2	V
V_{TH}	Trip Threshold	AmpOut to V_{REF}	3.4	3.5	3.6	V
V_{OS}	Amplifier Offset	R_{SET}=511KΩ, R_{IN}=500Ω	-450	0	450	μV
I_{OS}	Amplifier Input Offset(5)	Design Value	-50	0	50	nA
G	Amplifier DC Gain(5)	Design Value		100		dB
f_{GBW}	Amplifier Gain Bandwidth(5)	Design Value		1.5		MHz
V_{SW+}	Amplifier Positive Voltage Swing	AmpOut to V_{REF}, I_{FAULT}=10μA	4.0			V
V_{SW-}	Amplifier Negative Voltage Swing	V_{REF} to AmpOut, I_{FAULT}=-10μA	4.0			V
I_{SINK}	Amplifier Current Sink	AmpOut=V_{REF} + 3V, V_{FB}=V_{REF} + 100mV	400			μA
I_{SRL}	Amplifier Current Source	AmpOut=V_{REF} – 3V, V_{FB}=V_{REF} - 100mV	400			μA
t_d	Delay Filter	Delay from C_1 Trip to SCR, LOW to HIGH	0.75	1.00	1.25	ms
R_{OUT}	SCR Output Resistance	SCR to Neutral=250mV, AmpOut=V_{REF}		0.5	1.0	KΩ
V_{OUT}	SCR Output Voltage	SCR to Neutral, AmpOut=V_{REF}		1	10	mV
		SCR to Neutral, AmpOut =V_{REF} +4V	2.5			V
I_{OUT}	SCR Output Current	SCR to Neutral=1V AmpOut=V_{REF} + 4V	350	500		μA

Note:
5. Guaranteed by design; not tested in production.

Functional Description

Refer to Figure 1 and Figure 3.

The FAN4146 is a two-wire GFCI controller for AC ground-fault-circuit interrupters. The internal rectifier circuit is biased by the AC line during the positive half cycle of the AC line voltage. The internal 12V shunt regulator uses a precision temperature-compensated bandgap reference. The combination of precision reference circuitry and precision sense amplifier provides for an accurate ground-fault tolerance. This allows for selection of external components with wider and lower-cost parameter variation. Due to the low quiescent current, a high value external series resistor (R_1) can be used which reduces the maximum power wattage required for this resistor. The 12V shunt regulator generates the reference voltage V_{REF} for the sense amplifier's (A_1) non-inverting input (AC ground reference) and supplies the bias for the delay timer (t_1), comparators (C_1 & C_2), and the SCR driver.

The secondary winding of the sense transformer is directly DC coupled to the inverting input of the sense amplifier at pin 5 (V_{FB}). The R_{SET} resistor converts the sense transformer's secondary current to a voltage at pin 6 (AmpOut). This voltage is compared to the internal window comparator (C_1 & C_2) and, when the AmpOut voltage exceeds the +/-V_{TH} threshold voltage, the window comparator triggers the internal delay timer. The output of the window comparator must stay HIGH for the duration of the t_1 timer. If the window comparator's output momentarily goes LOW, the t_1 timer resets. If the window comparator's output is still HIGH at the end of the t_1 pulse, the SCR driver enables the current source I_1 and disables Q_1. The current source I_1 then enables the external SCR, which energizes the solenoid, opens the contact switches to the load, and removes the hazardous ground fault. The window comparator allows detection of a positive or negative I_{FAULT} signal independent from the phase of the line voltage. An internal under-voltage lockout circuit disables the SCR driver if the voltage at pin 3 (LINE) is below 7.5V. This prevents the SCR from energizing the solenoid when the SCR's anode voltage is below 65V.

The sense transformer typically has a toroidal core made of laminated steel rings or solid ferrite material. The secondary of the transformer is typically 1000 turns of #40 wire wound through the toroid. The primary is typically one turn made by passing the AC hot and neutral wires through the center of the toroid. When a ground fault exists, a difference exists between the current flowing in hot and neutral wires. The primary difference current divided by the primary-to-secondary turns ratio is the current that flows through the secondary wire of the transformer.

Calculation of R_{SET} Resistor

The AmpOut signal must exceed the window comparator's V_{TH} threshold voltage for longer than the delay timer and calculated by:

$$V_{TH}=I_{FAULT} \times 1.41 \times R_{SET} \times C_{OS}(2\pi \times (t/2P)) / N \quad (1)$$

$$R_{SET} = (V_{TH} \times N) / (1.41 \times I_{FAULT} \times C_{OS}(\pi \times t/P)) \quad (2)$$

where:

V_{TH}	=	3.5V
I_{FAULT}	=	5mA (UL943B)
t	=	1ms (timer delay)
P	=	Period of the AC Line (1/60Hz)
N	=	Ratio of secondary to primary turns (1000:1)
R_{SET}	=	505KΩ (511KΩ standard 1% value)

In practice, the transformer is non-ideal, so R_{SET} may need to be adjusted by up to 30% to obtain the desired I_{fault} trip threshold.

Calculation of V_{OS} Trip Threshold Error

Since the sense coil is directly connected to the feedback of the sense amplifier, the V_{OS} offset introduces an I_{fault} threshold error. This error can be calculated as follows:

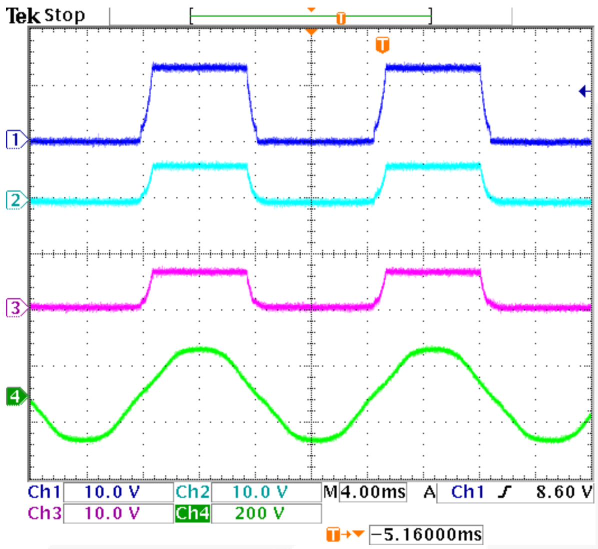
$$\%Error=100 \times (V_{OS} \times R_{SET}) / (R_{IN} + RL_{DC} + RL_{AC}) / V_{TH} \quad (3)$$

where:

V_{OS}	=	+/-450µV (worst case) +/-150µV (typical)
R_{SET}	=	511KΩ
R_{IN}	=	470Ω (typical value)
RL_{DC}	=	75Ω (sense coil secondary DC resistance)
RL_{AC}	=	1.5 KΩ ($AC_{(j\omega L)}$ impedance of sense coil), L= 4H, f= 60Hz)
V_{TH}	=	3.5V
%Error=		+/- 3.2% (worst case) +/- 1.1% (typical)

Typical Performance Characteristics

Unless otherwise specified, T_A=25°C and according to Figure 1 with SCR disconnected.



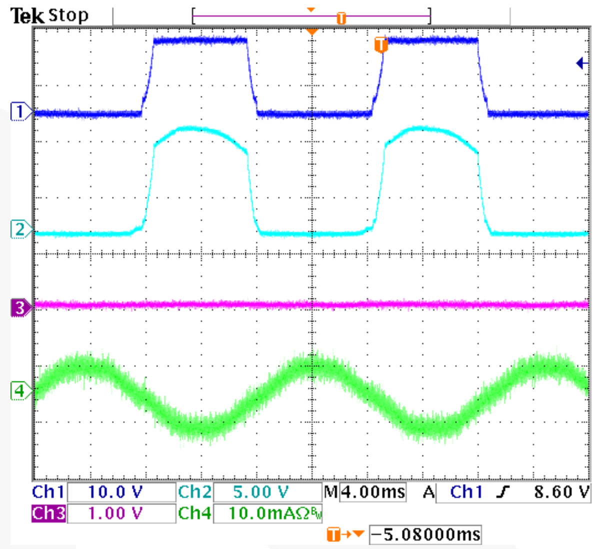
Ch1: V_{Line} (Pin 3), 10V/Div

Ch2: AmpOut (Pin 6), 10V/Div

Ch3: V_{REF} (Pin 4), 10V/Div

Ch4: V_{AC} Input, 200V/Div

Figure 5. Typical Waveforms, No Ground Fault



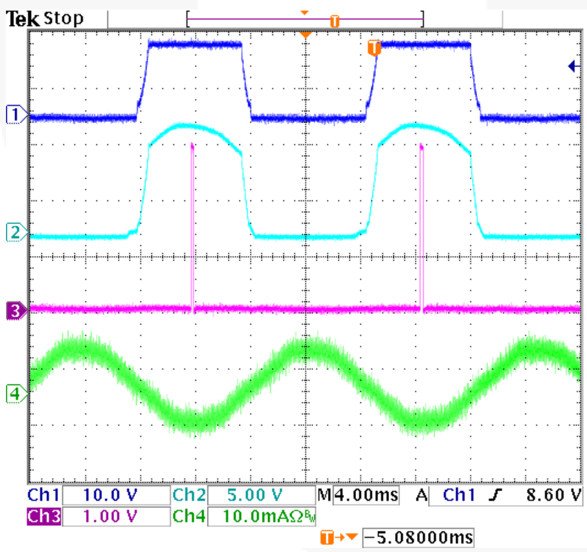
Ch1: V_{Line} (Pin 3), 10V/Div

Ch2: AmpOut (Pin 6), 5V/Div

Ch3: SCR (Pin 1), 1V/Div

Ch4: I_{FAULT}, 10mA/Div

Figure 6. Typical Waveforms, 4mA Ground Fault



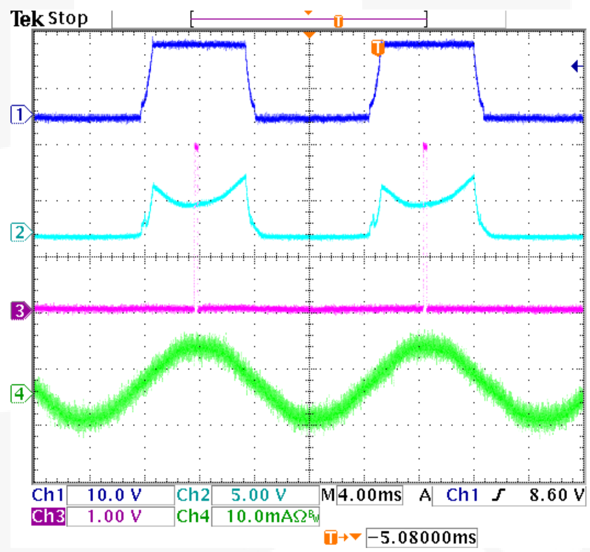
Ch1: V_{Line} (Pin 3), 10V/Div

Ch2: AmpOut (Pin 6), 5V/Div

Ch3: SCR (Pin 1), 1V/Div

Ch4: I_{FAULT}, 10mA/Div

Figure 7. Typical Waveforms, 5mA Ground Fault



Ch1: V_{Line} (Pin 3), 10V/Div

Ch2: AmpOut (Pin 6), 5V/Div

Ch3: SCR (Pin 1), 1V/Div

Ch4: I_{FAULT}, 10mA/Div

Figure 8. Typical Waveforms, 5mA Ground Fault (Line Polarity Reversal)

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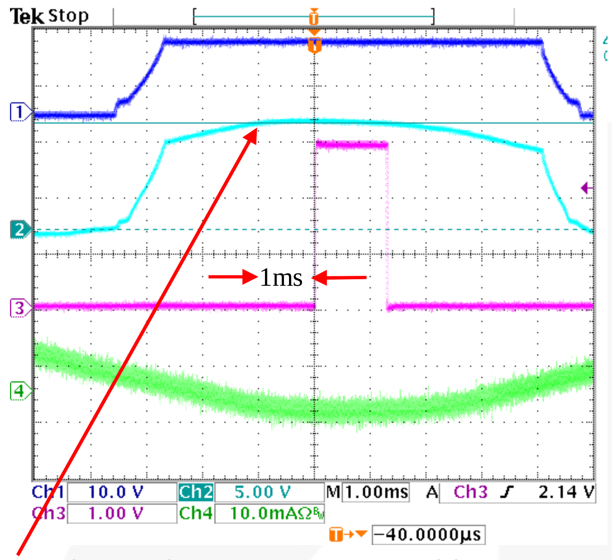
Typical Performance Characteristics (Continued)

Unless otherwise specified, T_A=25°C and according to Figure 1 with SCR disconnected.



1ms after AmpOut signal reaches 9.5V, SCR is triggered.

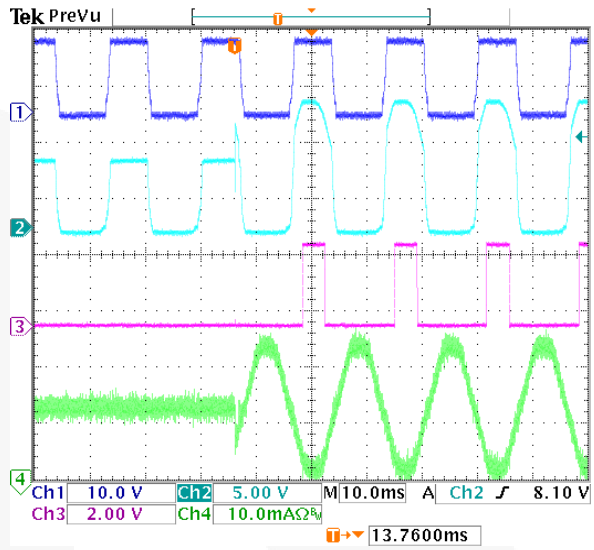
Ch1: V_{Line} (Pin 3), 10V/Div

Ch2: AmpOut (Pin 6), 5V/Div

Ch3: SCR (Pin 1), 1V/Div

Ch4: I_{FAULT}, 10mA/Div

Figure 9. AmpOut Threshold, Internal 1ms Delay



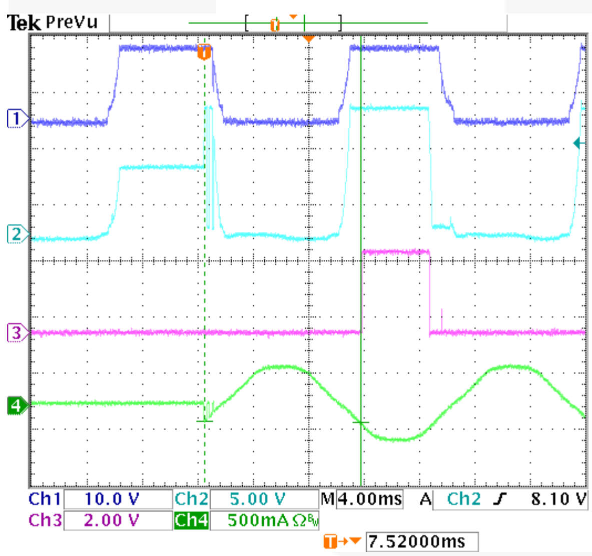
Ch1: V_{Line} (Pin 3), 10V/Div

Ch2: AmpOut (Pin 6), 5V/Div

Ch3: SCR (Pin 1), 2V/Div

Ch4: I_{FAULT}, 10mA/Div

Figure 10. 15KΩ Ground Fault



Ch1: V_{Line} (Pin 3), 10V/Div

Ch2: AmpOut (Pin 6), 5V/Div

Ch3: SCR (Pin 1), 2V/Div

Ch4: I_{FAULT}, 500mA/Div

Figure 11. 500Ω Ground Fault[6, 7]

Note:

6. Maximum trip time ~12ms.
7. Fault occurs at the end of the positive AC cycle.

Typical Temperature Characteristics (FAN4146E)

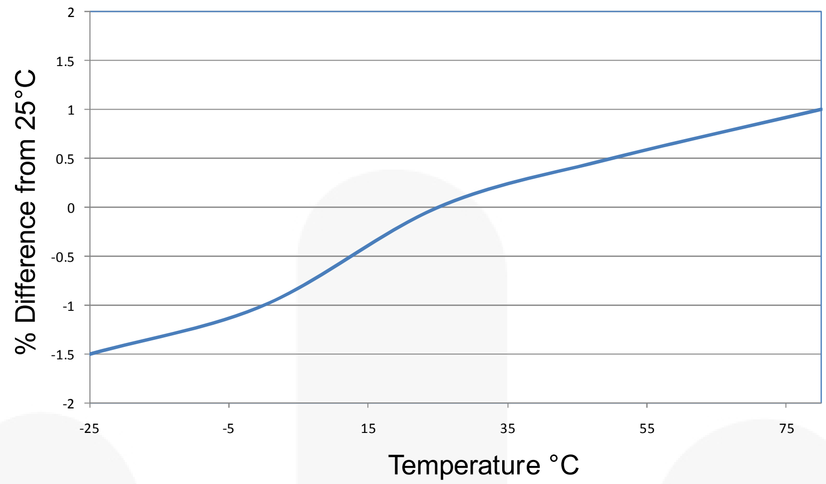


Figure 12. VThreshold (V_{TH}) vs. Temperature

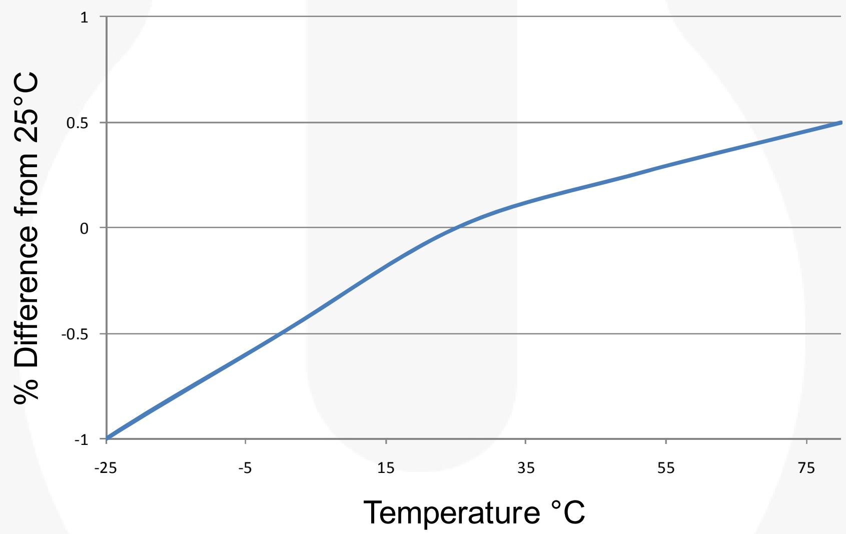


Figure 13. VReference (V_{REF}) vs. Temperature

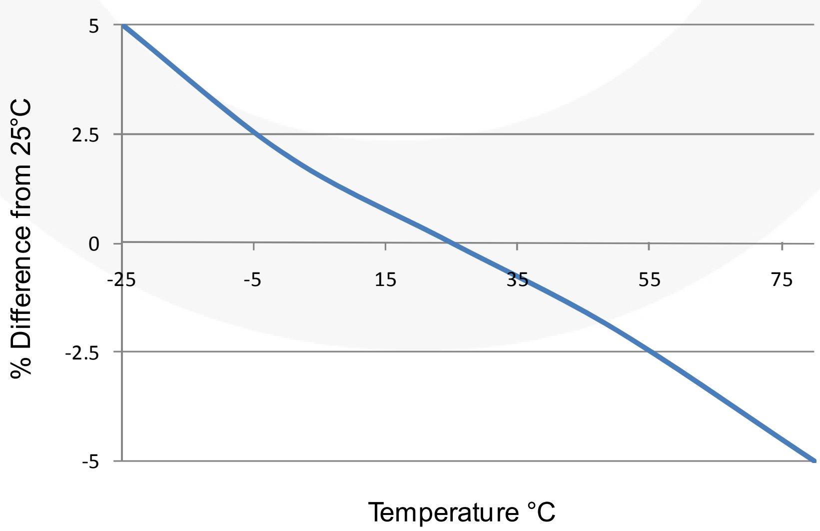


Figure 14. SCR Output Current (I_{OUT}) vs. Temperature

Physical Dimensions

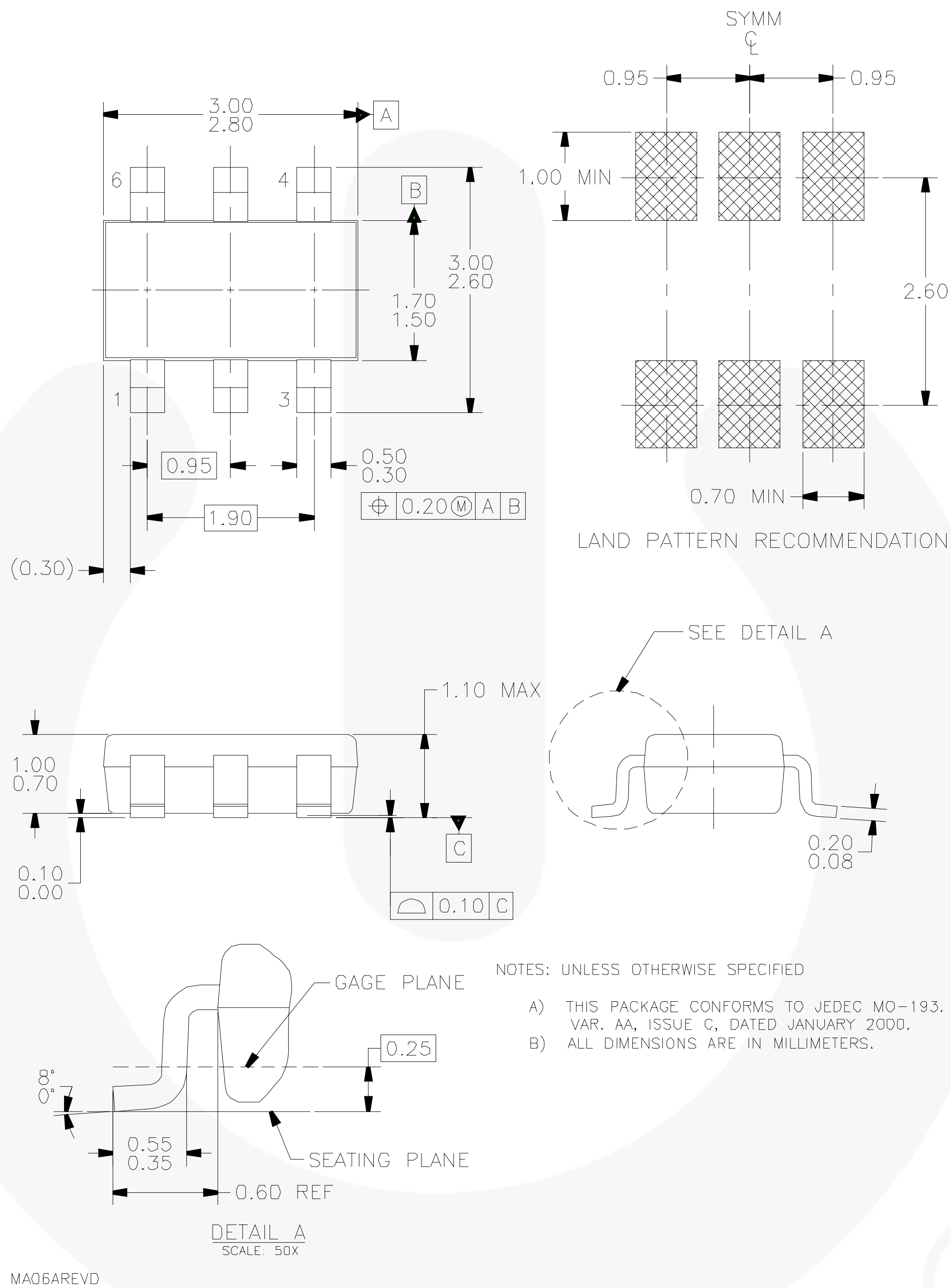


Figure 15. 6-Lead SUPERSOT6, JEDEC MO-193, 1.6mm Wide

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Preliminary	First Production	Datasheet contains preliminary data; supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve design.
No Identification Needed	Full Production	Datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve the design.
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