1. Description

The PIP401 is an OR-ing Intelligent Switch (ORIS), a dedicated power OR-ing device, that combines the simplicity of a diode with the efficiency of a MOSFET switch.

The PIP401 will have optimum use in supply lines with up to 40 A loads. For higher currents, two or more PIP401 devices can be used in parallel. The intended application is parallel redundant power supply networks, where the PIP401 provides a high-efficiency alternative to a rectifier diode. When the input voltage is greater than the output voltage, the PIP401 conducts with very low voltage drop. When the input voltage drops below the output voltage, the PIP401 switches off very quickly, blocking the flow of reverse current. Remote sensing of the load voltage compensates for inductance in the power supply lines. A thermal indicator is provided to allow power supply shutdown or load reduction if the junction temperature exceeds 150 °C.

2. Features

■ Very low voltage drop (typ 70 mV at 40 A)
■ Controlled turn-on
■ Fast turn-off
■ Remote sensing
■ Overtemperature flag
■ Low thermal resistance
■ ESD protected
■ Surface mount package.

3. Applications

■ Compact PCI power supplies
■ Telecommunications equipment power supplies
■ High-reliability, parallel redundant power supply networks.
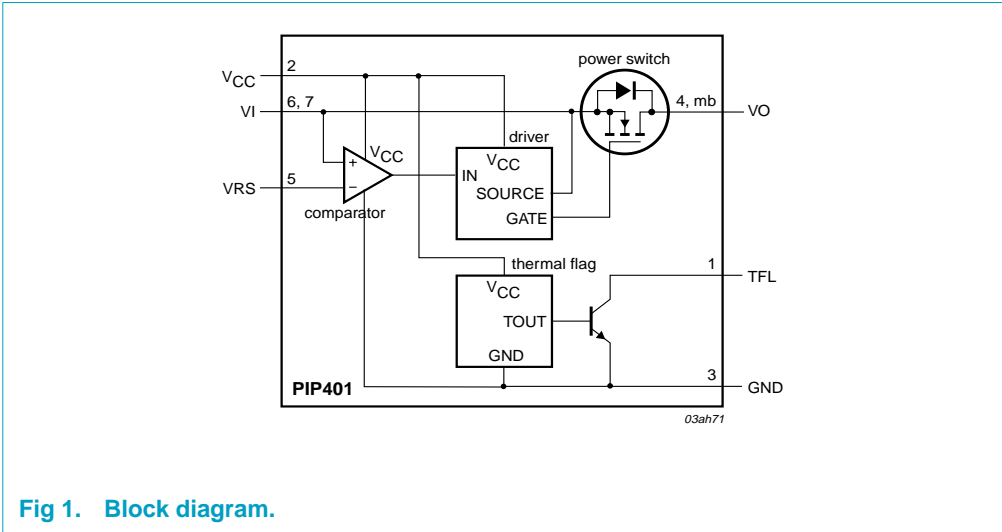
4. Ordering information

Table 1:   Ordering information

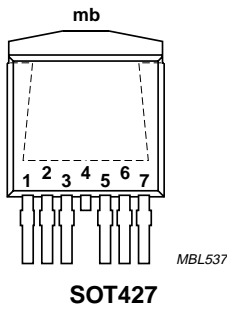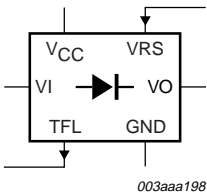| Type number	Package		
	Name	**Description**	**Version**
PIP401	D^2-PAK (7 lead)	Plastic, single-ended surface mount package (Philips version of D^2-PAK); 7 leads (centre lead cropped).	SOT427

5. Block diagram

Fig 1. Block diagram.

6. Pinning information

Table 2: Pinning

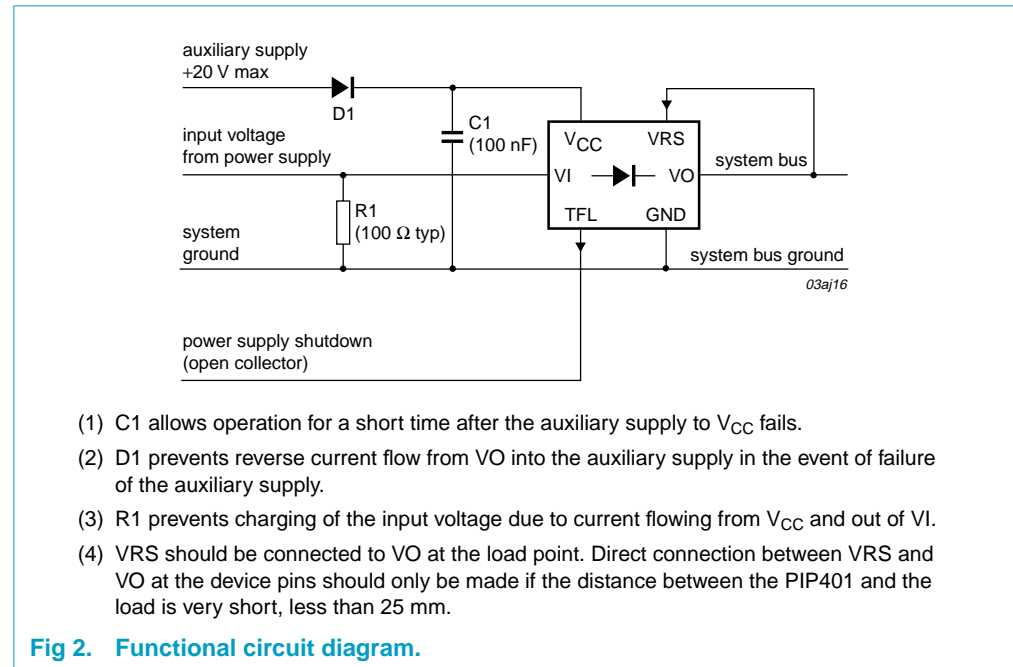| Symbol	Pin	I/O	Description	Simplified outline	Device symbol
TFL	1	O	overtemperature flag		
V_{CC}	2	-	positive supply voltage		
GND	3	-	ground		
VO	4, mb	O	output		
VRS	5	I	remote sense		
VI	6, 7	I	input		

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7. Functional description

Figure 1 shows the block diagram of the PIP401, which contains the following functional blocks:

- High-speed comparator with remote sense input
- Power switch driver stage
- Series power switch with very low on-state resistance
- Overtemperature detection circuit with open collector output.

Figure 2 shows the basic application circuit for the PIP401. The protected supply is connected to VI. The output (VO) is connected to the system bus. An auxiliary supply biases V_{CC}. The remote sense input (VRS) is joined to VO at the load point.

The open-collector overtemperature flag output (TFL) is fed back to the remote shutdown input of the protected supply. In a parallel redundant system, there will be at least one other protected supply feeding the system bus via another or-ing device.

(1) C1 allows operation for a short time after the auxiliary supply to V_{CC} fails.

(2) D1 prevents reverse current flow from VO into the auxiliary supply in the event of failure of the auxiliary supply.

(3) R1 prevents charging of the input voltage due to current flowing from V_{CC} and out of VI.

(4) VRS should be connected to VO at the load point. Direct connection between VRS and VO at the device pins should only be made if the distance between the PIP401 and the load is very short, less than 25 mm.

Fig 2. Functional circuit diagram.

7.1 Supply voltage

The PIP401 requires a supply voltage on V_{CC}. The supply voltage must be at least 5 V greater than the voltage on VI in order to supply sufficient drive voltage for the series power switch. The maximum rated supply voltage is 20 V.

7.2 Voltage drop monitoring

7.2.1 Comparator

The comparator monitors the voltage between the input (VI) and the remote sense input (VRS). When the voltage on VI is greater than the voltage on VRS by more than a few millivolts, the comparator output goes HIGH, turning on the series power switch.

When the voltage on VI is less than the voltage on VRS, the series power switch is turned off, blocking the flow of reverse current between VO and VI.

7.2.2 Remote sense input

The remote sense input (VRS) provides a high impedance connection to the load, bypassing the power supply line inductance. This connection enables the PIP401 to respond immediately to voltage changes at the load, removing the effects of voltage transients induced in the power supply line inductance due to changes in load current.

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7.3 Driver and series power switch

7.3.1 Soft turn-on

At switch on, the PIP401 turns on slowly to avoid current surges. These can cause oscillations in the output voltage and may cause the protected power supply to shut down. Typical turn-on time is 7 μs.

7.3.2 Low voltage drop

The on-state characteristic of the PIP401 is shown in Figure 5. In the on-state, the PIP401 has very low voltage drop, typically 70 mV at 40 A, 25 °C. This produces a power dissipation of 2.8 W. In comparison, a Schottky diode with a forward voltage drop of 320 mV would have a power dissipation of 12.8 W.

7.3.3 Low current operation

At low current levels, the voltage drop is only a few millivolts. This makes it difficult for the comparator to determine when to switch off. The PIP401 overcomes this problem by backing off the gate drive to the series power switch at current levels below 2 A. The effect is to increase the resistance between VI and VO so that the voltage drop is maintained at a constant level of approximately 6 mV. This is above the minimum detectable threshold voltage of the comparator. This is shown in Figure 5 by the flattening of the curves at low current.

7.3.4 Fast turn-off with no reverse current

When the input voltage (V_I) falls below the remote sense input voltage (V_{RS}), the PIP401 switches off very quickly, blocking the flow of reverse current. Figure 3 shows switching waveforms from an initial forward current of 20 A. Note the smooth ramp down of current from 20 A with no reverse current flow and minimum disruption of the output voltage. Total turn-off time is less than 400 ns.

The gate drive circuit in the PIP401 is referenced to VI. When the input voltage is less than the remote sense voltage, current flows into V_{CC} and out of VI. The maximum current is 35 mA. In order to prevent charging of the output capacitors of the protected supply connected to VI, a 100 W resistor should be connected between VI and GND. This is shown as R1 in Figure 2.
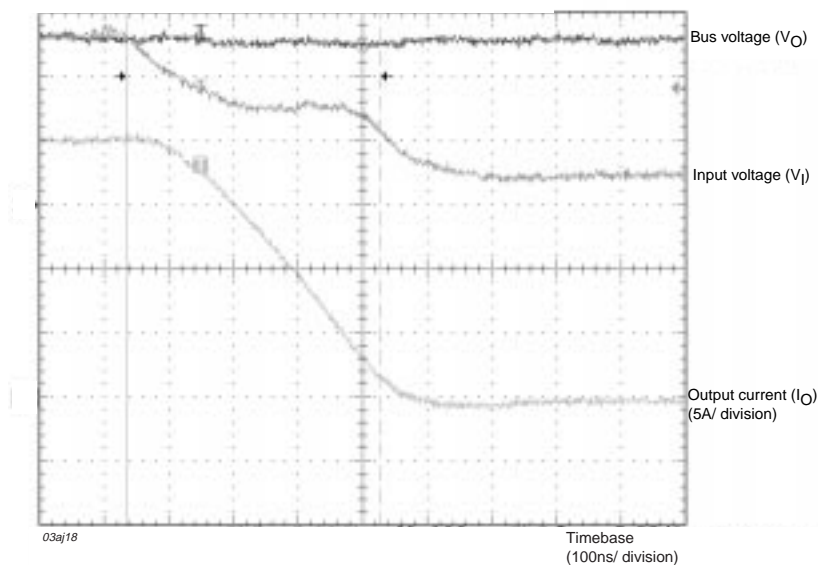
Fig 3.   Turn-off waveforms.

7.4 Overtemperature flag

In the event of failure of the supply to V_{CC}, the series power switch turns off and the forward voltage drop increases from a few millivolts to approximately 0.7 V. The power dissipation in the PIP401 increases causing the junction temperature to rise. A temperature detection circuit with an open-collector output is provided, that can be used to generate a warning signal for the power supply. The temperature flag operates at a typical junction temperature of 160 °C. A pull-up resistor of at least 1 kΩ is required between TFL and V_{CC}.

The temperature flag is intended to operate under fault conditions. The PIP401 should not be run continuously at junction temperatures above 150 °C.

8. Limiting values

Table 3: **Limiting values**

In accordance with the Absolute Maximum Rating System (IEC 60134).All voltages measured with respect to GND.

Symbol	Parameter	Conditions		Min	Max	Unit
V_{CC}	positive supply voltage			−0.3	+20	V
V_I	input voltage	VO open circuit; VI ≤ V_{CC}		−0.3	+20	V
V_O	output voltage	V_I = 0 V; V_O ≤ V_{CC}		−0.3	+20	V
V_{VRS}	remote sense voltage	V_{VRS} ≤ V_{CC}		−0.3	+20	V
V_{TFL}	temperature flag voltage	V_{TFL} ≤ V_{CC}		−0.3	+20	V
I_{TFL}	temperature flag current			-	20	mA
P_{TFL}	temperature flag dissipation			-	100	mW
I_I, I_O	continuous input or output current	T_{mb} ≤ 136 °C	[1]	-	75	A
I_{OM}	peak output current	t_p ≤ 10 µs		-	400	A
T_{stg}	storage temperature			−55	+150	°C
T_j	junction temperature			−40	+150	°C
V_{esd}	electrostatic discharge voltage	human body model; C = 100 pF; R = 1500 Ω	[2]	-	2000	V
		machine model; C = 200 pF; R = 10 Ω; L = 0.75 µH		-	200	V

[1] Assumes a thermal resistance from junction to mounting base of 0.65 K/W.

[2] The PIP401 meets class 2 for Human Body Model and Machine Model (JEDEC).

9. Thermal characteristics

Table 4: **Thermal characteristics**

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$R_{th(j-mb)}$	thermal resistance from junction to mounting base	Figure 4	-	0.5	0.65	K/W
$R_{th(j-a)}$	thermal resistance from junction to ambient	mounted on glass-epoxy circuit board with 25 mm x 25 mm copper area under mounting base, thermal vias and forced air cooling; airflow = 0.8 ms^{-1} (150 LFM).	-	15	-	K/W
		mounted on glass-epoxy circuit board with minimum footprint area	-	50	-	K/W

9.1 Transient thermal impedance

Fig 4. **Transient thermal impedance from junction to mounting base as a function of pulse duration.**
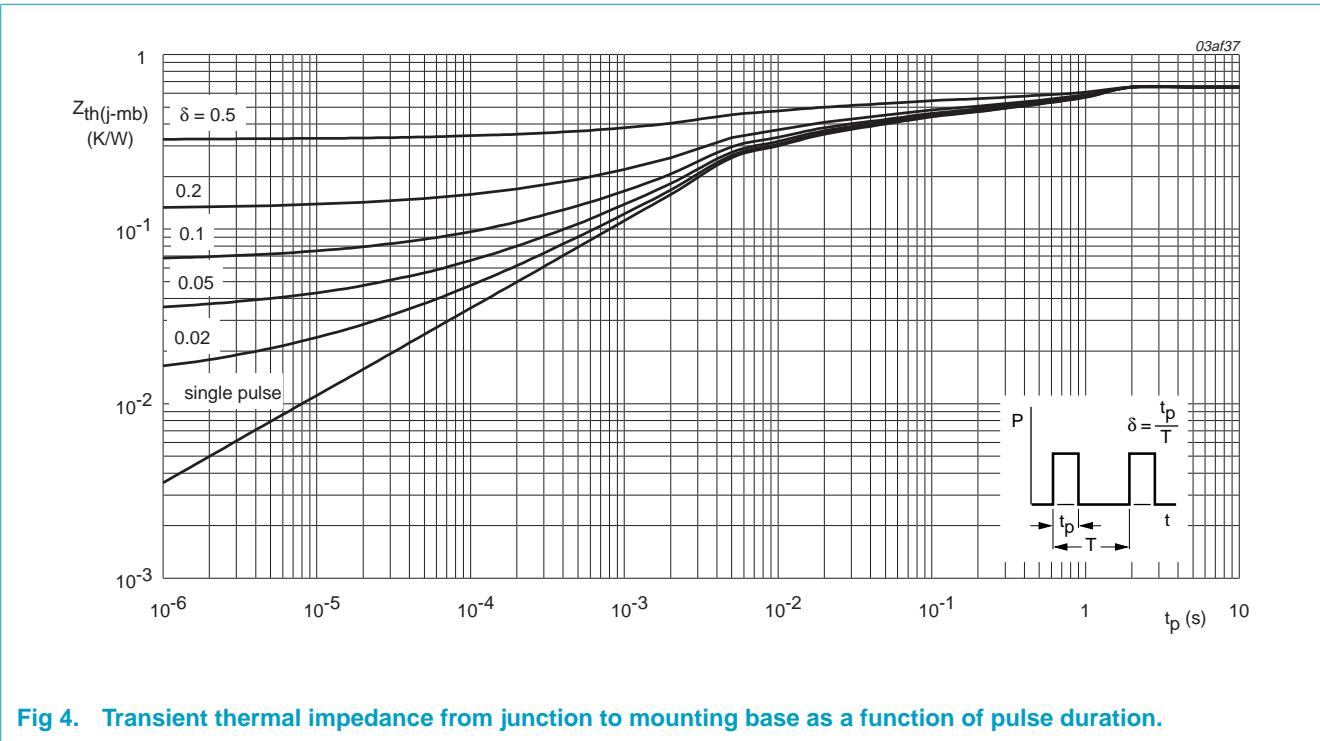
10. Characteristics

Table 5:   **Characteristics**

V_{CC} = 15 V; V_I = 5 V; VRS connected to VO; $-40\,°C \leq T_j \leq +150\,°C$ unless otherwise specified. All voltages measured with respect to GND.

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
V_{CC}	supply voltage			$V_I + 5$	15	20	V
V_I	input voltage	on-state; $V_I \geq V_{VRS}$	[1]	1.3	5	$V_{CC} - 5$	V
V_{VRS}	remote sense voltage			0	5	V_{CC}	V
ΔV_{ON}	on-state voltage	I_O = 40 A; T_j = 25 °C; Figure 5		-	70	80	mV
V_F	off-state forward voltage	V_{CC} = 0 V; I_O = 40 A; T_j = 25 °C		-	0.85	1	V
I_{CC}	supply current	on-state; VO open circuit; $V_I \geq V_{VRS}$		-	3	10	mA
		off-state; VO open circuit; $V_I < V_{VRS}$	[2]	-	16	35	mA
I_I	input current	on-state; VO open circuit; $0 \leq V_I \leq V_{CC}$		-	0.1	10	mA
		off-state; VO open circuit; $0 \leq V_I \leq V_{CC}$	[2]	-35	-16	-	mA
I_{VRS}	remote sense current	$0 \leq V_I \leq V_{CC}$		-2	+0.1	+2	mA
T_{TFL}	flag trip temperature			-	160	-	°C
$I_{LR(VO)}$	reverse leakage current into VO	V_{CC} = 0 V; V_O = 15 V; V_I = 0 V		-	10	500	nA
t_{on}	turn-on time	V_I = 0 V to 5 V; I_O = 5 A		3	7	-	µs
t_{off}	turn-off time	V_I = 5 V to 0 V; I_O = 5 A		100	200	300	ns
L_s	internal source inductance			-	2	-	nH

[1] When the input supply fails, the voltage on VI can fall to zero. However, the voltage on VRS must be at least 1.3 V for the comparator to operate and turn off the series power switch.

[2] In the off-state, the majority of the supply current into V_{CC} flows out of VI.

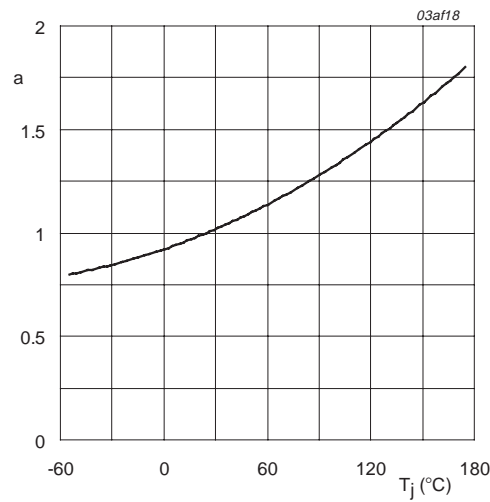[3] $\Delta V_{ON} = V_I - V_O$.
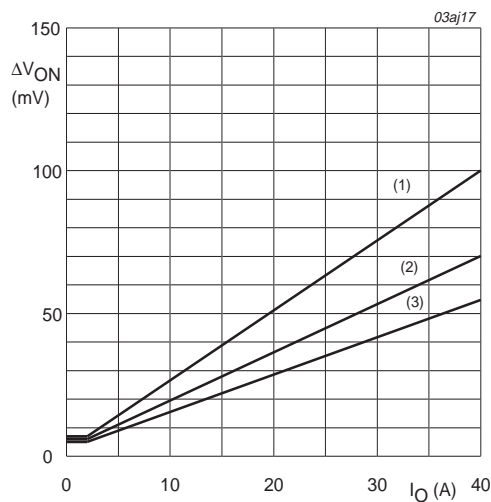
V_{CC} = 15 V; V_I = 5 V

(1) T_j = 125 °C

(2) T_j = 25 °C

(3) T_j = −40 °C

Fig 5. On-state characteristic; typical values.

V_{CC} = 15 V; V_I = 5 V; $I_O \geq$ 2 A

$$a = \frac{\Delta V_{ON}}{\Delta V_{ON(25°C)}}$$

Fig 6. Normalized on-state voltage drop factor as a function of junction temperature.

11. Application information
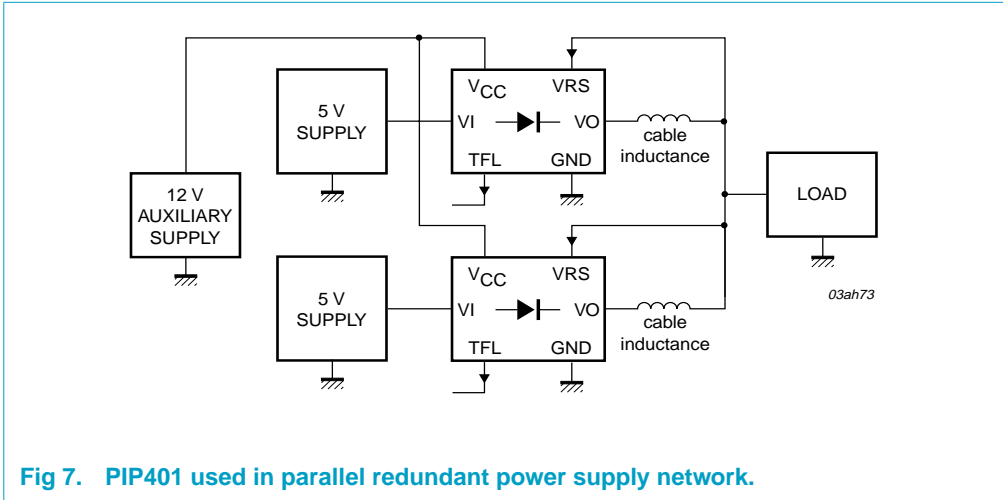
11.1 Parallel redundant operation

Fig 7. PIP401 used in parallel redundant power supply network.

Figure 7 shows a typical parallel redundant power supply system. Two 5 V system power supplies are connected via PIP401 devices to a shared load. An auxiliary supply provides the PIP401 devices with 12 V. Power supplies with forced current sharing capability are ideal for this application. The remote connection to each PIP401 is taken from a point close to the load in order to compensate for the effects

of line inductance. The VRS connection may be connected directly to VO if the circuit inductance is negligible. In general, this means that the distance between the PIP401 and the load must be less than 25 mm.

Assume that the 12 V supply to V_{CC} is present but both 5 V supplies are off. In this condition, with no voltage between input and output, both PIP401 devices will be off.

If one of the 5 V supplies is turned on, the comparator output in the associated PIP401 will go HIGH, slowly turning on the series power switch (soft start). The series power switch in the other PIP401 will remain off, preventing current from flowing from output to input.

If both 5 V supplies are on, and the power supplies have forced current sharing capability, then both PIP401 devices will be on.

If the power supplies do not have forced current sharing capability then the supply with the highest output voltage will tend to supply all the load current. If the difference in output voltage is greater than a few millivolts, then the PIP401 device connected to the power supply with the highest output voltage will be on, and the PIP401 device connected to the power supply with the lowest output voltage will be off.

Remote voltage sensing is not usually a feature of this topology of parallel redundant operation. This is because the remote sense lines provide an alternative path for fault currents when one of the power supplies fails. Therefore, in order to maintain good load regulation, the PIP401 must have a low forward voltage drop under normal operating conditions. The typical on-state voltage drop of the PIP401 is 70 mV at 40 A. Two or more PIP401 devices may be connected in parallel in order to reduce this further.

11.2 Fault condition

With reference to Figure 7, assume that both 5 V power supplies are supplying current to the load. Assume that one of the supplies fails and its output voltage collapses to zero. The voltage on the output terminal of the PIP401 drops from 5 V to zero and goes slightly negative as the voltage across the line inductance reverses in order to maintain current flow.

At the instant that the power supply fails, the PIP401 detects that the voltage on VI is less than the voltage on the remote sense connection VRS. The drive voltage to the series power switch is immediately turned off, but the series power switch takes up to a further 300 ns to switch off completely. During this delay time, the current decreases from its initial value to zero at a rate determined by the bus voltage and the line inductance.

If the PIP401 turns off completely before the current reaches zero, then there is no reverse current flow. On the other hand, if the rate of fall of current is very high, current will flow from VO to VI until the PIP401 turns off completely. The peak reverse fault current depends on the magnitude of the line inductance and the initial load current.

11.3 Overtemperature detection

Figure 8 shows how the thermal flag output of the PIP401 is used to shut down a power supply in the event of overtemperature. In this circuit, there are pull-up resistors from TFL to both the 5 V and 12 V supplies.

Fig 8.   Overtemperature detection.
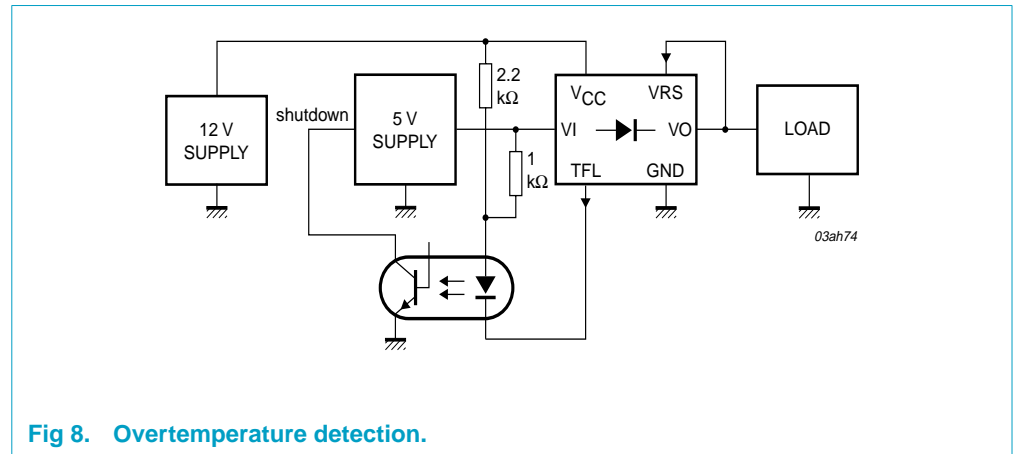
11.3.1 On-state

The overtemperature flag can be used to detect excessive load current. The overtemperature flag will operate when the power dissipation due to load current is sufficient to raise the junction temperature to approximately 160 °C. The typical on-state voltage of the PIP401 at 25 °C is 70 mV. To calculate the on-state voltage at 160 °C, the 25 °C value is multiplied by the normalized on-state voltage factor given in Figure 6. This factor is 1.6 giving an on-state voltage at 160 °C of 112 mV. Using a thermal resistance from junction to ambient of 15 K/W and an ambient temperature of 55 °C, the overtemperature flag will operate when the current exceeds:

(1)

$$I_O = \frac{T_{TFL} - T_{amb}}{\Delta V_{ON} \times R_{th(j-a)}} = \frac{160 - 55}{0.112 \times 15} = 62.5A$$

One possible use of the overtemperature flag is to detect failure of the cooling fan, in applications where forced air cooling is used.

If the thermal resistance from junction to ambient is higher, then the temperature flag will operate at a lower value of output current.

11.3.2 Off-state

If the 12 V supply to V_{CC} fails as a result of a fault in the auxiliary supply, this will cause the PIP401 to turn off, and the voltage drop to increase from a few millivolts to approximately 0.7 V. The increased dissipation in the PIP401 will cause its junction temperature to rise. Taking a junction to ambient thermal resistance of 15 K/W and an ambient temperature of 55 °C, the overtemperature flag will operate when the dissipation in the PIP401 is greater than:

$$P_{tot} = \frac{160 - 55}{15} = 7W$$

(2)

The voltage drop across the PIP401 in the off state is approximately 0.7 V. Therefore, the overtemperature flag will operate if the current through the PIP401 is greater than 10 A.

If the thermal resistance from junction to ambient is higher, then the temperature flag will operate at a lower value of output current.

12. Package outline

**Plastic single-ended surface mounted package (Philips version of D^2-PAK);
7 leads (one lead cropped)**

SOT427

0   2.5   5 mm
scale
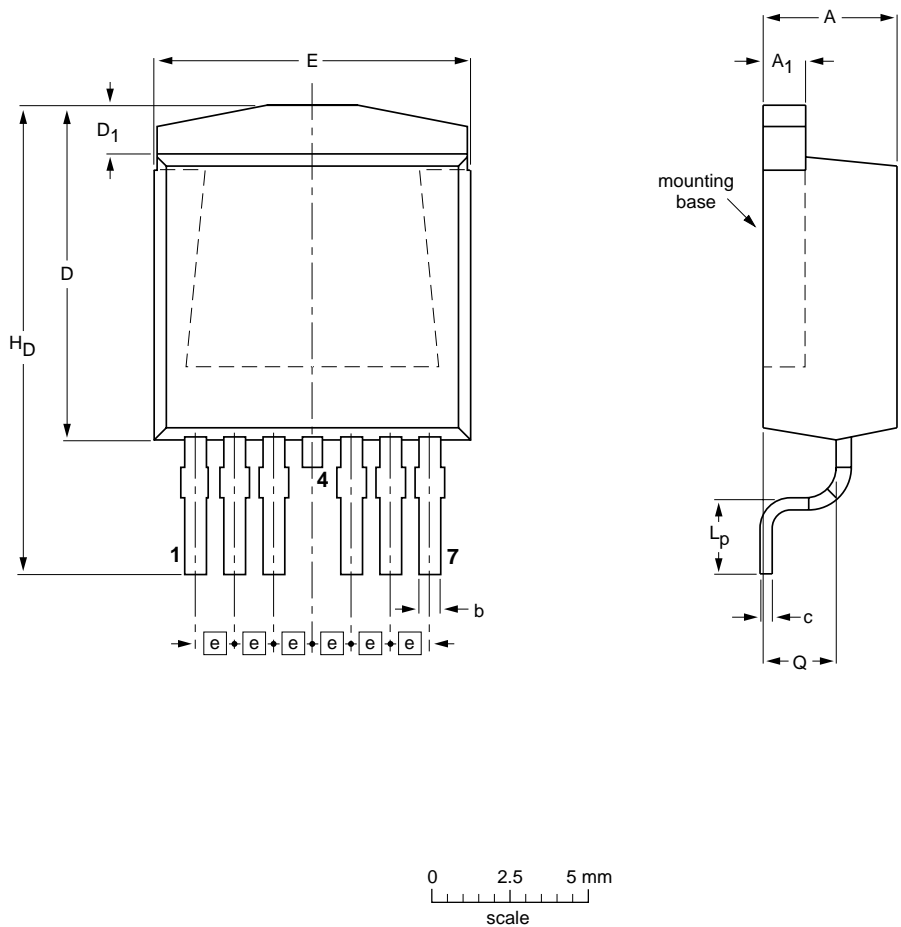
DIMENSIONS (mm are the original dimensions)

UNIT	A	A$_1$	b	c	D max.	D$_1$	E	e	L$_p$	H$_D$	Q
mm	4.50 4.10	1.40 1.27	0.85 0.60	0.64 0.46	11	1.60 1.20	10.30 9.70	1.27	2.90 2.10	15.80 14.80	2.60 2.20

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT427						~~99-06-25~~ 01-04-18

Fig 9. SOT427 (D^2-PAK).

13. Revision history

Table 6: **Revision history**

Rev	Date	CPCN	Description
03	20021105	-	**Product data (9397 750 10578)**
			Modifications:
			• Typ and Max values of forward voltage V_F changed in Table 5 and Section 7.3.2
			• Graphic changed in Figure 5
			• Typical on-state voltage drop of the ORIS changed in Section 11.1
			• Flag operating temperature added to Table 5.
			• $R_{th(j-a)}$ with airflow added to Table 4.
			• Block diagram changed Figure 1.
			• Limiting values Table 3. Power dissipation (P_{tot}) rating removed. Minimum voltage ratings changed from -0.5 V to -0.3 V. Normalized power dissipation and normalized output current figures removed.
			• Characteristics: Off-state characteristic curve removed.
02	20020828	-	**Product data (9397 750 10157)**
			Modifications:
			• Specification status changed from "Objective data" to "Product data"
			• Typ and Max values of forward voltage V_F changed in Table 5 and Section 7.3.2
			• Graphic changed in Figure 5
			• Typical on-state voltage drop of the ORIS changed in Section 11.1
01	20020621	-	**Objective data (9397 750 09971)**

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14. Data sheet status

Level	Data sheet status[1]	Product status[2][3]	Definition
I	Objective data	Development	This data sheet contains data from the objective specification for product development. Philips Semiconductors reserves the right to change the specification in any manner without notice.
II	Preliminary data	Qualification	This data sheet contains data from the preliminary specification. Supplementary data will be published at a later date. Philips Semiconductors reserves the right to change the specification without notice, in order to improve the design and supply the best possible product.
III	Product data	Production	This data sheet contains data from the product specification. Philips Semiconductors reserves the right to make changes at any time in order to improve the design, manufacturing and supply. Relevant changes will be communicated via a Customer Product/Process Change Notification (CPCN).

[1]   Please consult the most recently issued data sheet before initiating or completing a design.

[2]   The product status of the device(s) described in this data sheet may have changed since this data sheet was published. The latest information is available on the Internet at URL http://www.semiconductors.philips.com.

[3]   For data sheets describing multiple type numbers, the highest-level product status determines the data sheet status.

15. Definitions

Short-form specification — The data in a short-form specification is extracted from a full data sheet with the same type number and title. For detailed information see the relevant data sheet or data handbook.

Limiting values definition — Limiting values given are in accordance with the Absolute Maximum Rating System (IEC 60134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.

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