AXYS Water Level Sensor
Final Report

by

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Summary

This technical report concerns development of a water level sensor for AXYS Technologies Inc.(customer). The customer manufactures buoys and uses a sensor to detect water intrusion into the buoy hull.

We have chosen as our proposed solution, a similar sensor to the existing one used by the customer. The water levels are detected via the conducting water making contact across the sensor terminals. The existing sensor measures voltage difference when the water conducts and when it does not. We have designed the new control circuit for this sensor based on MOSFETs technology. This enabled us to eliminate the dependency on different water conductivity and have more reliable water level detection. A second circuit prototype that will use p-channel MOSFETs will be built and tested. The n-channel MOSFET circuit has been successfully tested and presented to the customer.

1. Introduction

AXYS Technologies Inc. is a member of the AXYS Group, a privately owned group of three companies that share common roots and ownership. These companies are independent, diversified and growth-oriented; specializing in advanced technology products and services with shared engineering, technical and scientific resources. The group enjoys international product, consulting and service sales in more than 30 countries[1].

AXYS Technologies Inc. makes buoys for weather, water condition and currents monitoring around the world, these buoys' are unmanned and remotely monitored. The power for these buoys comes from solar power stored in onboard batteries, which is used to run the diagnostic and monitoring equipment. One of the threats to the work life to these $50,000+ buoys is a water leak. A leak can cause damage to the electrical systems or in the worst case sink the buoy. That is why one vital self-diagnostic components is an accurate, and reliable inside water level sensor. This sensor has to not only detect a leak but also to detect the rate of water level increase. The buoy sensors status and data are usually transmitted once an hour to the monitoring station. When leak is detected, the owners of the buoy know, depending on the water level rate increase, how much time they have to save it.

2. Project Description

The current water level sensor used by AXYS Technologies (customer) does not work accurately with different water conductivity, which depends mainly on dissolved inorganic salts and water temperature. The inaccuracy can result in false alarms in better case and loss of equipment in the worst case.

The following project specifications were finalized during the water level sensor development:

- Reliable/repeatable measurement characteristics
- No false alarms
- Measurement of at least 4 water level increments (for example one sensor that detects at 0.5cm,, 2cm, 5cm and 10cm of water)
- The measurement heights are configurable – ie, the sensor can be built with measurement readings also at 1cm, 10cm, 20cm, 50cm) with same interface and output values
- Sensor should be reusable and can measure more than one water intrusion event.
- One digital or analog (0-2.5V) output signal
- Small cross section (<6.25cm^2) as it has fit into limited space
- Small power usage (<1mA @ continues 12 VDC)
- Inexpensive and simple to construct
- The original specs had required for the sensor to be powered from 5-30 VDC and also offered availability of RS-232 communication port. We have been given access to regulated 5 VDC power supply and the access to RS-232 communication port has been taken away.
- One more design limitation we have found, when presenting our first prototypes to AXYS Technologies, that the stainless steel or aluminum hull has the negative terminal of the buoy power system attached to it.

3. Proposed Design Solution

We have proposed two different ideas to the customer. The first idea was a small arm with a floating ball on one end, with the arm attached to a variable resistor. As the water level would rise the resistance and voltage would change as the float turned the dial of the resistor. The advantage of this design was linear output with infinite increments, no current would go through the water and simple design. The disadvantage of this design was larger footprint, possible mechanical damage from buoy movement and sealing the arm-resistor linkage.

The second idea is based on the current AXYS Technologies water level sensor. Our proposed design also monitors only finite number of water levels but eliminates the dependency on magnitude of water conductivity. The customer has chosen this idea as possible solution for the water level sensor. Below in Figure 4.0 is our testing prototype we have built to test the design viability.

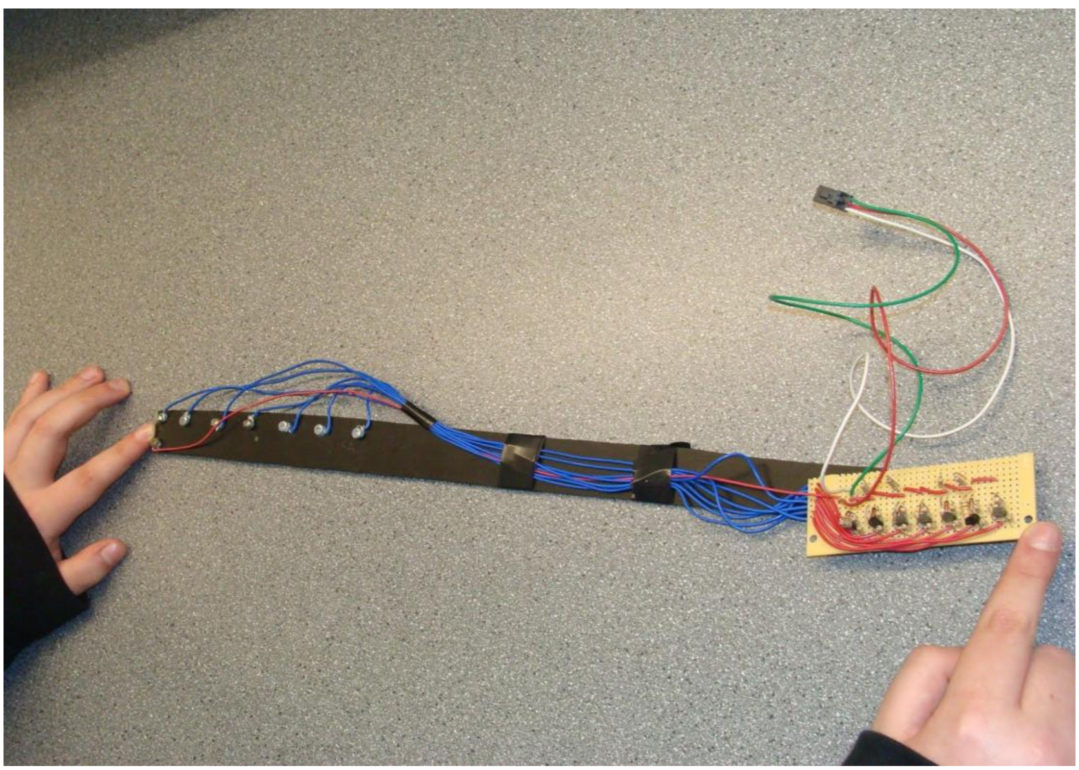


Figure 1 Prototype water level sensor with seven n-channel MOSFET stages

4. Solution Technical Parameters

The circuit we have designed in Figure 4.1 uses p-channel enhanced MOSFETs (Metal Oxide Semiconductor Field Effect Transistor). When the water level goes up and reaches two contacts the transistor is turned on and conducts current from drain to source across of pair of resistors (R3 and R4). The advantage using MOSFETs in this circuit is that it takes very little current (μA) to drive them. Each water level stage requires one of these circuits. The voltage drop across R3 brought out through the D1 diode to the WatchMan500 controller indicates which level is currently conducting.

The lowest level circuit has R3 the smallest as each level gets flooded the voltage on the common controller input is incremented. The voltage increment is determined by the difference of R3 and R4 (voltage divider). The voltage drop (0.6V) across D1 diode had to be taken in consideration.

From the discussion with the customer the controller turns on in some buoys only every hour to take diagnostic readings.

The C1 capacitor in circuit serves as a buffer for the measured level. Since the buoy is not stationary and will bounce side to side based on the wind conditions, current and buoy size, we need to keep the water level registered long enough for the control to read it in and get consistent measurement.

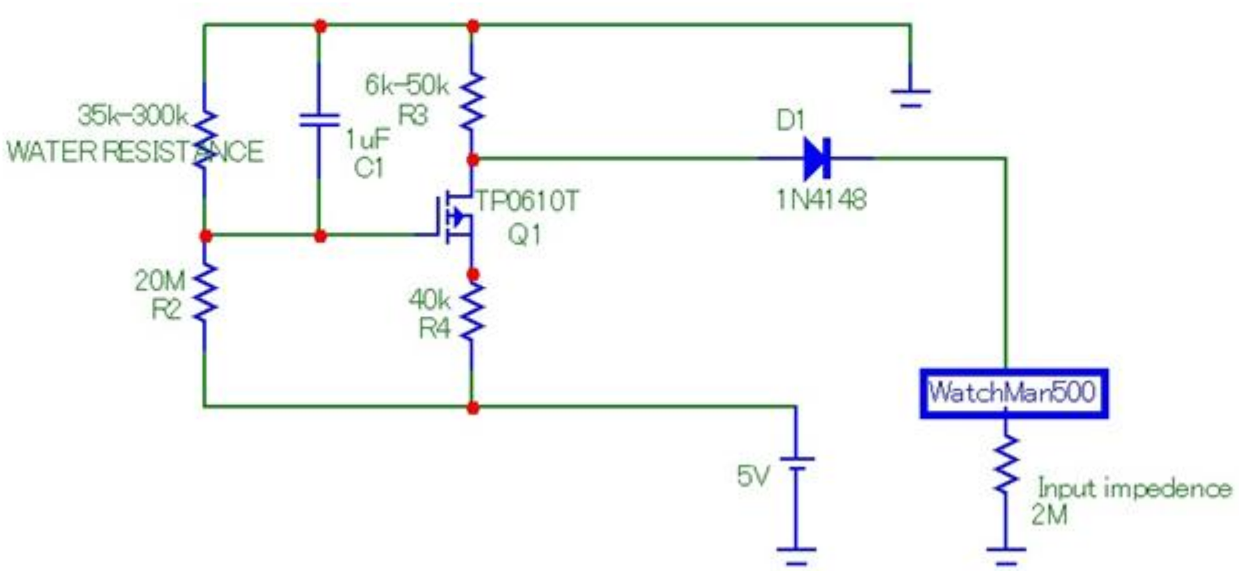


Figure 2 **The circuit diagram of one water level sensor stage**

	Fresh Water (Victoria Tap)			Salt Water (Cardboro Bay)	
Level	(V)	(mA)	Level	(V)	(mA)
0	0	0	0	0	0
1	0.4446	0.1168	1	0.443	0.117
2	0.5433	0.23	2	0.5419	0.23
3	0.6319	0.34	3	0.6305	0.34
4	0.7303	0.44	4	0.7287	0.44
5	0.8308	0.55	5	0.829	0.55
6	0.933	0.65	6	0.9306	0.65
7	1.0276	0.75	7	1.0246	0.75

Figure 3 **Probe voltage and current output testing fresh and salt water**

5. Design Limitations

The accuracy of the water level stages output is dependent on the tolerance of the components used for circuit manufacturing. Since the resistance ratio of fresh water to salt water is about 10:1 and measured 300kΩ for the fresh water, the voltage drop across water resistance is small compare to 20MΩ biasing resistor. The threshold voltage of TP0610T (-2.4V) is much larger than the -5V used to saturate the transistor. Therefore temperature swings will not affect the transistor switching performance as long as we keep the ID >0.05mA.

This is not the case with the resistor tolerances. With 10% resistor tolerances we can expect swings up to ± 0.1V from stage to stage. If we are looking only for five levels it would be acceptable otherwise we would have to use resistors with tighter tolerances.

One the design limitations we have not anticipated, was the danger of hydrogen generation through water electrolysis. In our first design we have used n-channel MOSFETs, while the current between the sensor contacts was small, the current between the negative buoy wall and the positive contact was significant enough (100μA) to generate dangerous level of hydrogen and also disabled the sensor functionality.

With the current design this problem was eliminated as the current passing through the water is only 250nA. That of course only happens when the water level contacts are flooded.

While the probe working environment is salt or fresh water, the probe will be protected for majority of time by the water tight buoys hull and plus the circuit itself encapsulated in epoxy. We can afford encapsulate the circuit as the heat generated by the components is minimal (<0.8mA when all the stages are conducting). The Figures 4.2.1, 4.2.2 and 4.23 show various buoys used to house batteries and electronic instruments.

Figure 4 One the AXYS Technologies larger buoys the WatchKeeper

Figure 5 TRYAXYS Directional Wave Buoy

Figure 6 TRYAXYS MINI Directional Wave Buoy

5.1. Design Calculations

5.1.1. C1 size

For calculating the C1 capacitor size we have used the equation $V_R(t) = Ve^{-t/RC}$ where VR is our maximum gate threshold voltage of the MOSFET . From the data sheet in the Appendix A for TP0610 it is -2.4V. We have arbitrarily selected the largest period for water splashing inside of the buoy about 15 seconds as we do not expect smaller waves to have enough energy to bounce it around.

$$C = \frac{-t}{\ln(\frac{V_R}{V_{source}}) \times R_{biasing}} = \frac{15}{ln\frac{2.4}{5} \times 2 \times 10^7} = 1 \times 10^{-6} F$$

5.1.2. Hydrogen generation

Since the main concern of our water level design is the hydrogen generation, we have included calculations for the hydrogen gas generation.

The P-channel MOSFET gate is biased to +5V through 20MΩ resistor. This is the positive contact (electrode).Once the water level rises and bridges two electrodes (contacts) the current flows to the negative electrode (the second contact) and the buoy shell as it is grounded to the negative terminal as well. This completes the circuit and the MOSFET is in the conducting mode. As the salt water resistance is approximately 30kΩ for the electrode and shell distance, we have 250nA of current passing through.

$$I = \frac{V}{R_{BIASING\ RESISTOR} + R_{WATER}} = \frac{5V}{20M\Omega + 30K\Omega} = 250 \text{ x } 10^{-9}\, A$$

Charge generated in a day when one set of contacts is submerged in sea water:

$$Q = 250 \text{ x } 10^{-9}\, A \text{ x } 60 \text{ x } 60 \text{ x } 24 = 0.216\; C/day$$

The Faraday's constant: k_F = 95600 *C/mole*

Electron moles generated per day = Q/k_F

$$\frac{Q}{k_F} = \frac{0.216C/day}{95600C/mole} = 2.26 \text{ x } 10^{-6} mole\; e^{-1}/day$$

Hydrogen generation *1 mole* e^{-1} generates *0.5mole* of hydrogen gas

Hydrogen gas generated per day

$$H_2(2g/mole) = \frac{0.5mole}{mole\; e^{-1}} \times\; 2.26 \text{ x } 10^{-6} mole \frac{e^{-1}}{day} = 1.1 \times \frac{10^{-6}mole}{day}$$

Volume of hydrogen generated per day using density ρ (20ºC, 101.3kPa) = 0.0854g/l

$$V = \frac{1.1 \times 10^{-6} g/day}{0.0854 g/l} = 1.9 \times 10^{-6} L/day = 0.0019 ml/day\; of\; hydrogen\; gas$$

This calculation is based on having one set of contacts submerged.

6. Project Discussion

During the project design we have considered several options for the water level sensor design. One key factor was the remoteness of the buoys installation, where a false alarm would be expansive, the other factor was calibration. The advantage of contactless methods as ultrasound, electromagnetic wave and capacitance is that they have all infinite number of sensing levels and they do not have any current going through the water. As the electronic components are these days relatively to manpower inexpensive, we were limited more by installation complexity, space arrangement and calibration requirements.

The contactless methods require certain space configuration as visible path from the sensor to the bottom of the buoy. Each type of buoy has different component configuration and even the same buoy can have different equipment on board.

Contactless sensors are more sensitive to miss calibration and positioning and very likely every installation would require new calibration.

Our design allows manufacturing of the water level sensors ahead of time. The same electrical circuit will fit all the buoy types. The sensors (contacts) are inexpensive to make and particular length can be made to fit type of buoy. They withstand harsh environment and rough handling.

7. Recommendations

The proposed design offers theoretically 50 levels or more of graduation. It is limited by the component tolerances and at the diode stage by mismatched components. If purchased resistors have 1% tolerances we will have maximum swings of ±0.01V from stage to stage compare to ±0.1V to 10% tolerance components. The other option is to buy larger quantities of components at same time from the same production batch as these components are expected to have similar production variations.

8. References

[1] http://www.axystechnologies.com/AboutUs.aspx

Log book grade (25%): _______________
Report grade (75%): _______________
Total Grade (100%): ________________

Supervisor's Comments:

_

_________________________ _______________________ _____________________
Supervisor's name (Print) Signature Date

Notes for the supervisor:

P-Channel Enhancement-Mode Vertical DMOS FETs

Ordering Information

BV_{DSS} / BV_{DGS}	$R_{DS(ON)}$ (max)	$I_{D(ON)}$ (min)	Order Number/Package TO-236AB*
-60V	10Ω	-50mA	TP0610T

*Same as SOT-23. All units shipped on 3,000 piece carrier tape reels.

Product marking for SOT-23:
T50❋
where ❋ = 2-week alpha date code

Features

- ❏ Free from secondary breakdown
- ❏ Low power drive requirement
- ❏ Ease of paralleling
- ❏ Low C_{ISS} and fast switching speeds
- ❏ Excellent thermal stability
- ❏ Integral Source-Drain diode
- ❏ High input impedance and high gain
- ❏ Complementary N- and P-channel devices

Advanced DMOS Technology

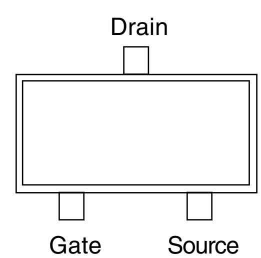
These enhancement-mode (normally-off) transistors utilize a vertical DMOS structure and Supertex's well-proven silicon-gate manufacturing process. This combination produces devices with the power handling capabilities of bipolar transistors and with the high input impedance and positive temperature coefficient inherent in MOS devices. Characteristic of all MOS structures, these devices are free from thermal runaway and thermally-induced secondary breakdown.

Supertex's vertical DMOS FETs are ideally suited to a wide range of switching and amplifying applications where high breakdown voltage, high input impedance, low input capacitance, and fast switching speeds are desired.

Applications

- ❏ Logic level interfaces – ideal for TTL and CMOS
- ❏ Solid state relays
- ❏ Battery operated systems
- ❏ Photo voltaic drives
- ❏ Analog switches
- ❏ General purpose line drivers
- ❏ Telecom switches

Package Option



TO-236AB
(SOT-23)
top view

Note: See Package Outline section for dimensions.

Absolute Maximum Ratings

Drain-to-Source Voltage	BV_{DSS}
Drain-to-Gate Voltage	BV_{DGS}
Gate-to-Source Voltage	± 20V
Operating and Storage Temperature	-55°C to +150°C
Soldering Temperature*	300°C

* Distance of 1.6 mm from case for 10 seconds.

11/12/01

Supertex Inc. does not recommend the use of its products in life support applications and will not knowingly sell its products for use in such applications unless it receives an adequate "products liability indemnification insurance agreement." Supertex does not assume responsibility for use of devices described and limits its liability to the replacement of devices determined to be defective due to workmanship. No responsibility is assumed for possible omissions or inaccuracies. Circuitry and specifications are subject to change without notice. For the latest product specifications, refer to the Supertex website: http://www.supertex.com. For complete liability information on all Supertex products, refer to the most current databook or to the Legal/Disclaimer page on the Supertex website.

Thermal Characteristics

Package	I_D (continuous)*	I_D (pulsed)	Power Dissipation @ $T_A = 25°C$	θ_{jc} °C/W	θ_{ja} °C/W	I_{DR}*	I_{DRM}
SOT-23	-120mA	-400mA	0.36W	200	350	-120mA	-400mA

* I_D (continuous) is limited by max rated T_j.

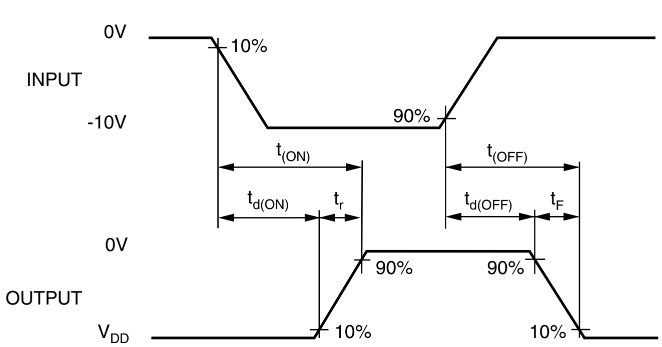
Electrical Characteristics (@ 25°C unless otherwise specified)

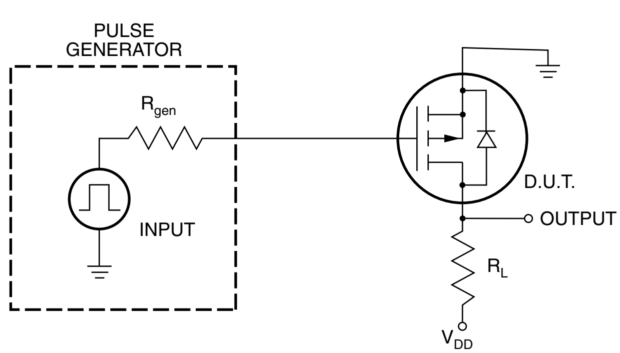
Symbol	Parameter	Min	Typ	Max	Unit	Conditions
BV_{DSS}	Drain-to-Source Breakdown Voltage	-60			V	$V_{GS} = 0V$, $I_D = -10\mu A$
$V_{GS(th)}$	Gate Threshold Voltage	-1.0		-2.4	V	$V_{GS} = V_{DS}$, $I_D = -1.0mA$
$\Delta V_{GS(th)}$	Change in $V_{GS(th)}$ with Temperature			6.5	mV/°C	$V_{GS} = V_{DS,}$ $I_D = -1.0mA$
I_{GSS}	Gate Body Leakage			±10	nA	$V_{GS} = \pm 20V$, $V_{DS} = 0V$
I_{DSS}	Zero Gate Voltage Drain Current			-1	µA	$V_{GS} = 0V$, V_{DS} = Max Rating
				-200	µA	$V_{GS} = 0V$, V_{DS} = 0.8 Max Rating $T_A = 125°C$
$I_{D(ON)}$	ON-State Drain Current	-50			mA	$V_{GS} = -4.5V$, $V_{DS} = -10V$
$R_{DS(ON)}$	Static Drain-to-Source ON-State Resistance			25	Ω	$V_{GS} = -4.5V$, $I_D = -25mA$
				10	Ω	$V_{GS} = -10V$, $I_D = -0.2A$
$\Delta R_{DS(ON)}$	Change in $R_{DS(ON)}$ with Temperature			1.0	%/°C	$V_{GS} = -10V$, $I_D = -0.2A$
G_{FS}	Forward Transconductance	60			m℧	$V_{DS} = -10V$, $I_D = -0.1A$
C_{ISS}	Input Capacitance			60	pF	$V_{GS} = 0V$, $V_{DS} = -25V$ f = 1 MHz
C_{OSS}	Common Source Output Capacitance			30		
C_{RSS}	Reverse Transfer Capacitance			10		
$t_{d(ON)}$	Turn-ON Delay Time			10	ns	$V_{DD} = -25V$ $I_D = -0.18A$ $R_{GEN} = 25\Omega$
t_r	Rise Time			15		
$t_{d(OFF)}$	Turn-OFF Delay Time			15		
t_f	Fall Time			20		
V_{SD}	Diode Forward Voltage Drop			-2.0	V	$V_{GS} = 0V$, $I_{SD} = -0.12A$
t_{rr}	Reverse Recovery Time		400		ns	$V_{GS} = 0V$, $I_{SD} = -0.4A$

Notes:

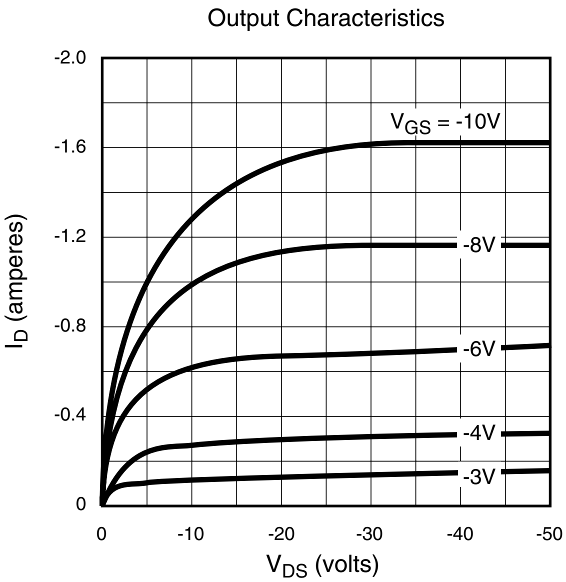
1. All D.C. parameters 100% tested at 25°C unless otherwise stated. (Pulse test: 300µs pulse, 2% duty cycle.)
2. All A.C. parameters sample tested.

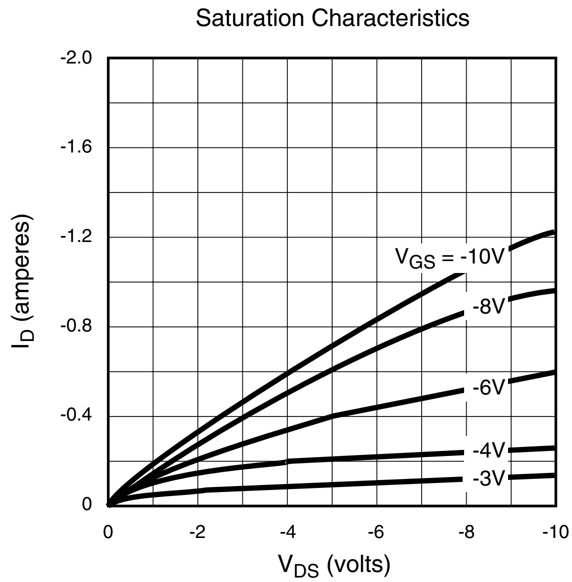
Switching Waveforms and Test Circuit

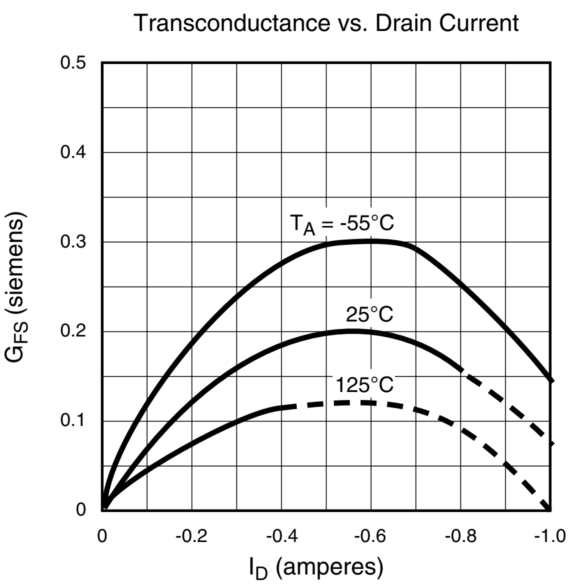


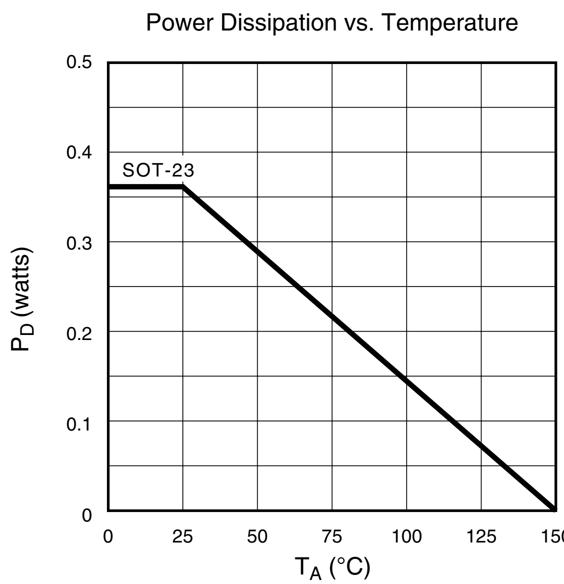


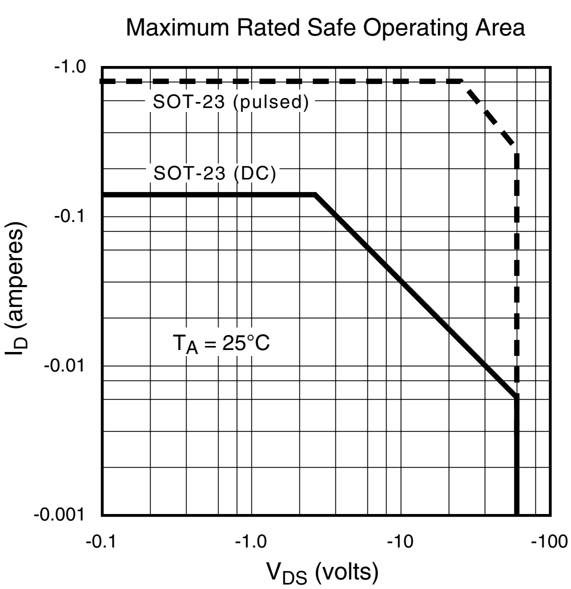
Typical Performance Curves

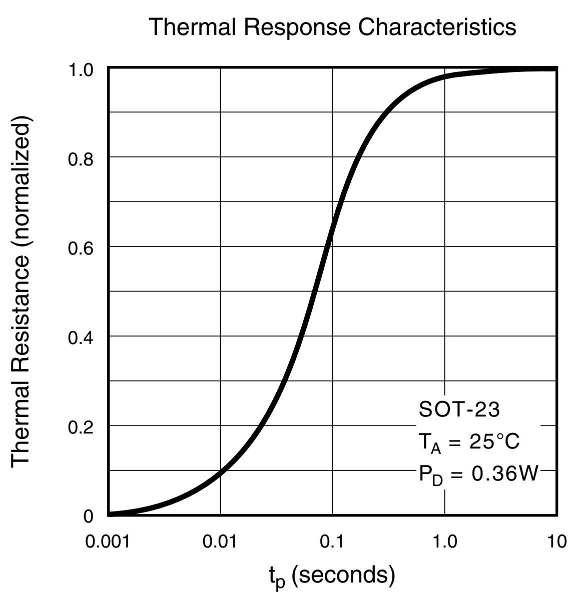




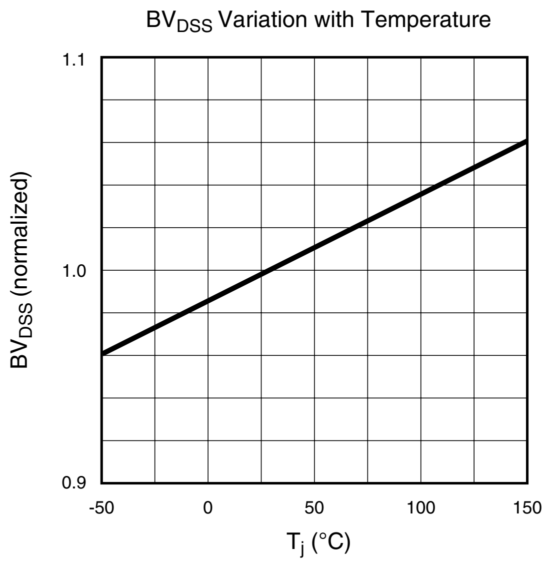


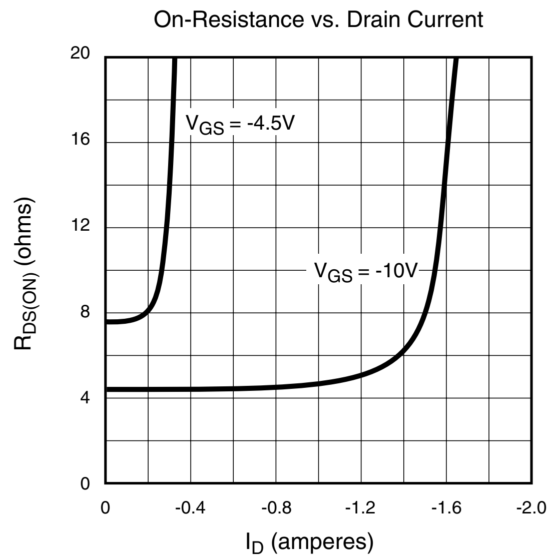


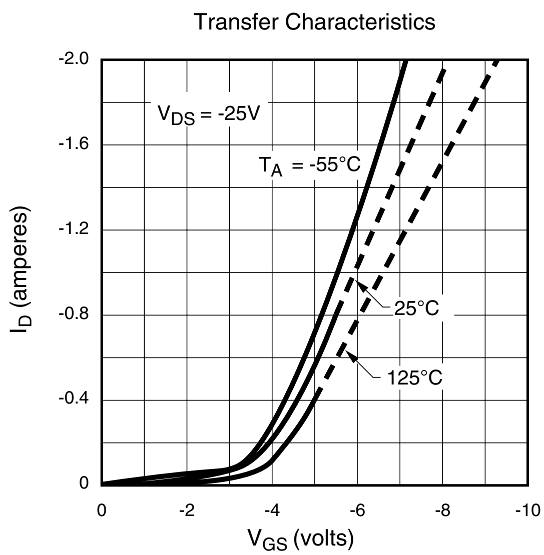


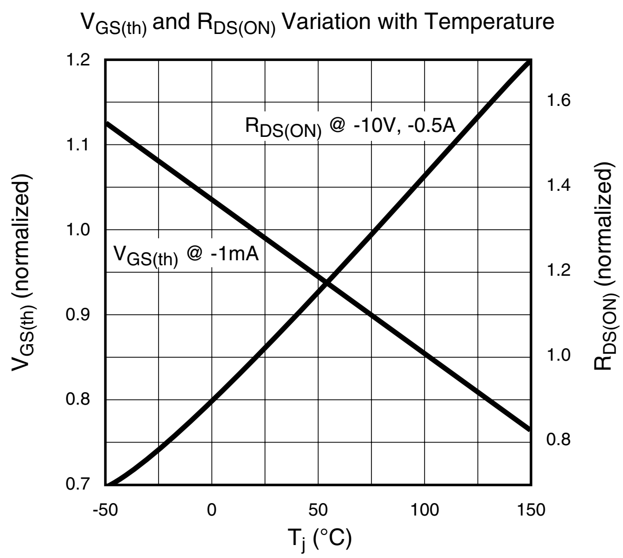


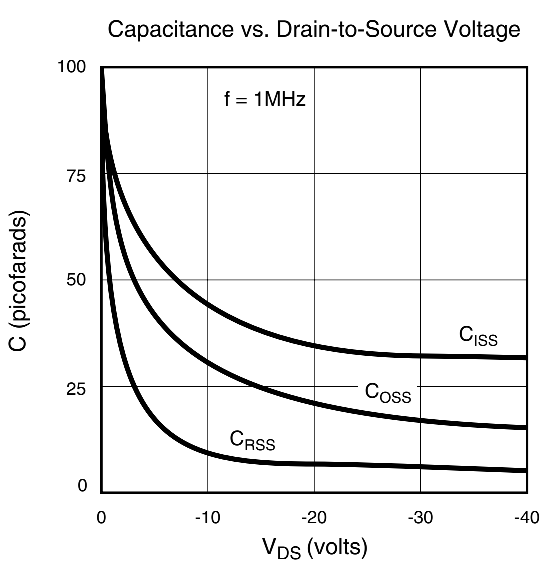
Typical Performance Curves

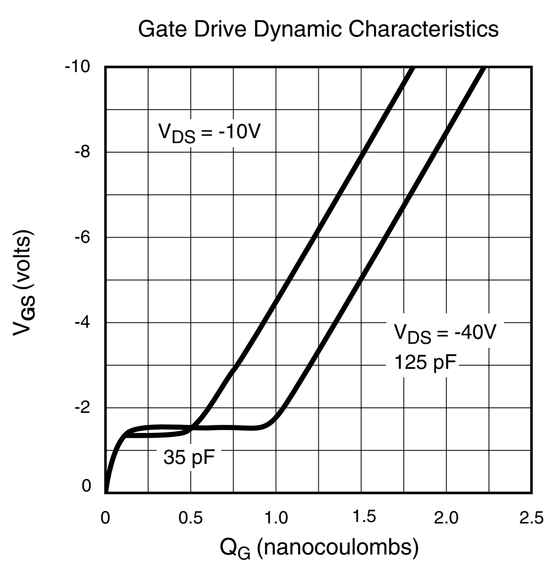












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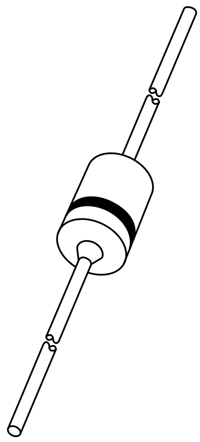
DISCRETE SEMICONDUCTORS

DATA SHEET



1N4148; 1N4448
High-speed diodes

Product data sheet
Supersedes data of 2002 Jan 23

2004 Aug 10

founded by Philips

FEATURES

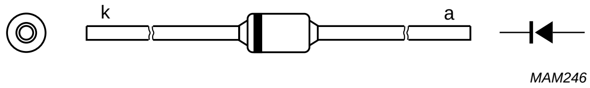
- Hermetically sealed leaded glass SOD27 (DO-35) package
- High switching speed: max. 4 ns
- General application
- Continuous reverse voltage: max. 100 V
- Repetitive peak reverse voltage: max. 100 V
- Repetitive peak forward current: max. 450 mA.

APPLICATIONS

- High-speed switching.

DESCRIPTION

The 1N4148 and 1N4448 are high-speed switching diodes fabricated in planar technology, and encapsulated in hermetically sealed leaded glass SOD27 (DO-35) packages.



The diodes are type branded.

Fig.1 Simplified outline (SOD27; DO-35) and symbol.

MARKING

TYPE NUMBER	MARKING CODE
1N4148	1N4148PH or 4148PH
1N4448	1N4448

ORDERING INFORMATION

TYPE NUMBER	PACKAGE		
	NAME	DESCRIPTION	VERSION
1N4148	–	hermetically sealed glass package; axial leaded; 2 leads	SOD27
1N4448			

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 60134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{RRM}	repetitive peak reverse voltage		–	100	V
V_R	continuous reverse voltage		–	100	V
I_F	continuous forward current	see Fig.2; note 1	–	200	mA
I_{FRM}	repetitive peak forward current		–	450	mA
I_{FSM}	non-repetitive peak forward current	square wave; T_j = 25 °C prior to surge; see Fig.4			
		t = 1 μs	–	4	A
		t = 1 ms	–	1	A
		t = 1 s	–	0.5	A
P_{tot}	total power dissipation	T_{amb} = 25 °C; note 1	–	500	mW
T_{stg}	storage temperature		–65	+200	°C
T_j	junction temperature		–	200	°C

Note

1. Device mounted on an FR4 printed-circuit board; lead length 10 mm.

ELECTRICAL CHARACTERISTICS

T_j = 25 °C unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_F	forward voltage	see Fig.3			
	1N4148	I_F = 10 mA	–	1	V
	1N4448	I_F = 5 mA	0.62	0.72	V
		I_F = 100 mA	–	1	V
I_R	reverse current	V_R = 20 V; see Fig.5		25	nA
		V_R = 20 V; T_j = 150 °C; see Fig.5	–	50	μA
I_R	reverse current; 1N4448	V_R = 20 V; T_j = 100 °C; see Fig.5	–	3	μA
C_d	diode capacitance	f = 1 MHz; V_R = 0 V; see Fig.6	–	4	pF
t_{rr}	reverse recovery time	when switched from I_F = 10 mA to I_R = 60 mA; R_L = 100 Ω; measured at I_R = 1 mA; see Fig.7	–	4	ns
V_{fr}	forward recovery voltage	when switched from I_F = 50 mA; t_r = 20 ns; see Fig.8	–	2.5	V

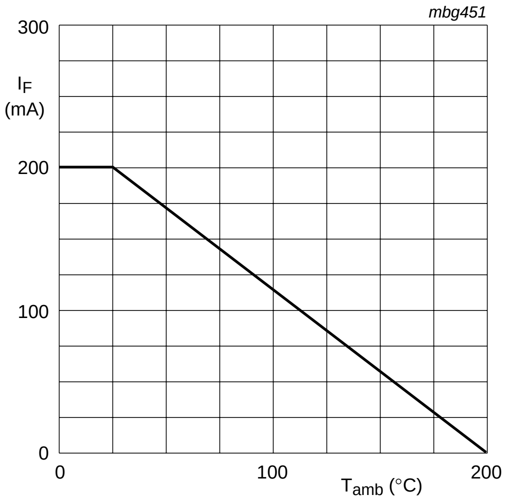
THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th(j\text{-}tp)}$	thermal resistance from junction to tie-point	lead length 10 mm	240	K/W
$R_{th(j\text{-}a)}$	thermal resistance from junction to ambient	lead length 10 mm; note 1	350	K/W

Note

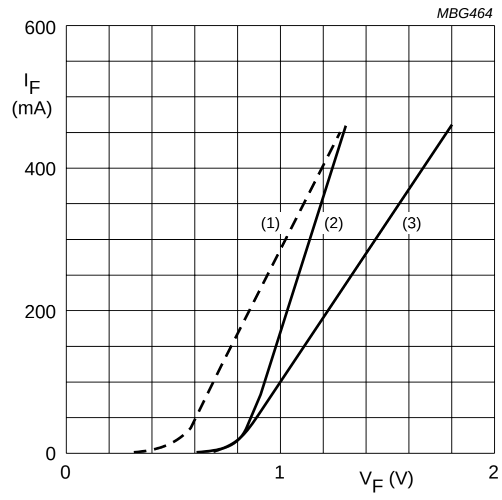
1. Device mounted on a printed-circuit board without metallization pad.

GRAPHICAL DATA



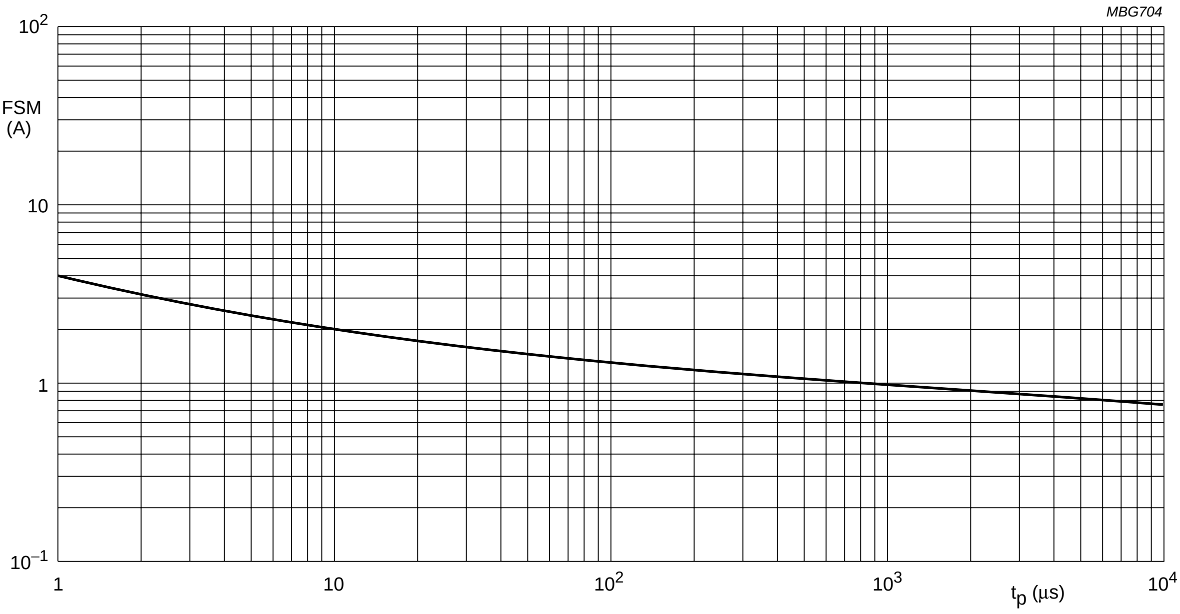
Device mounted on an FR4 printed-circuit board; lead length 10 mm.

Fig.2 Maximum permissible continuous forward current as a function of ambient temperature.



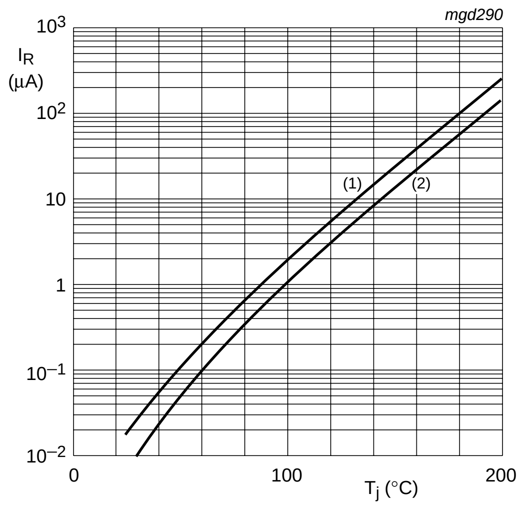
(1) T_j = 175 °C; typical values.
(2) T_j = 25 °C; typical values.
(3) T_j = 25 °C; maximum values.

Fig.3 Forward current as a function of forward voltage.



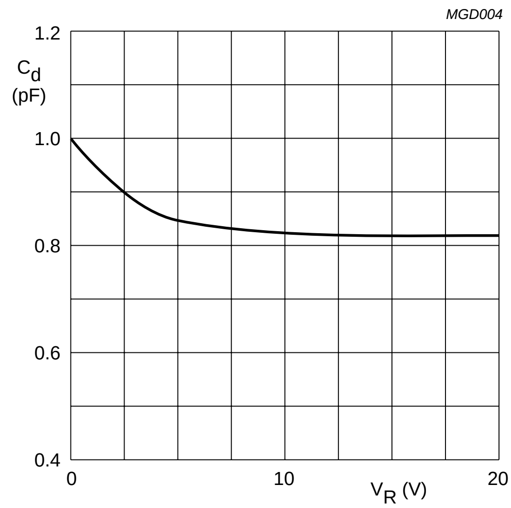
Based on square wave currents.
T_j = 25 °C prior to surge.

Fig.4 Maximum permissible non-repetitive peak forward current as a function of pulse duration.



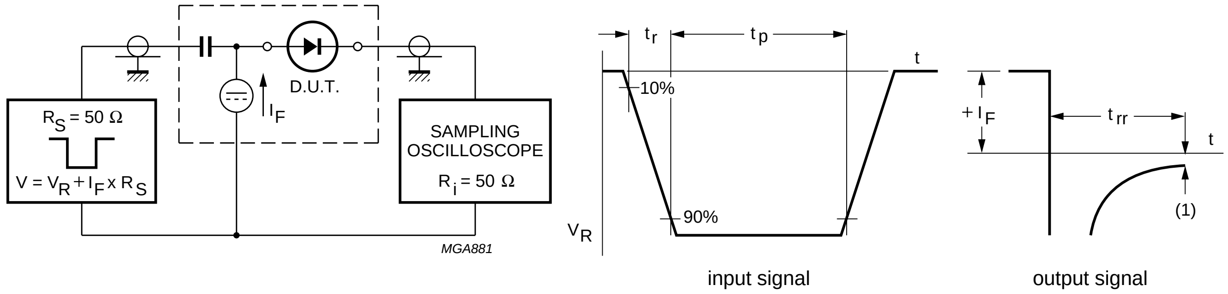
(1) V_R = 75 V; typical values.
(2) V_R = 20 V; typical values.

Fig.5 Reverse current as a function of junction temperature.



f = 1 MHz; T_j = 25 °C.

Fig.6 Diode capacitance as a function of reverse voltage; typical values.



(1) I_R = 1 mA.

Fig.7 Reverse recovery voltage test circuit and waveforms.

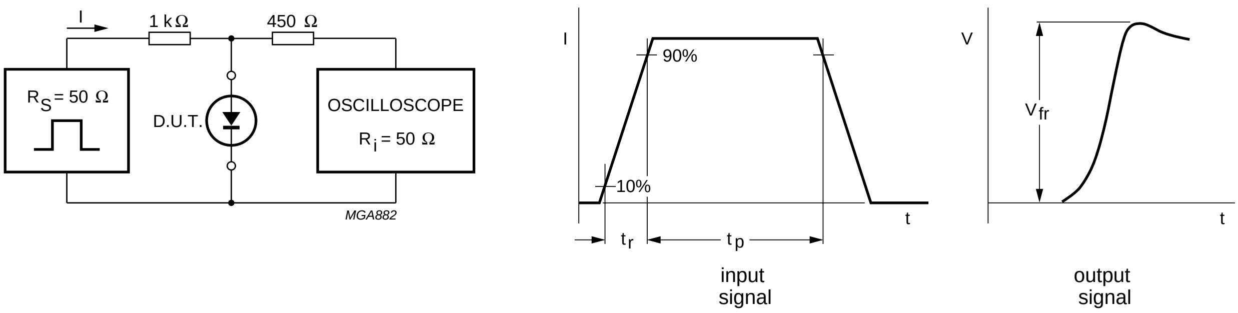
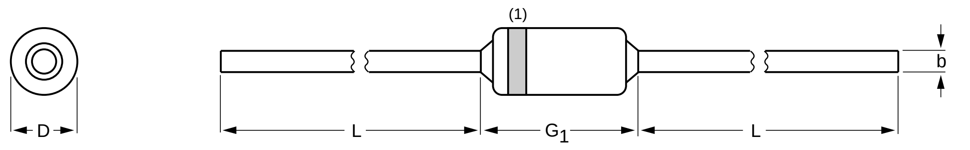


Fig.8 Forward recovery voltage test circuit and waveforms.

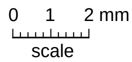
PACKAGE OUTLINE

Hermetically sealed glass package; axial leaded; 2 leads **SOD27**



DIMENSIONS (mm are the original dimensions)

UNIT	b max.	D max.	G_1 max.	L min.
mm	0.56	1.85	4.25	25.4



Note

1. The marking band indicates the cathode.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOD27	A24	DO-35	SC-40			~~97-06-09~~ 05-12-22

DATA SHEET STATUS

DOCUMENT STATUS[1]	PRODUCT STATUS[2]	DEFINITION
Objective data sheet	Development	This document contains data from the objective specification for product development.
Preliminary data sheet	Qualification	This document contains data from the preliminary specification.
Product data sheet	Production	This document contains the product specification.

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