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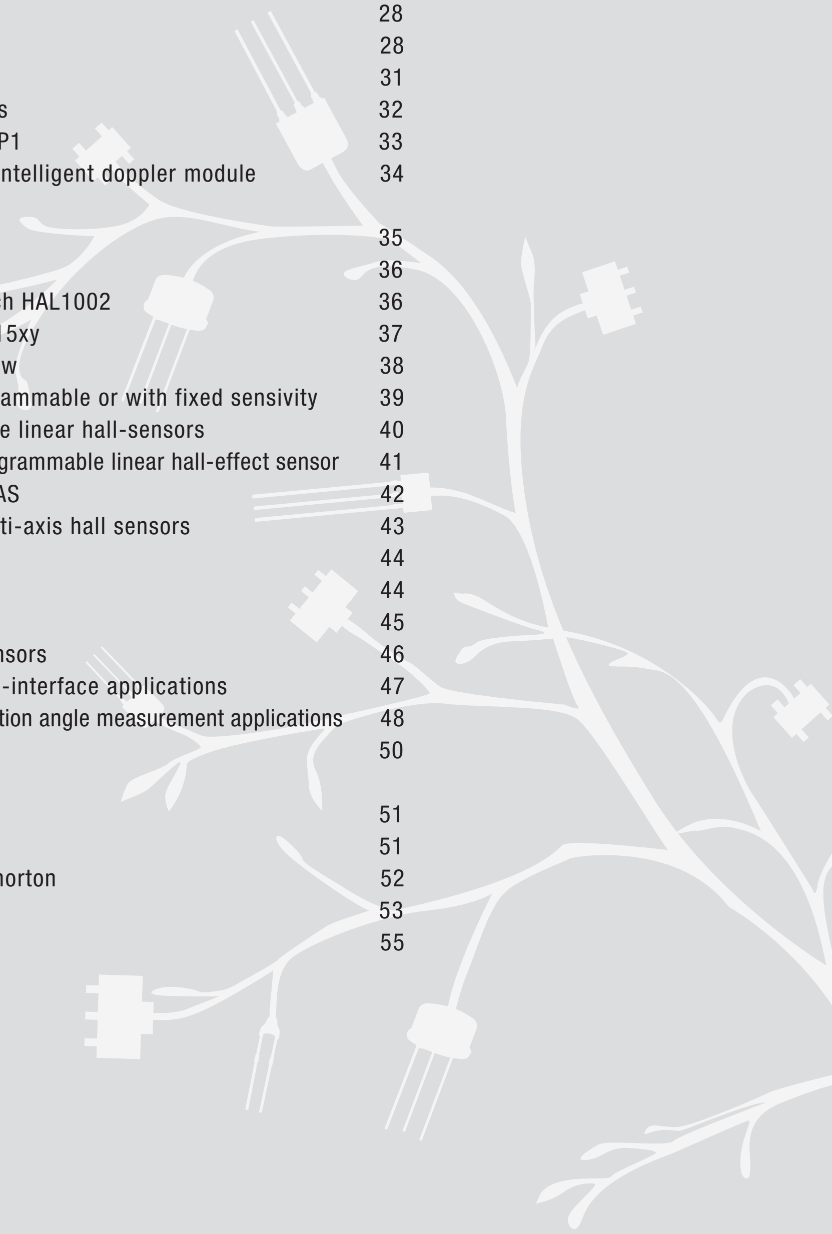


NTC (Negative Temperature Coefficient) thermistors are resistors which show a decrease in resistance as temperature increases, available as semiconductor type or thick film type. The benefits of NTCs based on semiconducting ceramics are high precision whereas thick film types are more cost-efficient. The current flowing through a thermistor may cause some heat which increases the thermistor's temperature above the temperature of the environment. For small currents this effect of self-heating is negligible (unloaded thermistor). We will describe only unloaded NTC thermistors in this application note.

Temperature dependence of the resistance

The resistance of an NTC as a function of temperature can be approximated by the following equation:

$$R(T_1) = R(T_2) \exp \left(B \left(1/T_1 - 1/T_2 \right) \right) \qquad (1)$$

$R(T_1)$: resistance in unit Ω at temperature T_1 in unit K
$R(T_2)$: resistance in unit Ω at temperature T_2 in unit K
B: B-value, material-specific constant of the NTC

This exponential law only roughly describes the characteristics of an NTC. This formula is suitable for describing the resistance in a small range around the temperature T_2 (see Fig.1). If a more precise formula is needed, the STEINHART-HART equation provides a more accurate description of the behaviour of the NTC. The parameters used in this equation (STEINHART-HART-coefficients) are dependent on the material of the NTC and are available on request.

B-value

The B value is dependent on the NTC technology and the materials used. It describes the slope of the R/T curve in a ln R-T diagram. The B value can be calculated by using two points of the R-T curve $R(T_1)$ and $R(T_2)$, i. e.:

$$B = T_1 \cdot T_2 / (T_1 - T_2) \cdot \ln \left(R(T_2)/R(T_1) \right)$$

The B-values of this catalogue are calculated based on temperatures 25 °C (T_1) and 85 °C (T_2).

Dissipation factor δ_{th}

The dissipation factor δ_{th} is defined as the ratio of the electrical power dissipated in the NTC and the resulting change of the thermistor´s temperature. It is expressed in mW/K and is a measure for the load which causes a thermistor in steady state to raise its body temperature by 1 K. $\delta_{th} = dP/dT$

Tolerance

The resistance R_{25}- and the B-value are subject to manufacturing tolerances. Due to those tolerances of the B and R_{25}-value, the resistance of a NTC varies within a certain tolerance area above and below the theoretical curve. The tolerance in resistance of the NTC thermistor is specified for one temperature point (usually 25°C). Using those tolerance values the temperature accuracy of the NTC can be calculated, i. e. the maximum error of temperature measurement at a given temperature.

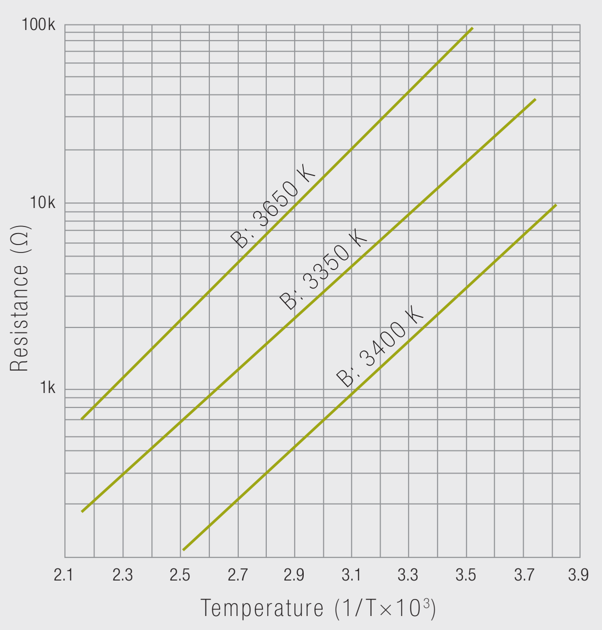
Zero-power measurement

The zero-power resistance is the resistance value measured at a given temperature with the electrical load kept so small that there is no noticeable change in the resistance value if the load is further decreased. If the electrical load is increased the self-heating will distort the measuring result.

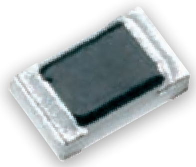
Thermal time constant

In most cases the NTC has to measure the temperature of the surrounding air or the temperature of an object, which has to be in thermal contact with the NTC. If the temperature of the air or the object changes, the NTC has to adopt the new temperature which does not happen instantaneously but needs some time. The so called thermal time constant refers to the time it takes for an unloaded thermistor to raise its temperature from 25 °C ... 62.9 °C when it is immersed in a medium having a temperature of 85 °C.

Fig. 1 - Characteristic resistance curve of NTC



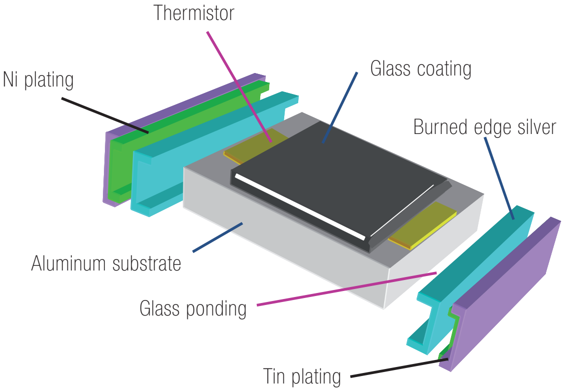
1.1 SMD-THERMISTORS



Thick film chip thermistors offer high mechanical strength and reliability due to the thermistor film and glass-coated structure on an aluminium substrate. The thickness is fixed and not related to the resistance value. High solderability and heat resistance are available due to triple structure electrodes. The thermistor element material, based on Mn, Co and Ni, is produced in-house. This core material technology allows to adjust the thermistor features.
The thermistors are TS 16949 and AECQ-200 certified.

Specifications of TFT series

PART NUMBER	RESISTANCE VALUE R_{25} [Ω]	TOLERANCE R_{25} [%]	B-VALUE (25/85) [K]	TOLERANCE B-VALUE [%]	DISSIPATION FACTOR [mW/°C]	THERMAL TIME CONSTANT [s]	MAX. POWER DISSIPATION [mW]	TEMPERATURE RANGE [°C]
TFT6G	100 … 2 M	±1 … ±10	2700 … 4900	±1 … ±5	1.3	2.5	5	-40 … +150
TFT3G				±1 … ±5	1.2	2.0	5	
TFT16G				±1 … ±5	1.1	1.5	5	
TFT20G				±3, ±5	1.1	1.5	5	



Applications

- Heat cost allocators
- Automotive (climate control, air conditioning, etc.)
- Blood sugar measurement
- White goods
- Medical

PART NUMBER	SMD SIZE (INCH)	QUANTITY PER REEL
TFT 6G	0805	5,000 pcs.
TFT 3G	0603	5,000 pcs.
TFT 16G	0402	10,000 pcs.
TFT 20G	0201	15,000 pcs.

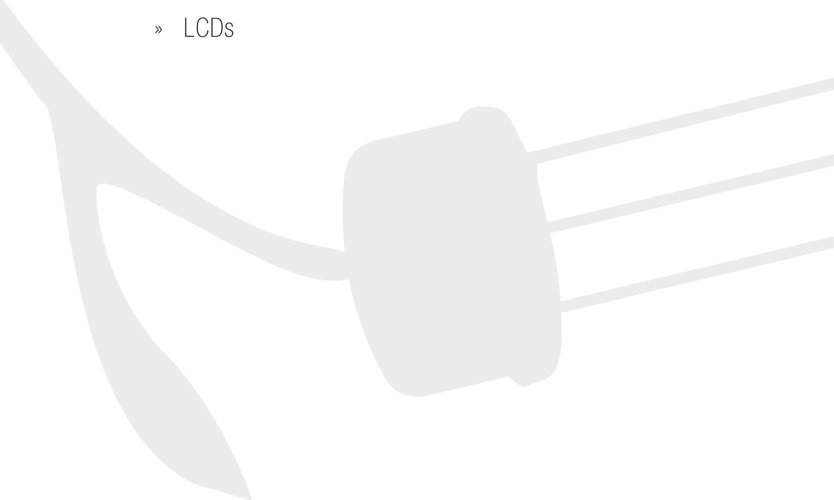
1.2 THIN FILM CHIP THERMISTOR

Features:

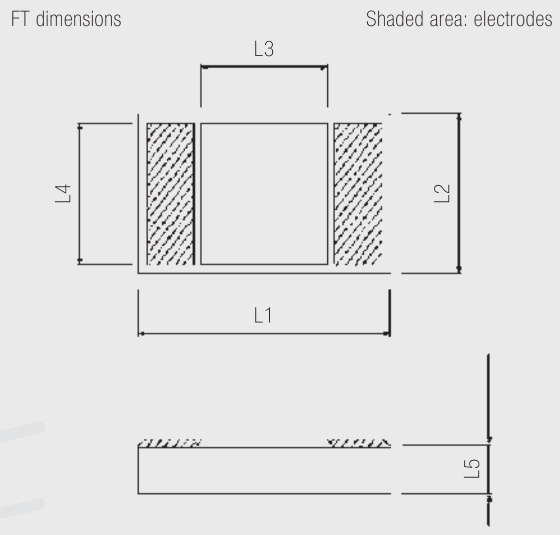
- High heat resistance
- Extremely quick response time
- Miniature size (0603)
- World-first development of this type of thermistor

Example applications:

- Medical devices
- Wearable devices
- Laser diodes
- Measurement instruments
- LCDs



Dimensional Drawing:



(Unit: mm)

Size	L1	L2	L3	L4	L5
1005	1.00±0.05	0.50±0.05	(0.50)	(0.44)	(0.15)
0603	0.60±0.05	0.30±0.05	(0.15)	(0.25)	(0.15)

Electrical specification and product numbers

PRODUCT NUMBER	R25 VALUE (KΩ) + TOLERANCE	B25/85 VALUE (K) + TOLERANCE	DISSIPATION FACTOR (mW/°C)	THERMAL FACTOR CONSTANT t(S)	MAXIMUM DISSIPATION AT 25°C	TEMPERATURE RANGE (°C)
103FT1005A5P	10 ± 5%[1]	3370 ± 1%	0,3	1	1,5	Au/Ni electrode (solder): -40 to 125 Au electrode (wire bonding): -40 to 250 Pt electrode (conductive resin): -40 to 250 (350)
103FT1005B5P	10 ± 5%[1]	3435 ± 1%				
103FT1005D5P	10 ± 5%[1]	3969 ± 1%				
503FT1005A5P	50 ± 5%[1]	3370 ± 1%				
503FT1005B5P	50 ± 5%[1]	3435 ± 1%				
364FT1005A5P	360 ± 5%[1]	3370 ± 1%				
364FT0603A5P	360 ± 5%[1]	3370 ± 1%	0,2	0,5	1	

[1] Other tolerance values available on demand.

1.3 F-MICRO THERMISTORS

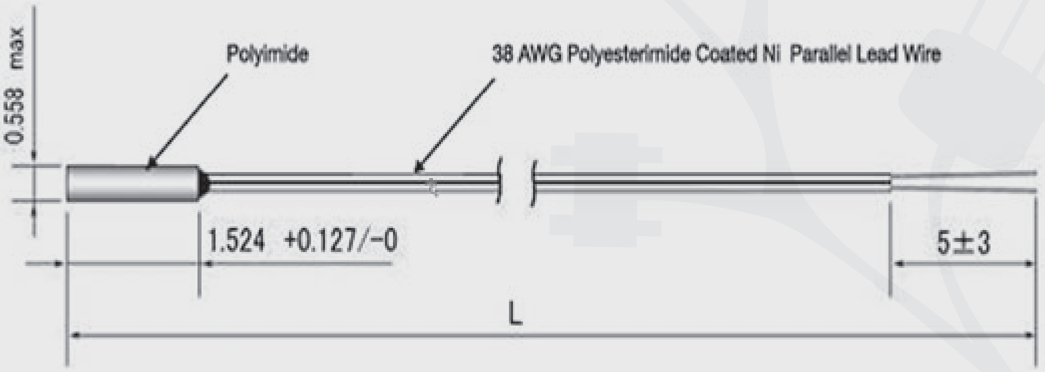
Features:

- High mechanical strength and reliability
- Extremely fast response time
- Excellent accuracy
- Miniature size (min. ø 0.3 mm)
- Special development using SEMITEC's FT thermistor

Example applications:

- Catheters
- Other medical devices

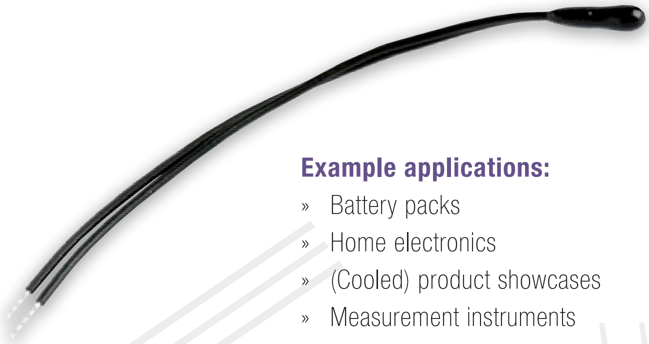
Dimensional Drawing (Ø 0.5 mm):



Electrical specification for 223F µ 5183

PARAMETER	VALUE	UNIT
Resistance at 37°C	14,054	kΩ
Tolerance on R37 value	±0.5 (0.14°C at 37°C)	%
B25/85 value	3454	K
Tolerance on B25/85 value	±1	%
Maximum dissipation at 25°C	1,75	mV
Dissipation factor	0,35	mW/°C
Thermal time constant t	52	ms
Operating temperature range	-10 … 70	°C

1.4 HIGH ACCURACY THERMISTORS



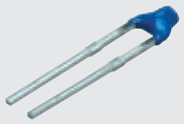
Example applications:

- Battery packs
- Home electronics
- (Cooled) product showcases
- Measurement instruments
- Automotive applications

Features:

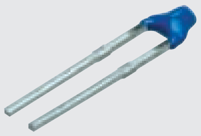
- High accuracy
- Long term reliability
- Ideal for automatic assembly (AT-5)
- Created world standard specification (10 kΩ, 3435K)
- Special development using SEMITEC's FT thermistor

Specifications of AT series

SHAPE	PART NUMBER	RESISTANCE VALUE R_{25} [kΩ]	TOLERANCE OF R_{25} [%]	B-VALUE (25/85) [K]	TOLERANCE OF B-VALUE [%]	TEMPERATURE RANGE (°C)
	102AT-2	1.00	±1	3100	±1	-50 to +90
	202AT-2	2.00	±1	3182	±1	
	502AT-2	5.00	±1	3324	±1	-50 to +110
	103AT-2	10.0	±1	3435	±1	
	203AT-2	20.0	±1	4013	±1	
	102AT-11	1.00	±1	3100	±1	-50 to +90
	202AT-11	2.00	±1	3182	±1	
	502AT-11	5.00	±1	3324	±1	-50 to +110
	103AT-11	10.0	±1	3435	±1	
	203AT-11	10.0	±1	3435	±1	
	103AT-4 Shape 1	10.0	±1	4013	±1	-30 to +90
	682AT-4	6.8	±1	3975	±1	
	103AT-4 Shape 2	10.0	±1	3435	±1	-30 to +90
	682AT-4	6.8	±1	3975	±1	
	103AT-5	10.0	±1	3435	±1	-50 to +110

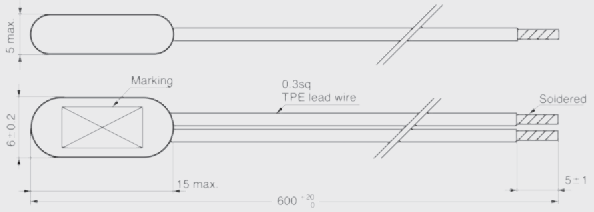
HIGH ACCURACY THERMISTORS

Specifications of AP series

SHAPE	PART NUMBER	RESISTANCE VALUE R_{25} [kΩ]	TOLERANCE OF R_{25} [%]	B-VALUE (25/85) [K]	TOLERANCE OF B-VALUE [%]	TEMPERATURE RANGE (°C)
	202AP-2	2.000	±0.5	3976	±0.5	-60 to +150
	232AP-2	2.252	±0.5	3976	±0.5	
	502AP-2	5.000	±0.5	3976	±0.5	
	103AP-2	10.00	±0.5	3435	±0.5	
	103AP-2-A	10.00	±0.5	3976	±0.5	
	203AP-2	20.00	±0.5	3976	±0.5	
	503AP-2	50.00	±0.5	4220	±0.5	
	104AP-2	100.00	±0.5	4261	±0.5	
	204AP-2	200.00	±0.5	4470	±0.5	

Dimensions (mm)

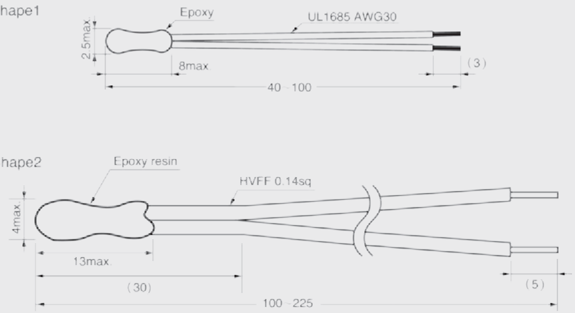
AT-11



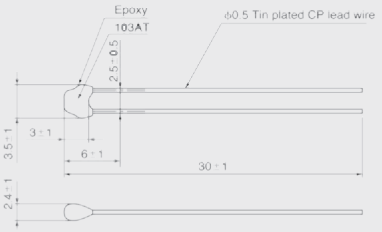
AT-4

Shape1

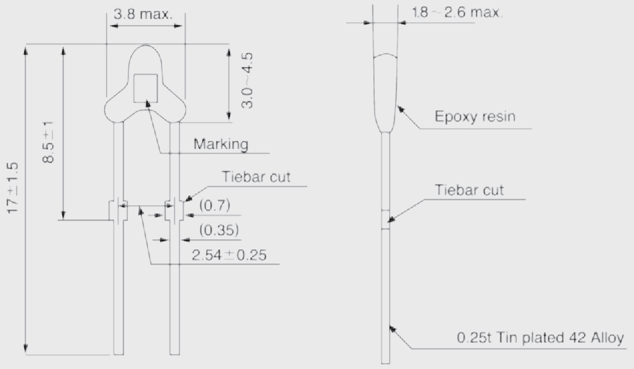
Shape2



AT-5



AP



1.5 EPOXY COATED INTERCHANGEABLE THERMISTORS

The TT-3 series NTC thermistors are small size epoxy coated sensing devices. Wide range of RT characteristics, tolerances and wire configurations makes them an ideal choice for temperature sensing, control and compensation.
Very tight resistance tolerance up to +/-0.05°C makes them one of the highest precision NTC thermistor available on the market.

Example applications:

- HVAC
- Ambient temperature sensing
- control and compensation
- Liquid or gas temperature control and monitoring
- Assembly into probes, automotive (air conditioning, cabin climate management, heated seats, other), industrial applications, white goods.

Specifications of TT-3:

PRODUCT NUMBER	RESISTANCE VALUES R25	RESISTANCE TOLERANCE	B-VALUE (25/85) K	WIRES/CABLES	DIAMETER	TEMPERATURE RANGE (°C)
TT3	100 Ohm ... 1 MOhm	±0.05°C ±0.1°C ±0.2°C	3348 ... 4261	AWG28 to AWG36 with/without Teflon insulation	1.2 mm ... 5 mm	-40 ... +150

1.6 FILM TYPE THERMISTORS

JT thermistors feature an ultra thinness of 500 µm and a superior electrical insulation. The usage in battery packs and heat allocators is possible.

Specifications of JT series

PART NUMBER, XXX = SHAPE	RESISTANCE VALUE R_{25} [kΩ]	B-VALUE (25/85) [K]	DISSIPATION FACTOR [mW/°C]	THERMAL TIME CONSTANT [s]	TEMPERATURE RANGE [°C]
103JT-XXX	10 ± 1 %	3435 ± 1 %	0.7	5	-50 to +90
104JT-XXX	100 ± 1 %	4390 ± 1 %	0.7	5	-50 to +125
103JT-W	10 ± 1 %	3435 ± 1 %	1,4	3,4	-50 to +125

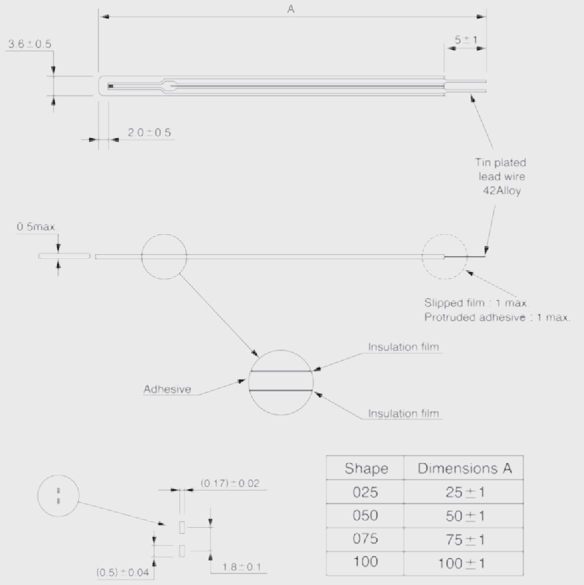
Features:

- Tight tolerance for B value and resistance (±1%)
- Ultra thin (>50 µm)
- Perfect for tight spaces
- Excellent electrical insulation
- World-first development of this type of thermistor

Example applications:

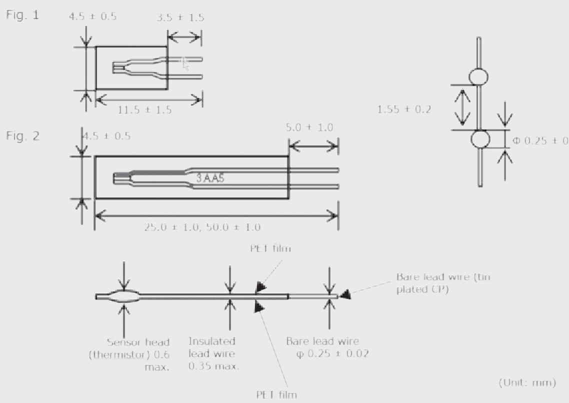
- Battery packs
- IT and mobile devices
- Surface temperature sensors
- Fast response air temperature sensors

Dimensions (mm)



Shape	Dimensions A
025	25±1
050	50±1
075	75±1
100	100±1

JT-W thermistor



1.7 GLASS ENCAPSULATED THERMISTORS

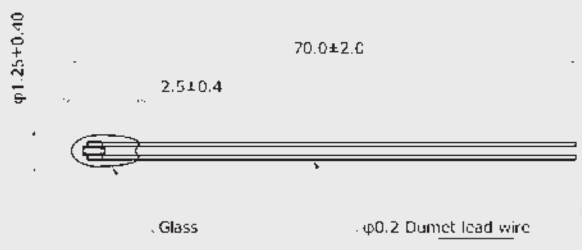
Features:

- High heat resistance
- High sensitivity
- Small size
- Fast response time
- Highly reliable for long-term use

Example applications:

- Automotive electronics
- HVAC equipment
- Water heaters
- Home appliances
- 3D printer

Dimensional drawing:



Electrical specification and product numbers

PRODUCT NUMBER	TEMPERATURE (°C)	RESISTANCE (Ω)	TOLERANCE	TEMPERATURE	TEMPERATURE RANGE (°C)	TEMPERATURE RANGE (°C)	TEMPERATURE RANGE (°C)
502NT-4-R025H39G	25	5	±3%[1]	25/85	3964	± 2%	-50 to +300
852NT-4-R050H34G	50	3,485		0/100	3450		
103NT-4-R025H34G	25	10		25/85	3435		
103NT-4-R025H41G	25	10		25/85	4126		
203NT-4-R025H42G	25	20		25/85	4282		
493NT-4-R100H40G	100	3,3		0/100	3970		
503NT-4-R025H42G	25	50		25/85	4288		
104NT-4-R025H42G	25	100		25/85	4267		
104NT-4-R025H43G	25	100		25/85	4390		
204NT-4-R025H43G	25	200		25/85	4338		
234NT-4-R025H42G	200	1		100/200	4537		
504NT-4-R025H45G	25	500		25/85	4526		
105NT-4-R025H46G	25	1000		25/85	4608		

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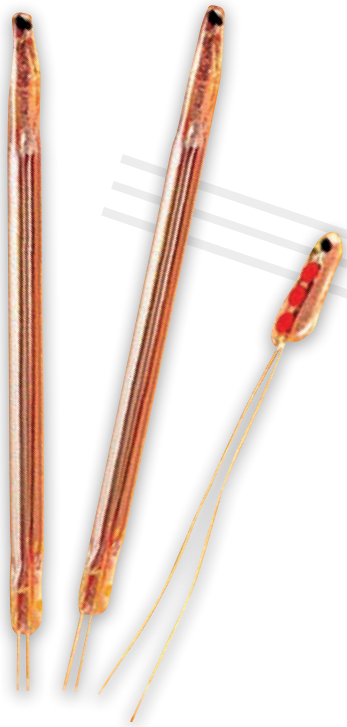
[1] Other tolerance values available on demand.

1.8 GLASS ENCAPSULATED NTC THERMISTORS

The TT-2 series NTC thermistors are glass encapsulated sensing devices with standard electrical characteristics. Custom electrical characteristics can be produced in this configuration too.
The glass encapsulation provides excellent stability and durability in an established product style. TT-2 series thermistors are available with dumet wire with or without polyimide tubes for insulation.



Example applications:

» HVAC
» White goods
» Industrial
» Medical

Specifications of TT-2:

PART NUMBER	RESISTANCE VALUES R25	RESISTANCE TOLERANCE	B-VALUE (25/85) K	WIRES/CABLES	DIAMETER	TEMPERATURE RANGE (°C)
TT2	1 KOhm ... 1.4 MOhm	±1% ... ± 20%	2700 ... 4535	bare dumet wire or with polyimide insulation	0.75 mm ... 3.0 mm	-50 ... +500

1.9 WATERPROOF TEMPERATURE SENSORS

TT-O series sensors are IP68 waterproof temperature probes encapsulated with thermoplastic elastomer materials in overmoulding technology. Excellent performance in extreme freeze-thaw conditions resulting from a wide choice of insulation material.
The TT-O overmoulded probes are a perfect solution for applications where the best waterproof and moisture protection is required.

Example applications:

- Refrigeration applications (evaporator)
- Air conditioning
- Underfloor heating
- Climat control systems
- Industrial process control

Specifications of TT-O:

PART NUMBER	MEASUREMENT ELEMENT	RESISTANCE TOLERANCE	B-VALUE (25/85) K	WIRES/CABLES	DIAMETER	TEMPERATURE RANGE (°C)
TTO	NTC, PTC, PtRTD, KTY	±0.5% ... ±5%	3325 ... 4750	TPE single & double insulated	3.9 mm, 5.0 mm, 6.5 mm	-50 ... +105

1.10 CUSTOMIZED TEMPERATURE SENSORS

Company Tewa Temperature Sensors offers a wide range of standard and customized temperature sensors designed according to individual customer's requirements covering applications in temperature range between -80°C and +800°C.

TT-4 series group contains temperature sensors using NTC/PTC thermistors, PTRTDs and other sensing elements mounted into a wide range of metal/plastic housings.

Features:

- Proven stability and reliability
- Low cost
- Variety of metal plastic housings and tubings designed for specific applications
- Potted with different kinds of resin for reliable sensor protection
- Available with special cables (2-core cables or stranded with PVC, teflon or kynar insulation, cables with screen & other), connectors and other attachments
- Provides good protection against the environmental conditions
- Proven high voltage and dynamic strength
- Wide range of resistance and temperature characteristics
- Designed for temperature measurement, temperature control and temperature compensation

Example applications:

- Automotive
- Consumer products
- Instrumentation industrial ovens
- Electric showers
- HVAC and refrigeration
- Fire detectors

Specifications of TT-4:

PART NUMBER	MEASUREMENT ELEMENT	RESISTANCE TOLERANCE	B-VALUE (25/85) K	WIRES/CABLES	DIAMETER	TEMPERATURE RANGE (°C)
TT4	NTC, PTC, PtRTD, KTY, DS1820	±0.25% ... ±5%	2700 ... 5100	PVC, Silicone, FEP, Fiberglass insulation, etc.	>1.25 mm	-80 ... 800

1.11 AUTOMOTIVE TEMPERATURE SENSORS


ECU unit

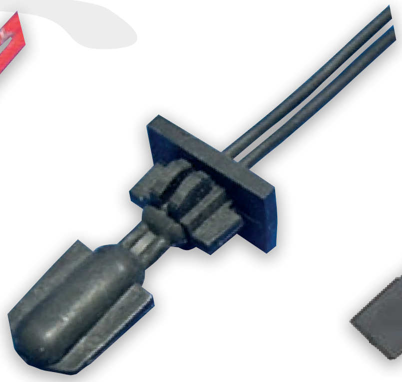

DC/DC converter


Inverter unit


Motor housing


Motor coil


HEV battery


Lead battery


HEV battery

Features:

- Extensive use in all global automotive brands
- Dozens of custom assemblies for battery and EV motor applications
- High market share for Japanese hybrid car batteries
- Competitive pricing especially for integrated design assemblies (sensor part + resin mold)

Example applications:

- EV batteries
- Electric motors
- Air conditioners
- Capacitors
- And more

Optical sensors detect electromagnetic radiation with wavelengths between 0.2 µm (ultraviolet) and several 10 µm (far infrared). Two different classes of optical sensor applications have to be distinguished.

In the first group of applications the light source is given by external sources of the application, e.g. the sun as a source of visible light or the human body as a source of far infrared radiation in the range of 5 µm to 10 µm. In most of these cases the purpose of the optical sensors is to measure the intensity of this electromagnetic radiation like a photometer in a photo camera. The radiation is converted into an electrical signal which is the measure of the intensity of the electromagnetic radiation. Since the different types of optical sensors only cover a certain bandwidth, the most important task for the engineer is to select a sensor with a sensitivity range that matches the spectral distribution of the given light source.

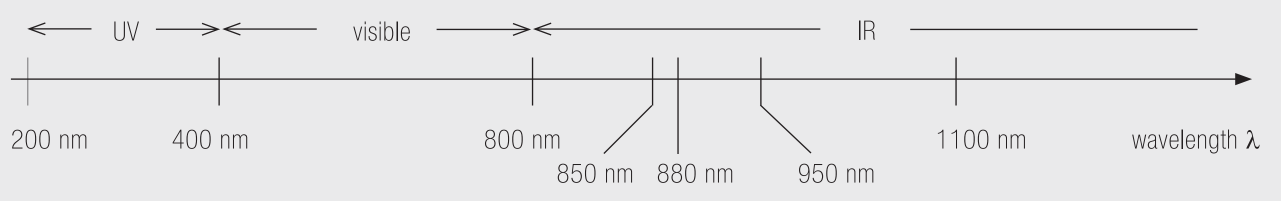
The second group are applications with an internal light source. The electromagnetic radiation is only a means to an end to detect e.g. the position, size or shape of an object. In this case the sensing system not only contains an optical sensor, but also a light source and the engineer is free in choosing the light source and the optical sensor. Very often it is convenient to choose infrared light between 800 nm and 1000 nm which is not visible for the human eye. For these wavelengths powerful LEDs as a light source are available (see table 1) and the spectral sensitivity of phototransistors and photodiodes made of silicon match perfectly to these infrared LEDs. Well-known examples are optical interrupters where the light, generated by an infrared LED, is detected by a silicon phototransistor.
Optical sensor solutions with internal light source sometimes compete with magnetic solutions (hall sensors). The advantages of magnetic solutions are that the hall sensors are not sensitive to polluted environments and fluids like oil or water. Further the output signals of digital hall sensors are TTL compatible and there is only one sensing device necessary (the hall sensor) because it is easy to generate magnetic fields by permanent magnets.

Table 1 – IRED features

Wave-length	Chip material	Output power	Speed	Price level
950 nm	GaAs	low	low	cheap
880 nm	GaAlAs	medium	high	medium
850 nm	GaAlAs	high	medium	high

On the other hand magnetic fields cannot be shielded easily which limits the downsizing of the magnetic sensor assemblies. Using light guides, optical grids and apertures, optical systems can have a very small design with a high resolution.
The sensing distance using optoelectronic solutions can easily reach some meters, while magnetic solutions only work on small distances of a few centimeters. Electromagnetic radiation like visible or infrared light can be used to detect objects of different materials like paper or wood, because the radiation is at least partially reflected by these objects. The magnetic field more or less penetrates most substances (except iron, nickel and cobalt) which makes those materials not detectable by magnetic sensor solutions.

Optical sensors – sensitivity ranges



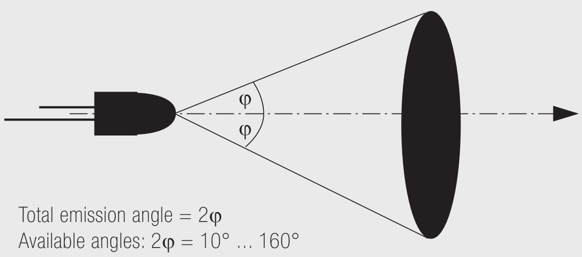
2.1 INFRARED-LED

IREDs are LEDs which emit infrared light with a wavelength in the range of 780 nm to 1550 nm. Although there is a variety of different wavelengths possible in this range, only few of them are used in standard optoelectronic sensors. The most important ones are 950nm, 880 nm and 850 nm. In some special applications like optical spectroscopy or blood oximetry special wavelengths are used. Similar to the LEDs in the visible range the material of the chip determines the wavelength.
Table 1 on page 17 gives a short summary about the different chip materials and their technical features.

There is a wide variety of different housings available for LEDs. Besides the basic elements like the semiconductor chip and the substrate to fix the chip onto, the LEDs may be composed of lenses and/or reflectors (mirrors) to collect and focus the radiation which is emitted by the chip. Two different LED constructions are used: In a **lead-frame-type LED** the semiconductor chip is mounted (bonded) onto a solid metal substrate called "lead frame". After bonding the chip onto the lead frame the epoxy housing is molded in a molding tool. In **Chip-LEDs** the semiconductor chips are bonded onto a non-metallic substrate (FR-4 or ceramic material, plated with a gold layer as terminal and sometimes also as optical reflector) and the housing is molded with epoxy or silicone.

The emission angle φ of the IRED is defined as the direction where the radiant intensity has decreased to a value of 50% of the radiant intensity on the optical axis (forward direction). In the data sheet usually 2φ is given as the total emission angle. The distance of the chip to the lens determines the emission angle of the LED (see Fig. 1). The IRED also emits some infrared radiation in directions outside the cone with angle 2φ. Since the size of the IRED-chip (typically 300 µm) is usually not negligible compared to the diameter of the lens of the IRED, there is a minimum emission angle of about $2\varphi=10°$ for standard IREDs. If there is no lens or other optical elements the theoretical emission angle is $2\varphi = 120°$ (Lambert-radiator).
During the production process minor displacements of the chip location from the optical axis are inevitable. For small emission angles this may lead to an essential unsymmetrical emission characteristics which is called **cross-eye-effect**. This effect always has to be taken into account if the application requires an extremely symmetrical emission characteristics of the IRED. Quite generally the cross-eye-effect is more pronounced for lead-frame LED. For chip LEDs the chip position is controlled by image processing during the chip bonding process.

Emission angle (Fig. 1)



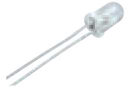
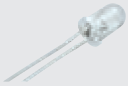
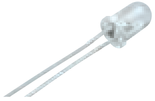
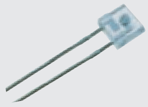
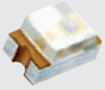
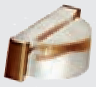
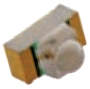
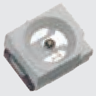
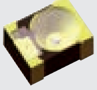
Total emission angle = 2φ
Available angles: 2φ = 10° … 160°

The **radiant intensity** of the IREDs is defined as the optical power which is emitted into a cone of 1 sr (sterad, spherical angle) along the optical axis of the system. The unit is mW/sr. In most sensor applications the radiant intensity of an IRED is much more important than the **total optical power** in mW. The radiant intensity is dependent on the emission angle while the total optical power is independent from the emission angle. The radiant intensity is always measured at direction 0° (i.e. on the optical axis) and most IRED are classified into classes (ranks) of different radiant intensity.

Infrared light penetrates most unfilled plastic materials, even if those materials are **not** transparent for the visible light. This should always be kept in mind during the design of the application. Especially in case of IR-reflection sensors it is almost impossible to distinguish e.g. black and white areas on a white substrate if the black areas are printed onto the substrate with black lacquer. With the use of digital photo cameras or cameras in mobile phones, infrared light in the range of wavelength 800 nm …1000 nm can be observed very easily. This may be a useful tool to trace a light path or to check the IR-transmission of some plastic materials.
For data transmission the **speed** of the infrared LED is important. Quite generally the GaAs-chips (950nm) are slow (raise/fall time some µs), whereas the GaAlAs-chips are much faster (up to 20ns). For most of the sensor-applications, however, the speed of GaAs is sufficient.

The selection of a proper IRED-type for a given application depends strongly on the **emission direction** of the LED. Available emission directions of the IREDs are **upright (u), sideways (s) and downwards (d)**.

Specifications of IR-LEDs

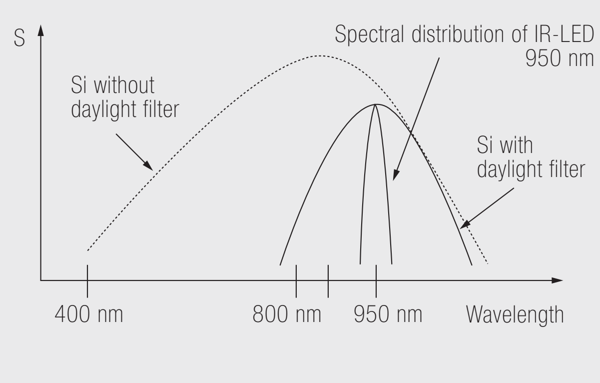
SHAPE	PART NUMBER	DESCRIPTION	WAVELENGTH [nm]	EMISSION ANGLE 2 φ [°]	EMISSION DIRECTION, u = up, d = down, s = side	RADIANT INTENSITY TYP. [mW/sr]
	IR204-A	ø 3 mm	950 (880 & 850 available)	35	u	5.6 @ 20 mA
	IR333-A	ø 5 mm	950 (880 & 850 available)	20	u	20 @ 20 mA
	IR333/H0/ L10	ø 5 mm	950 (880 & 850 available)	40	u	12 @ 20 mA
	IR908-7C	rectangular housing	950 (880 & 850 available)	60	s	n. a.
	IR15-21C/ TR8	SMD size 1206	950 (880 & 850 available)	160	u	0.8 @ 20 mA
	IR17-21C/ TR8	SMD size 0805	950 (880 & 850 available)	120	u	0.8 @ 20 mA
	IR19-21C/ TR8	SMD size 0603	950 (880 & 850 available)	150	u	0.7 @ 20 mA
	IR11-21C/ TR8	SMD 1206 with inner lens	950 (880 & 850 available)	100	u	1.6 @ 20 mA
	IR26-21C/ L110/TR8	SMD with lens	950 (880 & 850 available)	20	u, d	3.5 @ 20 mA
	IR12-21C/ TR8	SMD	950 (880 & 850 available)	160	s	0.8 @ 20 mA
	IR26-51C/ L110/TR8	SMD with lens	950 (880 & 850 available)	20	s	3.5 @ 20 mA
	IR67-21C/ TR8	SMD, PLCC2, TOPLED	950 (880 & 850 available)	120	u	1.5 @ 20 mA
	IR91-21C/ TR7	SMD, with lens small angle	950 (880 & 850 available)	25	u, d	5 @ 20 mA
	HIR89-01C	SMD with reflector	850	30	u	55 @ 70 mA
	HIR83-01B	SMD with lens	850	40 (X) 100 (Y)	s	5 @ 20 mA

2.2 PHOTODIODES AND PHOTOTRANSISTORS

In most optoelectronic sensor applications with infrared LEDs a detecting device is as well needed. It is a fortunate coincidence of nature that the spectral sensitivity of photodiodes and phototransistors made of silicon match perfectly with the infrared range of the electromagnetic radiation of IREDs around 900 nm. Silicon as a material for photodiodes and phototransistors has many advantages: it is cheap, the production process is very sophisticated and optimized, and the photodetector can be integrated into a silicon integrated circuit. In the following the expression „photodetector“ is valid for both, photodiodes and phototransistors.

The sensitivity of silicon is shown in the following diagram. The minimum wavelength which can be detected by silicon is around 400 nm (using special blue-enhancement technology also shorter wavelengths are possible). At about 880 nm a maximum of sensitivity is reached and then sensitivity decreases and is almost zero at 1100 nm. Hence silicon devices can be used for detection of the visible range (400 nm to 800 nm) and for the infrared range of electromagnetic radiation (800 nm to 1100 nm).

Sensitivity range of silicon with and without daylight filter



Features photodiode/phototransistor

Item	Chip size	Speed	Photo-current	Price level
Photodiode	large	fast	low	expensive
Photo-transistor	small	slow	high	cheap

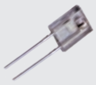
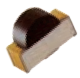
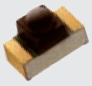
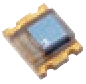
For applications where infrared LEDs are used as a light source there is no need for the detector to be sensitive in the visible range. In these cases photodetectors with so called “daylight filters” are used. This is simply a black epoxy mold instead of clear epoxy mold. It is blocking the radiation in the range of 400 nm to 800 nm whereas the radiation above 800 nm will pass the epoxy with almost no loss. The transition range of wavelength between IR-blocking and IR-passing is dependent on the type of epoxy material. The expression daylight filter is misleading in the following sense: The sun, incandescent lamps, fluorescent lamps etc. do not emit only visible light but also infrared light. If a detector with a “daylight filter” is exposed to the radiation of those light sources there will be an essential signal detected because of the IR-radiation contained in the spectrum.

Quite often the brightness of the daylight should be detected. Photodetectors made of silicon work quite well during the bright day and after the sun has gone down completely. But during dawn a problem may occur (so called red-sky-effect): when the sun goes down the fraction of visible light is decreasing drastically, but there is still a lot of infrared radiation present. As the sensitivity of the silicon detectors has its maximum in the infrared range the signal of silicon detectors under “red-sky” conditions is too high compared to the impression created by the human eye.

The above mentioned spectral behaviour is valid for both, photodiodes and phototransistors. Electrically, these two types are quite different.

The photo current of phototransistors is quite high compared to the current of photo diodes. The phototransistor is composed of a photodiode and an amplifying transistor. In most cases the amplification factor of a phototransistors is between 1000 and 1500 which results in photocurrent of some 100 µA or even few mA.

On the other hand, photodiodes are much faster than phototransistors. The raise time of photodiodes is typically a few ns, whereas the raise time of phototransistors is a couple of microseconds. The photo current of the photodiodes is proportional to the size of the chip. To get a high photo current in an application the chip size has to be chosen as big as possible. Quite generally the photodiode chips are much larger than the size of the phototransistor dice. As a consequence many photodiode chips do not fit in the same housings as phototransistors and hence much less housings are available for photo diodes. If a linear behaviour of the photo current as a function of incident light is requested it is better to use a photo diode instead of a photo transistor. Table 1 gives a summary of the comparison of photodiodes and phototransistors.

	SHAPE	PART NUMBER WITHOUT DAYLIGHT FILTER	PART NUMBER WITH DAYLIGHT FILTER	DESCRIPTION	RISE/FALL TIME	SENSITIVITY DIRECTION, u = up, d = down, s = side	LIGHT CURRENT
Phototransistors		PT204-6C	PT204-6B	3 mm	15 µs	u	2 mA (typ.)
		PT333-3C	PT333-3B	5 mm	15 µs	u	3 mA (typ.)
		PT908-7C	PT908-7B	rectangular	15 µs	s	0.8 mA (min.)
		PT15-21C/ TR8	PT15-21B/ TR8	SMD size 1206	15 µs	u	0.3 mA (typ.)
		PT11-21C/ L41/TR8	PT11-21B/ L41/TR8	SMD size 1206 with lens	15 µs	u	0.8 mA (typ.)
		PT12-21C/ TR8	PT12-21B/ TR8	SMD	15 µs	s	1.14 mA (typ.)
		PT19-21C/ L41/TR8	PT19-21B/ L41/TR8	SMD size 0603	15 µs	u	0.6 mA (typ.)
		PT26-21C/ TR8	PT26-21B/ TR8	SMD size 1206 with lens	15 µs	u, d	2.6/1 mA (typ.)
		PT26-51C/ TR8	PT26-51B/ TR8	SMD with lens	15 µs	s	1 mA (typ.)
		PT67-21C/ L41/TR8	PT67-21B/ L41/TR8	SMD TopLED (PLCC2)	15 µs	u	0.3/0.016 mA (min.)
		PT91-21C/ TR7/9/10	PT91-21B/ TR7/9/10	SMD with lens	15 µs	u, d	1.5 mA (typ.)
Photodiodes		PD204-6C	PD204-6B	3 mm	6 ns	u	3 µA (typ.)
		PD333-3C/ H0/L2	PD333-3B/ H0/L2	5 mm	45 ns	u	35 µA (typ.)
		PD438C	PD438B	5 mm	50 ns	s	18 µA (typ.)
		PD15-21C/ TR8	PD15-21B/ TR8	SMD size 1206	6 ns	u	0.8 µA (typ.)
		PD15-22C/ TR8	PD15-22B/ TR8	SMD size 2 mm × 2 mm	10 ns	u	6.5 µA (typ.)
		PD70-01C/ TR7/10	PD70-01B/ TR7/10	SMD size 3 mm × 3 mm	50 ns	u, d	25 µA (typ.)
		PD95-21C/ TR7/10	PD95-21B/ TR7/10	SMD with lens	6 ns	u, d	4 µA (typ.)
		PD12-21C/ L458/TR8	PD12-21B/ L458/TR8	SMD with lens 3 × 2 × 1 mm	6 ns	s	1.5 µA (typ.)

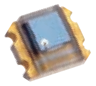
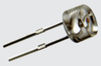
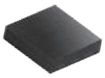
2.3 AMBIENT LIGHT SENSORS (ALS)

In many applications the intensity of visible light has to be measured. The crucial point is that the word "visible" introduces a physiological element into the problem. The output signal of the sensor has to correspond to the subjective impression of the human eye, i. e. if the subjective impression of the human eye is "bright", the sensor signal should also be high. And for the impression "dark" the sensor should show a low signal.

Standard silicon photodetectors work quite well during the bright day and at complete darkness some hours after sunset. But during dawn and dusk a problem may occur (so called red-sky-condition): when the sun goes down the fraction of visible light is decreasing drastically, but there is still a lot of infrared radiation present. As the sensitivity of the silicon detectors has its maximum in the infrared range the signal of silicon detectors under "red-sky" conditions is too high compared to the brightness impression of the human eye. Figure 1 shows the sensitivity curve of the human eye (which is known as V (λ) -curve), the spectral sensitivity of silicon and the sensitivity spectrum of an ambient light sensor of EVERLIGHT. Using a standard silicon photodiode as a light sensor for garden lights, it would be tough to find an adjustment where the light would switch on during dusk. In most cases it would switch on after complete darkness.

Many of the ambient light sensors are based on silicon photodiode chips which are plated by some optical filter layers. These optical filters absorb the infrared light from the incident radiation and therefore restrict the sensitivity of the silicon photodiode chip to the visible area. Due to the small photo currents at low incident light levels it is convenient to use an ambient light sensor-IC, which has an amplifier on the same chip. For higher light intensity levels, also photodiodes and phototransistors are available as ambient light sensors.

Specifications of ambient light sensors

SHAPE	PART NUMBER	SENSOR ELEMENT	ANALOG/DIGITAL	REMARKS	LIGHT CURRENT [µA]	ILLUMINATION CONDITIONS	DIMENSIONS [mm]
	ALS-PD15-22C	Photo Diode	Analog	Linear, low cost	0.14	100 lx	2.3 × 2.1 × 1.1
	ALS-PD70-01C	Photo Diode	Analog	Linear, large chip size	1.1	100 lx	4.4 × 3.9 × 1.2
	ALS-PT243-3C/451	Photo Transistor	Analog	Linear	20	10 lx	ø 5, flat
	ALS-PT19-315C/L177	Photo Transistor	Analog	Linear, small size	15	100 lx	1.7 × 0.8 × 0.6
	ALS-PDIC15-21C/L230	Photodiode +Amplifier IC	Analog	Linear	56	100 lx	3.2 × 1.5 × 1.1
	ALS-PDIC17-77C	Photodiode +Amplifier IC	Analog	Linear, small size	50	100 lx	2.1 × 1.35 × 0.8
	ALS-PDIC17-77B	Photodiode +Amplifier IC	Analog	Linear	30	1000 lx	2.95 × 2.35 × 1.25
	ALS-PDIC17-79NB	Photodiode +Amplifier IC	Digital	I²C	-	-	2.0 × 2.0 × 0.45
	APM-12023-20-DF8 Proximity + ALS-Sensor	Photodiode +µController +Proximity-sensor	Digital	With proximity-function	0,195 lx/count	800 lx	2.0 x 2.1 x 0.6

2.4 PYROSENSORS

In the past pyrosensors were used as detectors for non-contact temperature measurement. The basic principle behind this was the fact, that a black, solid body of temperature T emits electromagnetic radiation with an energy distribution, that depends only on the temperature of the body. The wavelength where the energy distribution shows a maximum, is given by λ_{max} (unit µm)= 2899 / T(unit K). For a human body with a temperature of 37°C the emitted radiation has its maximum at a wavelength of 9.4 µm.

In the last years it became very popular to use pyrosensors to detect the presence (or more precise the movement) of a human body. These sensors consist of two or four pyroelectric elements in a hermetic housing with a silicon window which is transparent in the range of 5 to 10 µm. The pyroelectric elements show ferroelectric behaviour and are characterized by some permanent electrical polarization on the surface of the elements, see Fig.1. However, the polarization is not detectable because the surface charges are compensated by some charged ions in the environment of the surface. If infrared radiation hits the pyroelectric elements their temperature increases by a very small amount. Due to the thermal expansion, the crystal structure has to rearrange and thus the polarization on the surface of the elements changes. This change in polarization can be detected by electrodes on the top and bottom side of the pyroelectric elements. The electrical charge necessary to compensate the change in electrical polarization is detected and amplified by an internal FET, see Fig.3. Each temperature change of the elements leads to a short spike in the output signal of the FET which is used to detect the presence of a human body. The changes in polarization are very small and therefore it is necessary that the changes are fast enough in order to be detectable by the FET. As a consequence, only moving infrared emitting sources can be detected. In order to cancel false signals due to temperature change of the environment there are at least two pyroelectric elements connected in series with antiparallel polarization (Fig. 3).

For movement sensors usually a Fresnel lens (sometimes also a mirror) is used to focus the infrared radiation onto the detecting elements of the pyrosensor. In most cases the Fresnel lenses are divided into several zones and each zone acts as a separate lens. As soon as the infrared radiation source starts to move there are many images of the infrared source in the plane of the sensing elements which pass the pyroelectric element. Each time one of the images passes the elements a spike in output voltage is created. The more zones the lens has, the more

Fig. 1 - Pyroelectric principle

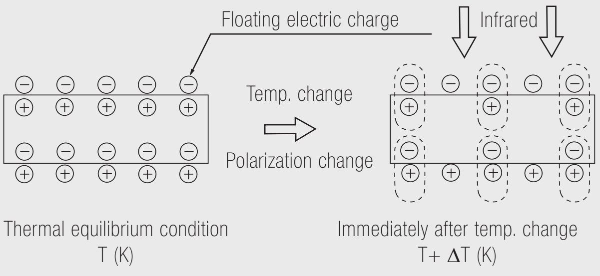
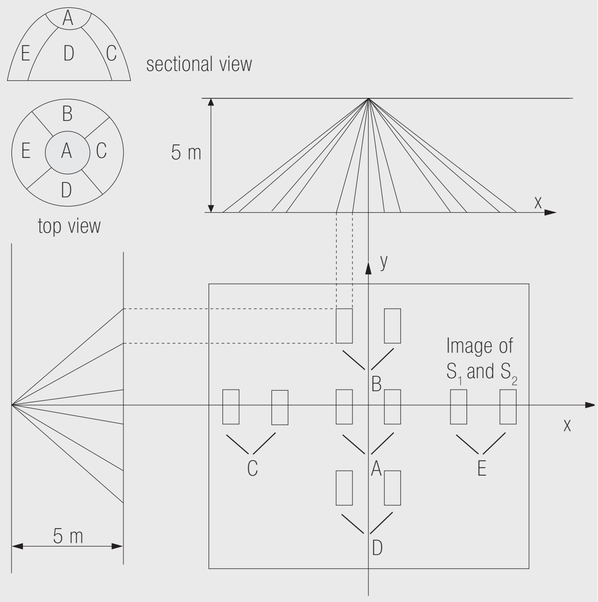


Fig. 2 - Field of view pattern



Field of view pattern for a lens with 5 zones A ...E in a distance of 5 m (pyrosensor with two elements S_1 and S_2)

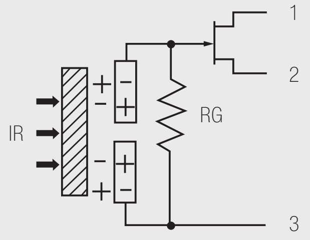
NICERA Lenses by Endrich Bauelemente Vertriebs GmbH

TYPE	ZONE	TOTAL HEIGHT (mm)	TOTAL DIAMETER (mm)	RECOMENDED MOUNTING	ANGLE CA.
NCL-10(S) (1)	1	9.5	10.4	wall/ceiling	19°
NCL-10(IL) (1)	3	9.5	10.4	wall	90°
NCL-3(B) (1)	4	8.65	10.4	wall/ceiling	61°
NCL-3(R) (1)	7	8.65	10.4	wall/ceiling	90°
NCL-8 (1)	9	10.0	14.8	ceiling	100°
NCL-9(S) (1)	1	14.45	17.0	wall/ceiling	16°
NCL-9(10) (1)	10	11.5	17.0	wall	120°
NCL-9(26) (1)	26	12.37	17.0	ceiling	100°
NCL-11 (2)	16	12.7	23.0 x 11.0	wall	105°
SAA-Pe.cover lens-4 (2)	16	12.0	24.0 x 15.0	wall	110°
NCL-13 (2)	20	15.75	24.2	wall	100°
NL-11 (2)	17	17.2	24.0	wall/ceiling	107°
SL-7512 (3)	12	16.3	15.7	ceiling	110°
NCL-14 (2)	18	15.0	22.7 x 15.0	wall	120°

(1) = Cap style; (2) = PCB catch style; (3) = PCB catch style, sensor to set on a spacer

images are created. This makes it possible to detect even slowly moving objects. To describe the optical properties of a Fresnel lens it is convenient to look at the field of view pattern, see Fig. 2. In this drawing the sensing elements are facing to the plane of the moving object. The rectangular images of the two sensor elements created by the 5 zones of the lens are shown in a plane at a distance of z=5 m from the sensor. Whenever an object is moving from one rectangular area to its neighbouring area, the sensor will detect the moving object. If the object is moving only in the x-direction (e.g. for wall mounted pyrosensor modules) a pyrosensor with two elements is sufficient. If the object is moving in x- and y-direction (e.g. for ceiling mounting of the sensor module) a four element pyrosensor is recommended.

Fig. 3 - Equivalent circuit

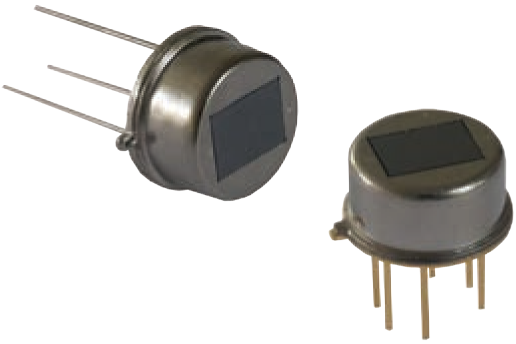


Other pyrosensors, pyrosensor modules and lenses are available on request!

2.5 DIGITAL PYROSENSORS

The new generation of pyrosensors contains the pyroelectric elements, amplifier and a microcontroller chip inside the same housing. The signals generated by the pyrosensor elements are converted into a digital signal. These pyrosensors are therefore called digital pyrosensors. Their main advantages are an easy signal evaluation with only a few external devices and high immunity to electromagnetic interference (EMI).

There are two different types of digital pyrosensors available:



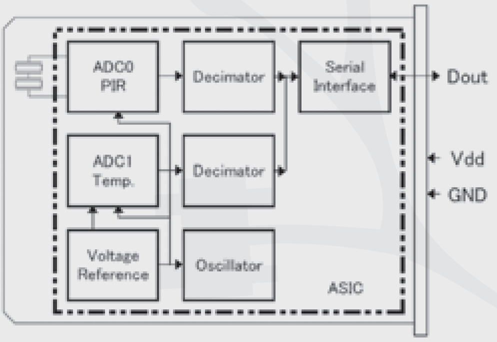
PSH3-323-36AA: Communication type

This type communicates with a host controller by a one-wire interface (via Dout-pin). The IR-signal of the two pyroelectric elements as well as the temperature data of a built-in temperature reference are transferred with a resolution of 14 bit. The PSH3-323-36AA is assembled in a TO5-housing.

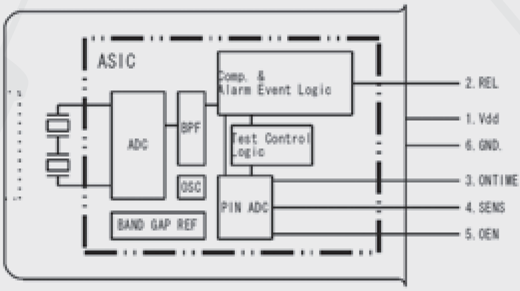
PSH2-323-66AA: “all-inclusive”- type

This type includes all electronics of a movement detector in one housing. The signal of the pyroelectric elements is converted into a digital signal and processed by some internal logic. It may communicate with a host controller, but the device can also be used as “stand-alone” with the ouput signal at pin 2 driving an amplifier with e.g. relay-output. The sensitivity and hold time are fixed by an appropriate voltage divider at the SENS and ONTIME pin. There are also types available with fixed values for the sensitivity and hold time and types with four pyroelectric elements.

PSH3-323-36AA



PSH2-323-66AA



Applications

Intrusion alarm
Automatic light switching
Automatic backlight control of LCD panels
Door opener

2.6 SUMMARY PYROSENSORS

MODEL	COMMENTS	EMC	AMPLIFIED SIGNAL OUTPUT VP-P	FIELD OF VIEW DEG.	BALANCE OUTPUT %	NOISE OUTPUT MVP-P
NICERA Pyrosensors by Endrich Bauelemente Vertriebs GmbH						
RE200G	General, low cost, low noise	Good	3,3	138°	15	70
RE200GE	General, low cost, low voltage	Good	3,3	138°	15	90
SBG323-671	Standard,low noise,wide window	Good	4.0	134°	10	70
SBG323-611	Standard, low voltage, wide window	Good	4.0	134°	10	90
SBG342-671	High sensitivity	Good	5,8	134°	15	100
SFG323-671	High security, excellent EMC, low noise	Excellent	3,5	134°	10	70
SBA02L2-81RC2-P	Low profile, TO-39	Good	3,4	159°	15	90
SBG446-671	Quad element for ceiling	Good	6,5	132°	15	120
Special types						
SFG323-771	low noise	Good	3,8	134°	10	70
SBG323-711	high output voltage, high sensitivity	Good	5,5	134°	10	90
Built-In amplifire						
SW-IVC-15G	High speed response, low cost	Fair	0,005	134°	n/a	n/a
SW-ULP23-20	Ultra low power consumption	Fair	1,5	134°	n/a	160

DIGITAL PYROSENSORS MODEL	COMMENTS	EMI	SIGNAL OUTPUT AMPLIFIED VP-P	FIELD OF VIEW	BALANCE OUTPUT %	OUTPUT
NICERA Pyrosensors by Endrich Bauelemente Vertriebs GmbH						
PSH3-323-36AA	digital communication	Fair	n/a	134°	n/a	digital communication
PSH2-323-66AA	digital motion sensor	Good	n/a	134°	n/a	switching output
PSH2-446-3	digital motion sensor, four elements	Good	n/a	132°	n/a	switching output

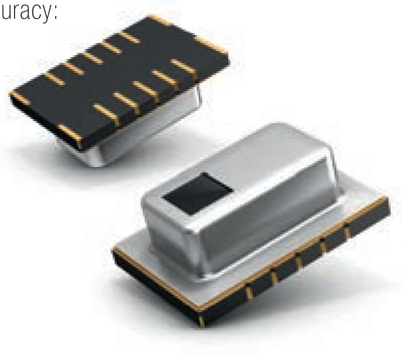
2.7 INFRARED-ARRAY-SENSOR – GRID-EYE

GRID-EYE is a thermopile array sensor that features 64 thermopile elements in an 8x8 grid format. Contrary to conventional thermal sensors which only measure the temperature of a certain point-of-contact, Grid-EYE, based on Panasonic's MEMS technology, can measure the temperature of the entire specified area without any contact; in other words, it is a "contactless thermopile array sensor". 64 pixels yield accurate temperature measurement over a viewing angle of 60° provided by a silicon lens. Grid-EYE uses an I2°C communication interface, enabling temperature measurements at speeds of 1 or 10 frames/sec. An interrupt function is also available.
With an array of detection elements Grid-EYE can use passive infrared detection to determine temperature differentiation allowing it to detect multiple objects simultaneousely. Grid-EYE is able to measure actual temperature and temperature gradients, providing thermal images and identifying direction of movement. Compared to single thermopile sensors or pyroelectric sensors, Grid-EYE offers immense benefits:

- Digital output (I2C)
- SMD package (reflow compatible)
- 8×8 (64) pixel range
- Frame rate: 10 frames/s or 1 frame/s

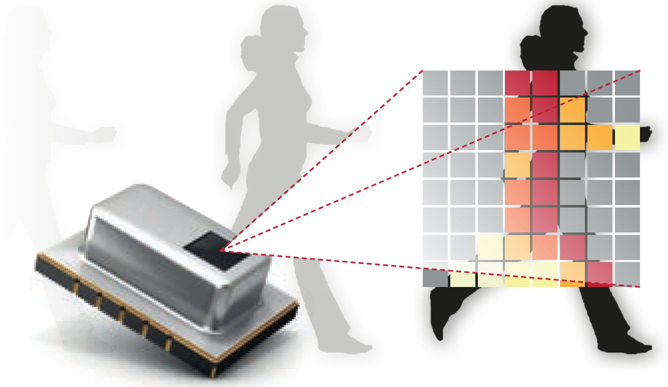
Features:

- Dimensions: 11,6 mm×4,3 mm×8,0 mm (L×H×W)
- Operating voltage: 3,3 V or 5,0 V
- Current consumption: Typ. 4,5 mA (normal mode); 0,8 mA (stand-by mode), 0,2 mA (sleep mode)
- Temperature range of measuring object: With amplification factor high gain: 0°C ... 80°C, Low gain: -20°C ... 100°C
- Field of view: 60° (vertical and horizontal)
- Number of thermopiles: 64 (8 vertical x 8 horizontal)
- External interface: I²C (fast mode)
- Frame rate: 1 or 10 picture/s
- Absolute temperature accuracy: Typ. ±2,5 °C



Evaluation board

We offer a Grid-EYE Evaluation Kit that combines its "nanopower" PAN1740 Bluetooth Smart module and a microcontroller together with the Grid-EYE-Sensor on one PCB. By combining its new IR sensor technology with Bluetooth technology and using a special software for IR detection of people and objects on one board, Panasonic enables customers to develop rapid prototypes and quickly build their own wireless sensor "Internet of Things" applications.



Applications:

Grid-EYE opens the door to a whole world of applications, ranging from energy savings in the lighting industry (commercial and public places as well as residential spaces) to household applications (air conditioners, microwave ovens, etc.), from security systems (automatic doors, elevators, ATMs, kiosks, etc.) to the medical industry (patient detection and positioning), and many more.

- Security: occupancy detection, people counting, multiple person detection
- Household: cooking stoves, microwave ovens, air conditioners, heating systems
- Medical: patient detection, movement detection, thermal imaging, position detection
- Lighting control: energy savings, detection without movement
- Industrial temperature measurement: industrial process management and control, preserving maintenance, contactless temperature measurement

RFbeam

3.1 RADAR SENSORS – GENERAL

written by K. Mezger, RFbeam, St. Gallen, Switzerland

What does K-band mean?

K-band stands for the radio frequency range of 18...27 GHz. A portion of this range from 24...24.250 GHz is a so called ISM (Industrial, Science and Medical) radio band. RFbeam sensors use the ISM K-band. The ISM K-band allows operating our sensors in nearly all countries worldwide.

What does "Radar transceiver" mean?

Transceivers are devices containing a transmitter and a receiver. RFbeam radar devices contain always a transmitter and at least one receiver in order to send an electromagnetic wave and to receive the echo of this wave. Radar transceivers are often simply called radar sensors.

Radar transceivers can be operated in different modes (Doppler, FMCW, FSK, ...) depending on the physical quantity that has to be detected, e. g. speed, distance, presence of objects.

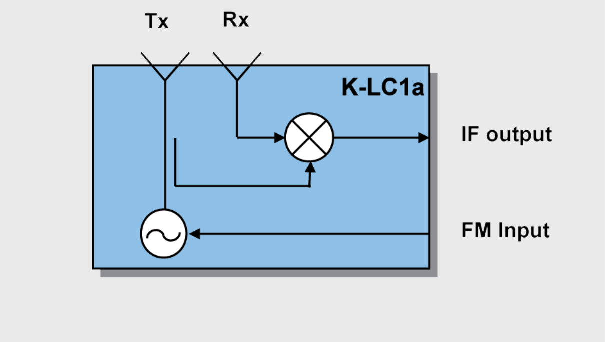
What does Doppler sensor mean?

Doppler Radar is used to detect moving objects and evaluate their velocity. A reflective moving object in sight of the sensor generates a low frequency sine wave at the sensor output. The amplitude depends on the distance and the reflectivity of the moving objects. The output frequency is proportional to the object speed: 158 Hz per m/s or 44 Hz per km/h for a radial moving object. Some RFbeam sensors are "stereo" sensors with 2 outputs, called I (In phase) and Q (Quadrature). These sensors allow detecting the moving direction (approaching, receding).

About Doppler radar

A more precise title would be, "CW (Continuous Wave) Doppler Radar", when using RFbeam radar sensors. These sensors do not produce pulses, but send continuously in the K-band (24.125 GHz).

Fig. 1 - Typical radar transceiver



RFbeam radar transceivers (Fig. 1) return a so called IF signal, that is a mix-product of the transmitted (Tx) and the received (Rx) frequency. A moving object generates a slightly higher or lower frequency at the receiver. The IF signal is the absolute value of the difference between transmitted and received frequency. These transceivers operate in the CW (Continuous Wave) mode as opposed to the pulse radars, that measure time of flight. CW radars can operate with very low transmitting power (< 20 dBm resp. 100 mW).

Calculating the Doppler frequency

$$f_d = \frac{2 \cdot f_{Tx} \cdot \nu}{c_0} \cdot \cos\alpha \quad (1)$$

or

$$\nu = \frac{c_0 \cdot f_d}{2 \cdot f_{Tx} \cdot \cos\alpha} \quad (2)$$

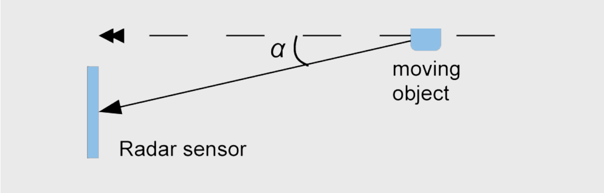
f_d = Doppler frequency
f_{Tx} = Transmitting frequency (24 GHz)
c_0 = Speed of light (3×10^8 m/s)
ν = Object speed in m/s
α = Angle between beam and object moving direction (see Fig. 2)

At a transmitting frequency of f_{Tx}= 24 GHz we get a Doppler frequency for a moving object at the IF output of

$$f_d = \nu \, \frac{44\ \text{Hz}}{\text{km/h}} \cdot \cos\alpha\ .$$

RADAR SENSORS – GENERAL

Fig. 2 - Definition of angle α



The angle α reduces the measured speed by a factor of cos α. This angle varies with the distance of the object. To evaluate the correct speed, you need a trigger criteria at a known point. This can be accomplished by measuring the distance with the radar sensor (e.g. using FSK technology) or by measuring the angle using a monopulse radar such as K-MC4.

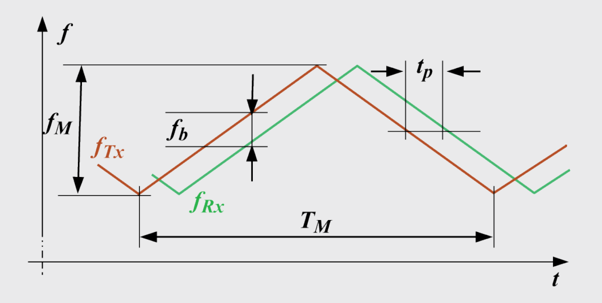
About FMCW

FMCW stands for Frequency Modulated Continuous Wave. This technique allows the detection of stationary objects. FMCW needs radar sensors with an FM input. This input accepts a voltage that causes a frequency change. There are also sensors with digital frequency control based on digital PLL designs. Modulation depth is normally a very small amount of the carrier frequency. In the K-band most countries allow a maximum frequency range of 250 MHz. Description of many effects such as velocity-range unambiguities go beyond the scope of this paper. Please refer to radar literature for more detailed explanations.

Triangle modulation

The transmitting frequency is modulated by a linear up and down ramp. Figs. 3a+3b show a typical signal f_{Rx} returned by stationary and constantly moving objects. Note, that the difference frequency f_b is constant throughout nearly the whole ramp up time. At the output of the radar transceiver we get a low frequency signal f_b called beat frequency. This is the result of mixing (=multiplying) transmitted and received frequencies.

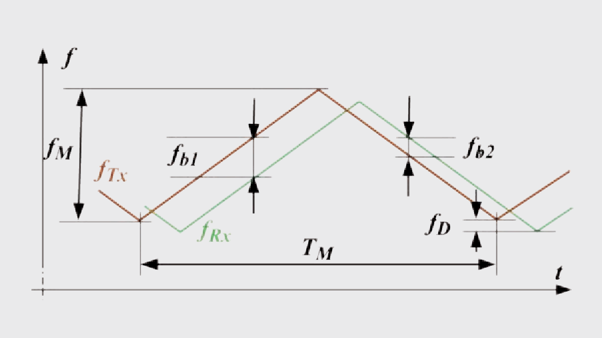
Fig. 3a - Triangle modulation - stationary object



Returned echo from stationary object

f_M	Modulation depth
T_M	Modulation period
f_{Tx}	Transmitted frequency
f_{Rx}	Received frequency
t_p	Signal propagation time (time of flight)
f_b	Beat frequency f_{Tx} - f_{Rx}
f_d	Doppler frequency

Fig. 3b - Triangle modulation - moving object



Returned echo from moving object

The received frequency f_{Rx} is shifted by f_d. This is the Doppler frequency caused by a receding object moving at a constant speed.

By measuring during up and down ramp, the Doppler frequency f_d is the diffence between f_{b1} and f_{b2}.

Distance can be calculated as follows:

$$R = \frac{c_0}{2} \cdot \frac{f_b}{f_M} \cdot \frac{T_M}{2}$$

For legend refer to Fig. 3a
R = Range, distance to target
c_0 = Speed of light (3×10^8 m/s)

RADAR SENSORS – GENERAL

Maximum unambiguous range:

$$R_{max} = \frac{c_0}{2} \cdot \frac{T_M}{2}$$

For legend refer to Fig. 3a

R_{max} = Max. unambiguous target distance

c_0 = Speed of light (3×10^8 m/s)

Distance and resolution

In K-Band (24 GHz), the maximum allowed frequency modulation depth f_M is <250 MHz. We also have to take in account tolerances and temperature influences. This limits the usable frequency shift f_M to typically 150 MHz.

For measuring f_b to evaluate distance we need at least one period of f_b during T_M, the range resolution is limited to

$$R_{min} = \frac{c_0}{2 \cdot f_M} = \frac{3^8 \text{ m/s}}{2 \cdot 250 \text{ MHz}} = 0.6 \text{ m}$$

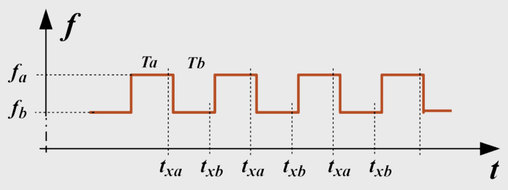
This is a theoretical value, because we have to consider drifts and tolerances in order to stay in the allowed frequency band.
Working with the more realistic value of f_M = 150 MHz, we get a minimum distance and resolution of R = 1 m.
Resolution may be enhanced by using phase conditions, correlation and other sophisticated algorithms.

About FSK mode

FSK stands for Frequency Shift Keying. FSK uses two discrete carrier frequencies f_a and f_b, (Fig. 4) while FMCW uses linear ramps.

For each carrier frequency, separate IF signals must be sampled in order to get 2 buffers for separate FFT processing. Due to the very small step f_a-f_b a moving target will appear nearly with the same Doppler frequency at both carriers, but with a different phase (Fig. 5). Phase shift due to the modulation timing and sampling must also be taken into account.

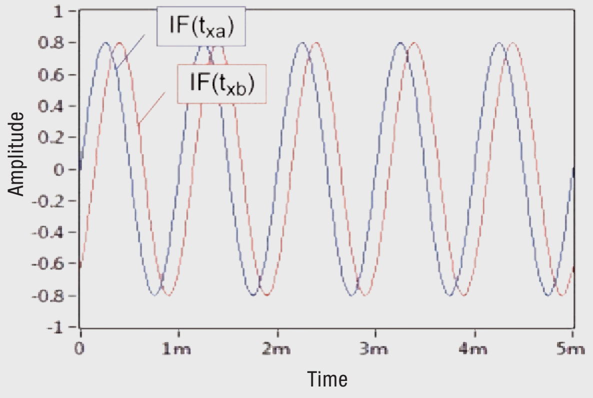
Fig. 4 - FSK modulation scheme



f_a	Carrier Frequency a
f_b	Carrier Frequency b
t_{xa}	Sampling point for Doppler a
t_{xb}	Sampling point for Doppler b

Switching must be performed at a sampling rate high enough to meeting the Nyquist criteria for the Doppler signal acquisition.

Fig. 5 - Resulting Doppler frequencies



IF(t_{xa})	Sensor output signal at carrier frequency f_a
IF(t_{xb})	Sensor output signal at carrier frequency f_b

Doppler signals of the same moving target have thesame frequency, but are phase shifted by Δφ.
For both IF signals, phase must be determined at the spectral peak of the object.

$$R = \frac{c_0 \cdot \Delta\varphi}{4\pi \cdot (f_a - f_b)}$$

Δφ = Phase shift of IF(t_{xa}) and IF(t_{xb})

The smaller the frequency step, the higher the maximum range. To achieve an unambigous distance range of 150 m, a frequency step of 1MHz is required.

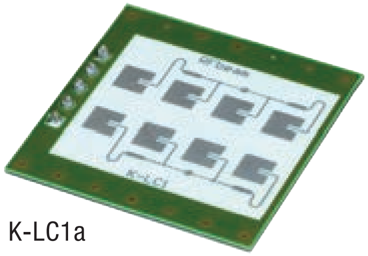
Remarks

- FSK can only be used for moving objects
- Multiple objects at different speeds may be detected
- Distance resolution depends mainly on signal processing and is not limited by the carrier bandwidth limitations
- FSK has the advantage of simple modulation and does not suffer from linearity problems
- VCO signal generation is simple, but sampling and phase measurement is challenging

3.2 RADAR SENSORS – PRODUCT SELECTION

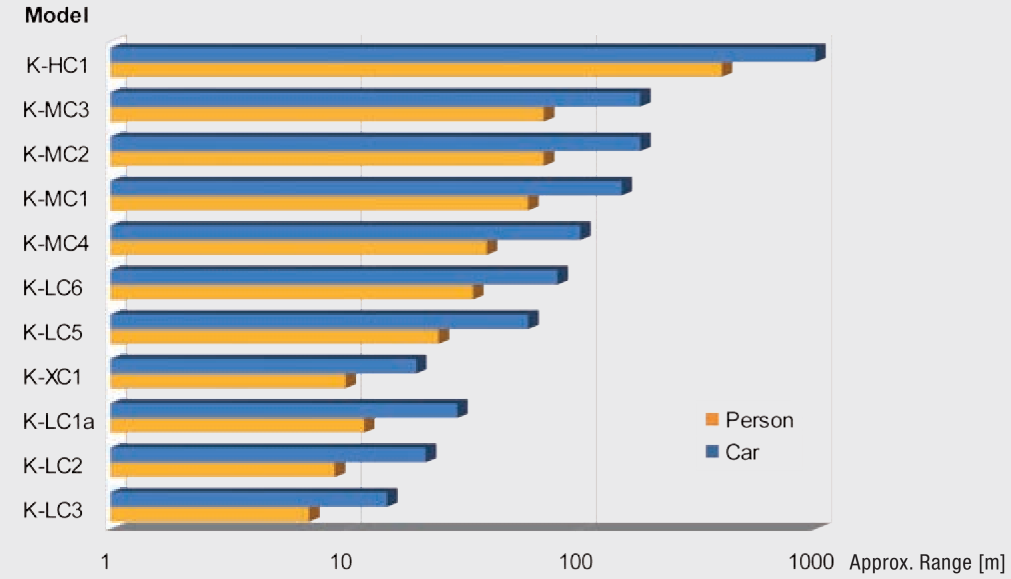
Selection by detection range

These are indicative values only and cannot be guaranteed. Range depends on many parameters like size of object, direction of movement and data processing method.



K-LC1a

Selection by detection range



Selection by parameters

PART NUMBER	MIN. RANGE PERSON [m] [1]	MIN. RANGE CAR [m]	FIELD PATTERN VERTICAL [°]	FIELD PATTERN HORIZONTAL [°]	OUTPUT I/Q	IF AMPLIFIER	SUPPLY VOLTAGE [VDC] [2]	CURRENT CONSUMPTION [mA]	FM/VCO	SIZE [mm]
K-LC3	7	15	138	132	no	no	5	35	no	25 × 25 × 6
K-LC2	9	22	80	34	yes	no	5	35	yes	25 × 25 × 6
K-LC1a	12	30	80	34	no	no	5	35	yes	25 × 25 × 6
K-XC1	10	20	Ext. ant.	Ext. ant.	yes	yes	12…24	300	n. a.	
K-LC5	25	60	80	34	yes	no	5	45	yes	25 × 25 × 6
K-LC5-v2	25	60	80	34	yes	no	5	45	no	25 × 25 × 6
K-LC6	35	80	80	12	yes	no	5	45	yes	66 × 25 × 6
K-LC6-v2	35	80	80	12	yes	yes	5	47	yes	66 × 25 × 6
K-MC4	40	100	30	12	yes	yes	5	120/10	yes	98 × 78 × 7
K-MC1	60	150	25	12	yes	yes	5	100/10	yes	65 × 65 × 6
K-MC2	70	180	25	7	yes	yes	5	100/10	yes	138 × 65 × 6
K-MC3	70	180	25	7	yes	yes	5	100/10	yes	105 × 85 × 5
K-HC1	400	1000	25	12	yes	yes	15…30	220	digital	110 × 77 × 19

[1] - values with simple comparator detector, [2] - 3.3 V on request

3.3 RADAR SENSORS – DEVELOPMENT TOOLS

ST100 starter kit, ST200 evaluation kit and ST500 lighting evaluation board

These kits allow to learn radar basics and evaluating radar technology for your specific application. STxxx kits can save a lot of initial time and money in order to get first radar experience.

ST100 starter kit vs. ST200 evaluation kit vs. ST500 lighting evaluation board

APPLICATION	ST100	ST200	ST500	COMMENTS
Learning Doppler basics	x	x		
Exploring Doppler sensors	x	x		
Developing movement sensors	x	x	x	
Analyzing Doppler frequency spectra	x	x		
Working with complex FFT		x		important for separating multiple objects, suppressing interferences...
Recording and playback of Doppler signals	x	x		
Output of recorded Doppler signals	x			Very helpful for analyzing real world signals in the laboratory
Exploring FSK ranging		x		Ranging of moving objects
Exploring FMCW ranging		x		Ranging of moving and stationary objects
Exploring different sampling conditions		x		Predict behavior of final embedded solutions
Exploring monopulse principle		x		Detect direction angle of moving objects
Kit contains K-LC1a module	x	x	x	Good for learning basics
Kit contains also K-LC2 and K-MC1 modules		x		For advanced investigations
Kit contains also K-LC6 and K-LC1 modules			x	
For LED lighting applications (distance ≤30 m)			x	
1 V ... 10 V output			x	
Suppression of false triggering			x	in a later version of ST500

3.4 RADAR DOPPLER SIGNAL PROCESSOR RSP1

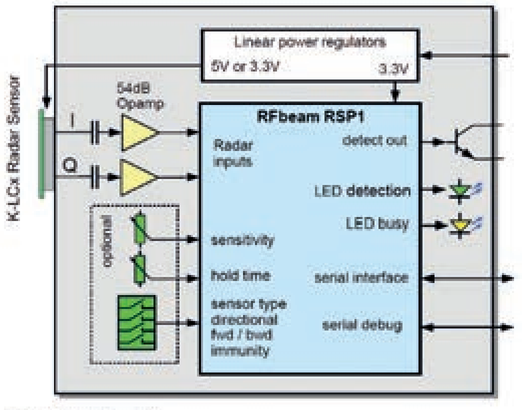
NEW: Radar signal processing unit RSP1

RSP1 is a new microcontroller, which is designed for smart evaluation of output signals of radar transceivers operating in the Doppler-mode. Speed and presence of moving objects will be detected.

Features

- Universal Doppler radar signal processor
- Complete I/Q radar sensor interface
- Double detection distance compared to traditional solutions
- Object speed and direction detection
- Complex FFT based signal processing
- Efficient adaptive interference suppression
- Inherent object speed detection up to 200km/h
- Stand-alone or hosted operation
- Serial interfaces to host processor
- Reference design and evaluation board available

Stand-alone application circuitry

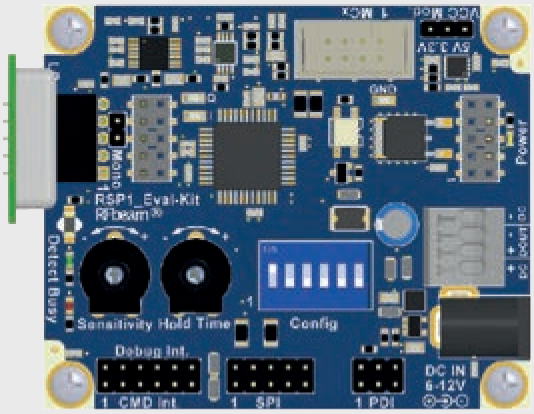


RSP1 Typical Application

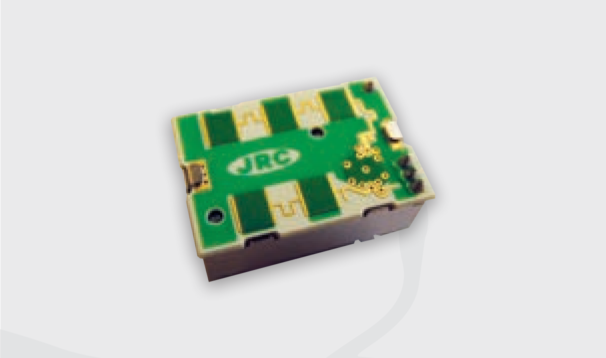
Key Data

- 12 bit ADC
- Differential analog inputs for I and Q signals
- Internal programmable gain amplifier
- Sampling rates from 1280Hz ... 22.5kHz
- Efficient 256 pt complex FFT
- Logarithmic detection algorithms
- Adaptive noise and interference analysis and canceling algorithms
- Serial command and debug/streaming interfaces
- Highly configurable by serial interface and/or digital and analog inputs
- Application settings can be down- and uploaded from chip
- Sophisticated serial outputs like peak magnitude, frequency and sign, noise level and many more

Evaluation board for RSP1



3.5 MOTION SENSOR NJR4265/ K-BAND INTELLIGENT DOPPLER MODULE



NJR4265 J1 is an intelligent motion sensor that is designed for the sensing of short distance low speed moving objects like pedestrians etc. The steady sensing of a moving object is realized by embedded software. It is suitable for the built-in use of the sensing function to various equipments as all functions are integrated in a small package and it can easily be controled from PC/MCU by UART interface. Further stand alone operation is also possible.

Features

- Motion Sensor based on 24 GHz Microwave Doppler effect technologies
- Antenna, RF circuit, IF amp, MCU and voltage regulator are integrated in a small package (14 × 20.4 × 8.8 mm)
- Signal processing software for the steady sensing
- Enhancing signal from movement object and decreasing random noises
- Decreasing mutual interference between sensors
- Identification of moving direction (approaching and leaving)
- Low voltage operation and low power consumption

APPLICATIONS

- Energy saving equipment (lighting equipment, air conditioner etc.)
- Room access control system equipment
- Human detection sensor for various instruments

SENSING PERFORMANCE

» Speed range of target:	0.25 ... 1 m/s
» Max. distance in the front:	10 m
» Detectable angle:	±35 deg.

ENVIRONMENTAL CHARACTERISTICS

» Operating temp. range:	-20°C ... +60°C
» Storage temp. range:	-40°C ... +80°C
» Humidity:	0-95% at +30°C

4 | HALL SENSORS

In 1879 Edwin H. Hall (1855-1938), an American physicist, discovered this effect. The electrons of the current flowing in an electrical conductor are diverted from their normal direct path by an external magnetic field perpendicular to their motion. Due to the so-called Lorentz force a potential difference (the Hall voltage) is created, proportional to the field strength of the magnetic field and to the current. Silicon is used almost exclusively as a basic material for the technical implementation of magnetic field sensors as the Hall-effect is most pronounced in semiconductors. In modern Hall-effect sensor devices the magnetic field sensitive Hall element is combined with the signal processing on a single silicon chip. Three different types of sensor architecture are available today:

- Digital switches
- Linear sensors
- Direct angle sensors

Hall switches

The simplest application is to use the sensor as a "digital switch". The magnetic field strength is measured and compared with a fixed threshold level predefined or programmable in the sensor. As soon as this value is exceeded (switching point) the switching state at the output of the sensor changes and the output transistor is switched on or off. Two types of switches are available: 3-wire versions with an open-drain output or 2-wire versions with a current-coded output.

Linear Hall sensors

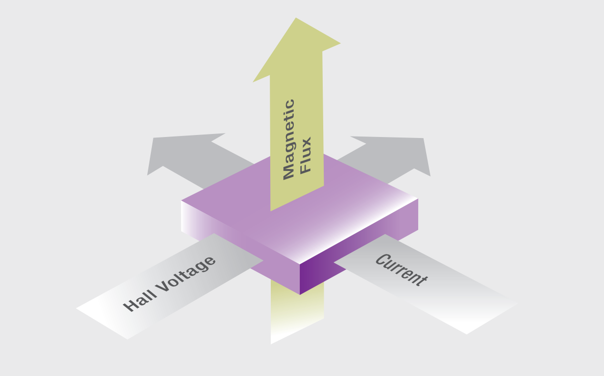
Linear Hall sensors differ from the switches as follows: Depending on the magnetic field, the output does not have a discrete switching state, but provides a signal proportional to the magnetic field strength.

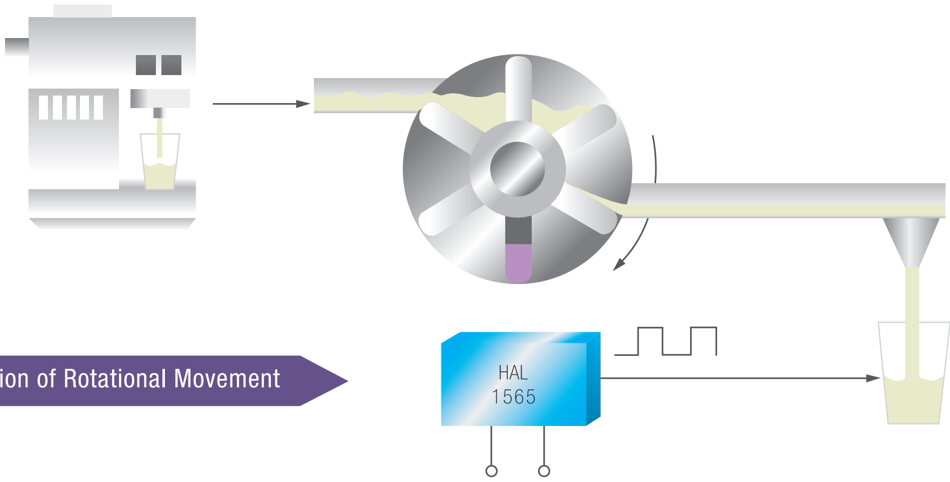
This output signal can be delivered as an analog output voltage, a pulse-width-modulated signal (PWM) or even as a modern bus protocol (LIN, SENT).

Direct angle sensors

New types of Hall-effect sensors do not measure the absolute magnetic field anymore. So-called direct angle sensors capture the field vector by measuring sine and cosine components of the magnetic field. This is possible due to the new 3D-HAL technology from Micronas. Vertical Hall plates measure the magnetic field components in the chip plane as well as the components perpendicular to the chip surface. This kind of sensors provide angular and position information directly via an output signal proportional to the measured angle or position.

Principle of the Hall effect





Application example: Detection of Rotational Movement

4.1 HALL SWITCH OVERVIEW

HAL15 Switch Family

- Open-drain output (3-wire) or current output (2-wire)
- Chopper stabilized
- High-precision thresholds
- Different switching points and behaviour
- T_J = -40 ... 170°C
- SOT23 or TO92 package

HAL1002 Switch

- Open-drain output (3-wire)
- Different switching points
- T_J = -40 ... 170°C
- TO92 package

Hall Switches for Position Detection

Hall Switches are commonly used for end-position detection. The sensor recognizes the presence of a magnetic field by signalling an ON/OFF state. Therefore, Hall Switches are widely used to replace micro switches, offering superior quality and durability performance.

4.1.1 IN SYSTEM PROGRAMMABLE HALL SWITCH HAL1002

The major sensor characteristics, the two switching points B_{ON} and B_{OFF}, and the output behavior are programmable for the specific application. The sensor can be programmed to be unipolar or latching, sensitive to the magnetic north pole or sensitive to the south pole, with normal or with an electrically inverted output signal.

Target applications

- End position detection
- Kick down
- Bending lights

Key features

- Programmable through modulation of supply voltage
  - Switching points programmable from -150 mT ... 150 mT independent programming of B_{ON} and B_{OFF}
  - Output behavior (unipolar [inverted] or latching)
  - Temperature coefficient
- Short-circuit protected push-pull output
- Over and under voltage detection
- Over and reverse voltage protection at all pins
- Wire break detection (VDD and GND)
- Supply voltage range: 4.5 ... 8.5 V (target 11 V)
- T_J range: -40 ... 170°C
- ESD HBM protection up to 8 kV

Specifications of HAL 1002

PART NUMBER	TYP. B_{ON} / TYP. B_{OFF}	TYPE	CONFIGURATION
HAL1002	programmable	Unipolar, unipolar inverted, latching	3-wire

4.1.2 LOW-POWER HALL SWITCH FAMILY HAL15XY

The HAL15xy family consists of different Hall Switches containing a temperature-compensated Hall plate with active offset compensation and comparator, available optionally with open-drain or current output.

Key features

- ISO 26262 compliant, ASIL A ready device
- Very low current consumptions of typ. 1.6 mA (3-wire)
- Wide supply voltage operation from 2.7 ... 24 V, over voltage protection capability up to 40 V
- Highest HBM ESD performance up to ±8 kV
- Reverse-voltage protection at supply pin
- Operating with static and dynamic magnetic fields up to 12 kHz at lowest output jitter
- T_J -40 ... 170 °C
- SOT23 Jedec package
- AEC-Q100 qualification

Target applications

- Endposition detection
- BLDC motor commutation
- Brake light switch
- Clutch pedal position
- Gear shift lever
- Window lifter

Specifications of HAL 15XY

PART NUMBER	TYP. B_{ON}	TYP. B_{OFF}	TYPE	CONFIGURATION
HAL1501	0.4 mT	-0.4 mT	bipolar, high sensitivity	3-wire
HAL1502	2.5 mT	-2.5 mT	latching, high sensitivity	
HAL1503	5.5 mT	3.7 mT	unipolar, medium sensitivity	
HAL1506	18.9 mT	17.3 mT	unipolar, low sensitivity	
HAL1507	28.2 mT	23.9 mT	unipolar, low sensitivity	
HAL1508	-5.5 mT	-3.7 mT	unipolar, medium sensitivity	
HAL1509	3.7 mT	5.5 mT	unipolar inverted, medium sensitivity	
HAL1562	12 mT	-12 mT	latching, low sensitivity	2-wire
HAL1563	7.6 mT	9.4 mT	unipolar inverted, medium sensitivity	
HAL1564	4.1 mT	6 mT	unipolar inverted, medium sensitivity	
HAL1565	6 mT	4.1 mT	unipolar, medium sensitivity	
HAL1566	9.4 mT	7.6 mT	unipolar, medium sensitivity	

TO92UA leaded package Sampling start in Q3 2016

4.2 LINEAR DISTANCE HALL SENSOR OVERVIEW

HAL 8 Product Family
- T_J = -40 ... 170°C
- TO92 package
- Programmable (EEPROM)
- Proven-in-use quality
- Temperature stability

HAL 83x
- Analog output

HAC 830
- Integrated caps
- High accuracy
- Analog output

HAL 24 Product Family
- T_J = -40 ... 170°C
- TO92, SOIC8 or TSSOP14 package
- Programmable (EEPROM)
- On-board diagnostic features
- Versatility and high precision

HAL 2420
- 2-point calibration
- Analog output

HAL 2425
- 2-point calibration
- 16 set points linearization
- Analog output

HAR 2425
- Dual-Die version
- Analog output

HAL 2455
- 2-point calibration
- 16 set points linearization
- PWM output

HAR 2455
- Dual-Die version
- PWM output

Linear Hall Sensors for Linear Movement

Linear sensors are used to obtain a signal proportional to a linear movement or an electric current level being measured. The output signals can be analog or in digital formats. Due to these proven advantages Hall-effect sensors are widely used to replace conventional potentiometers.

HAL 18 Product Family
- T_J = -40 ... 170°C
- TO92 or SOT89 package
- Ratiometric analog output
- Value optimized version (10bit)
- Versatility and high precision

HAL 1820
- Programmable (EEPROM)

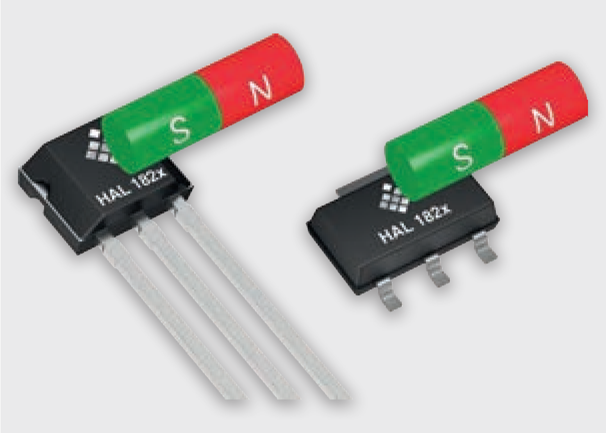
HAL182x
- Pre-configured sensitivity (EEPROM)

HAL 28 Product Family
- T_J = -40 ... 170°C
- TO92 package
- High-precision sensors
- Digital signal processing
- Direct 12V battery supply

HAL 283x
- SENT interface (SAE J2716 rev.3)
- Up to 16-bit resolution

HAL 2850
- Programmable PWM output
- 12-bit resolution

4.2.1 HAL182X LINEAR HALL SENSOR – PROGRAMMABLE OR WITH FIXED SENSITIVITY



HAL182x consists of an universal magnetic field sensor with a linear analog output based on the Hall effect. The ICs can be used for angle and linear measurements if combined with a rotating or moving magnet. The major characteristics of the HAL1820 such as magnetic field range, sensitivity, offset (output voltage at zero magnetic field) and the temperature coefficients are programmable in a non-volatile memory. The sensors HAL1821, HAL1822, and HAL1823 have a fixed sensitivity.

Target applications

- Linear movement e.g. gear position in dual clutch transmission
- Motor control

Key features

- Magnetic field range: ± 20 ... ± 160 mT
- Under/over-voltage protection
- Junction temperature -40°C ... 170°C
- ESD protection up to 6kV
- AEC-Q100 qualification

Specifications of HAL 182x

PART NUMBER	SENSITIVITY [mV/mT]	MAGNETIC RANGE B_{MIN} [mT] / B_{MAX} [mT]
HAL1820	programmable	±20 / ±160
HAL1821	50	-50 / +50
HAL1822	31.25	-80 / +80
HAL1823	25	-100 / +100

4.2.2 HAL83X ULTRA-RELIABLE MULTI-PURPOSE LINEAR HALL-SENSORS

The **HAL83x family** brings over 15 years know-how and a proven-in-use quality experience. It can work in harsh environment due to high temperature stability and offers flexibility thanks to the selectable output (analog & PWM) of the HAL835.

Target applications

Linear movement, angle detection, pedal, throttle, turbo charger, transmission and joystick

Key features

- Junction temperature -40 ... 170°C
- Under/over-voltage & wire break detection
- ESD protection @ 7.5 kV
- Reverse-voltage protection at all pins

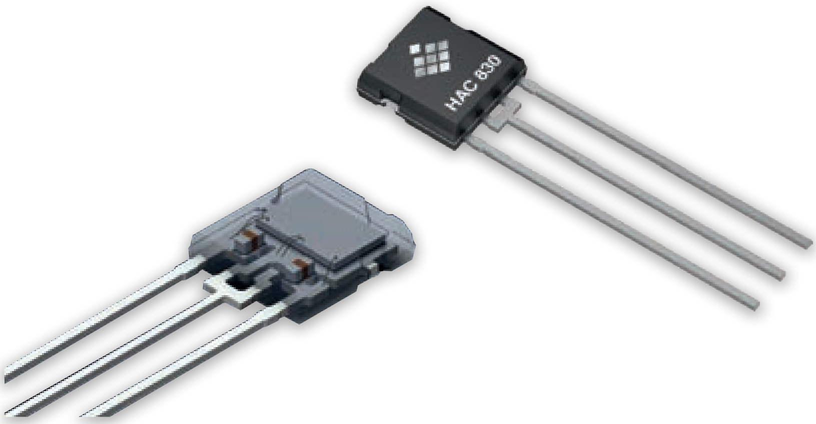
Specifications of HAL 83x

PART NUMBER	MAGNETIC RANGE [mT]	OUTPUT	PACKAGE
HAL830	± 30 ... 100 mT	Analog (12 bits)	TO92-UT
HAC830	± 30 ... 100 mT	Analog (12 bits)	TO92-UP
HAL835	± 15 ... 150 mT Low offset and sensitivity drift	Analog (12 bits) & PWM (125 Hz, 11 bits)	TO92-UT

HAC830: NEW CONCEPT OF INTEGRATED CAPACITORS

Key features

- Same features as HAL830
- EMC robustness (BCI up to 300 mA)
- Available in the TO92UP-package



4.2.3 HAL24XY IS A PRECISE AND ROBUST PROGRAMMABLE LINEAR HALL-EFFECT SENSOR

The versatile **HAL24xy family** offers an extended measurement for distance up to 2 times magnet length & angle up to 180° and state-of-the-art diagnostic functions for applications under stringent conditions.

Target applications

Linear distance measurement, throttle, pedal and joystick

Key features

- » 16 set points for output linearization
- » Junction temperature -40 ... 170°C
- » Under/over-voltage & wire break detection
- » ESD protection @ 8 kV
- » On board diagnostics
- » AEC-Q100 qualification

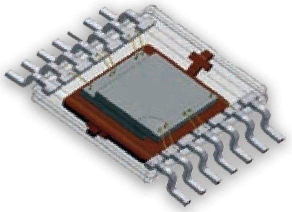
Specifications of HAL 24x5

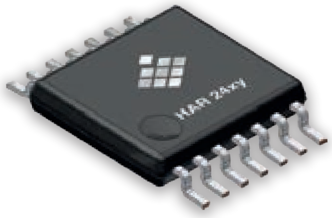
PART NUMBER	CHARACTERISTICS	OUTPUT	PACKAGE
HAL2420	• ± 25 ... 200 mT magnetic range • Programmable temperature compensation for sensitivity and offset • Continuous self-test	Analog (12 bits)	TO92-UT, SOIC8
HAL2425		Analog (12 bits) with 16 programmable setpoints	TO92-UT, SOIC8
HAL2455		PWM (2 kHz, 12 bits) with 16 programmable setpoints	TO92-UT, SOIC8
HAR2425		Analog (12 bits) with 16 programmable setpoints	TSSOP14
HAR2455		PWM (2 kHz, 12 bits) with 16 programmable setpoints	TSSOP14

HAR24XY: REDUNDANCY IN A VERY THIN PACKAGE

Key features

- » Same features as HAL24xy
- » Redundancy with stacked die configuration
- » Package height < 1 mm





4.3 3D HAL® TECHNOLOGY FROM MICRONAS

Two-dimensional Measurement with Vertical Hall Plates

In the area of position detection in automotive or industrial applications, the requirements to sensors are steadily increasing. Their accuracy and reliability in harsh environments has to grow steadily. For applications measuring small distances (up to 6 mm) or small angle ranges (up to 60°), established linear (1D) Hall-effect sensors could show excellent and reliable performance. For larger ranges a new technology is needed. To this end, Micronas has developed the new Hall-effect sensor family HAL 37xy.

This family represents a new level of performance for Hall-effect sensors enabling a significant simplification in the design of magnetic systems. The sensors are based on Micronas' innovative 3D HAL® technology. A major advantage of this technology is the use of the so-called pixel cell. It consists of a combination of two vertical and one horizontal Hall plate. With this pixel cell it is possible to measure the three magnetic field vector components at one spot. Magnetic field lines parallel to the sensor surface are measured by the vertical Hall plates, whereas the component perpendicular to the chip surface is measured by the horizontal Hall plate. The measurement of the relative strength of both components is the key for the excellent angular performance. Even a varying distance between magnet and sensor does not prevent a stable output signal. Also temperature effects are mainly suppressed by relative measurements of the two components.

The combination of vertical and horizontal Hall plates enables robust linear position measurements with reduced magnet sizes. Using a magnet with a length of 10 mm, distances of ≥15 mm can be easily achieved. Overall 40 mm movement can be realized with simple magnetic setups.

Overall, the various family members support different output formats like ratiometric analog PWM and SENT. The devices can be easily adapted to the different applications by providing easy programmability. Key parameters like offset, gain, zero angle, output offset and gain, 33 set points for linearization and clamping levels can be stored in the built-in memory.
Today the whole product family consists of the second generation HAL 37xy featuring further improved angular performance.

MULTI-AXIS SENSORS OVERVIEW

HAL 37 Product Family

» T_J = -40 ... 170°C
» SOIC8, TO92 package
» Superior accuracy
» Programmable characteristics in a non-volatile memory
» Diagnostic functions
» Measurement of angular and liniar position

HAL 3715
» 12 bit analog module output

HAL 372x
» 12 bit analog output

HAL 373x
» PWM and SENT output

HAR 3715
» 12 bit analog module output
» Dual-die variant

HAR 372x
» 12 bit analog output
» Dual-die variant

HAR 373x
» PWM and SENT output
» Dual-die variant

HAC 3715
» 12 bit analog module output
» Integrated capacitors

HAC 372x
» 12 bit analog output
» Integrated capacitors

HAC 373x
» PWM and SENT output
» Integrated capacitors

4.3.1 HAL37XY SECOND GENERATION OF MULTI-AXIS HALL SENSORS

Target applications

Clutch position, turbo charger actuators, transmission position, chassis position sensors, fuel level and steering angle detection, encoder, linear distance measurement

Key features

- High ESD protection according to stringent requirements of the automotive industry
  - ESD protection 8 kV (active pins)
- Wide junction temperature range from -40 ... 170°C
- SOIC8 SMD, TO92-UP for pin leaded package
- No output linearization required for rotary applications
- "open source" programming interface and software
- Unique „Virtual Offset Feature" to
  -> reduce magnet size & cost
  -> Accuracy of <0.5% full scale for linear or angular measurements

Specifications of HAL 37xy

PART NUMBER	OUTPUT	MAGNETIC FIELD AXIS	MAGNETIC RANGE [MT]	SETPOINTS	MAGNETIC SETUP
HAL 3725	Analog	XY	± 20 ... ±100	33	End of shaft
HAL 3726		YZ			Off-axis or linear position
HAL 3727		XZ			Off-axis or linear position
HAL 3735	PWM or SENT SAE-J2716 Rev. 2010	XY			End of shaft
HAL 3736		YZ			Off-axis or linear position
HAL 3737		XZ			Off-axis or linear position

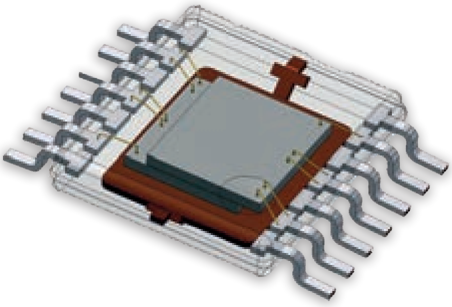
Additional features

- Supply voltage range 4.5 ... 5.5 V
- Programming via sensor output TTL-Level (0 … 5 V)
- Memory with redundancy and lock function
- AEC-Q100 qualification
- Various safety features
  - Wire-break & under/over-voltage detection
  - Full signal path and memory supervision
  - Overflow and state machine self-test
  - Magnet lost detection

4.3.2 HAR37XY

Redundant Multi-axis Hall Sensor for Position Detection

The HAR37xy Hall-effect sensors offer redundant high-precision angle and linear position measurement in a small SOIC8 package for demanding automotive and industrial applications.



Thanks to:

Stacked Die Technology

- Small distance between the two dies‘ sensitive area
- Each die bonded on a separate side of package
- Isolated per construction

4.3.3 HAC37XY

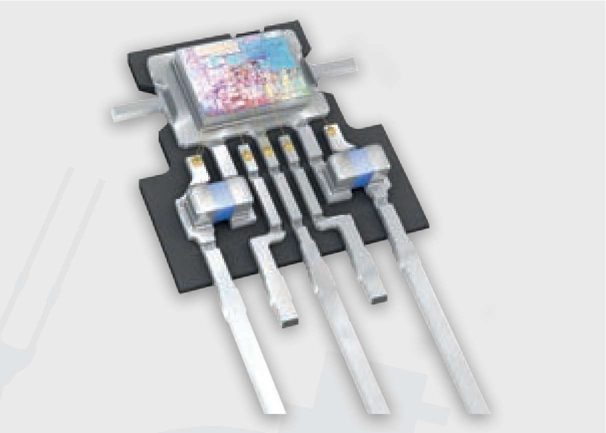
Multi-axis Hall Sensor with Integrated Capacitors for more robust Position Detection

The HAR37xy Hall-effect sensors offer redundant high-precision angle and linear position measurement in a small SOIC8 package for demanding automotive and industrial applications.

Thanks to:

Stacked Die Technology

- Robust and compact single-mold leaded package TO92UF
- Fault coverage according to ASIL-B
- Analog or digital (PWM / SENT / triggered SENT) output signal
- BCI test class A

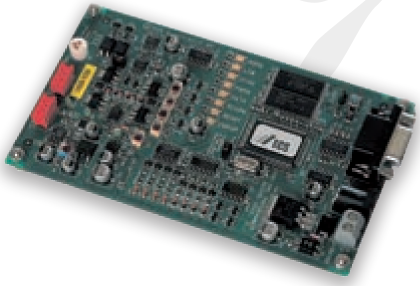


4.4 PROGRAMMING TOOLS & ENVIRONMENT

These programmer boards are used as a general-purpose programming interface, which is capable of addressing all programmable Micronas Hall-effect sensor families within the Micronas sensor portfolio.

Programming hardware: **HAL-APB V5.1**

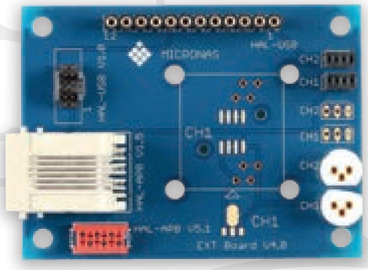
- HAL8xy
- HAL85x
- HAL1000
- CUR31xy

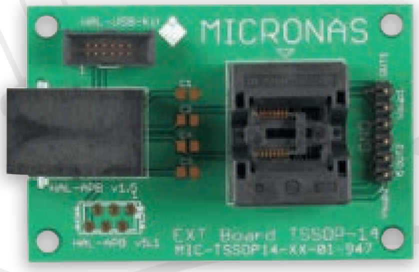


Programming hardware: **HAL-APB V1.5** **or** **HAL-USB Kit**

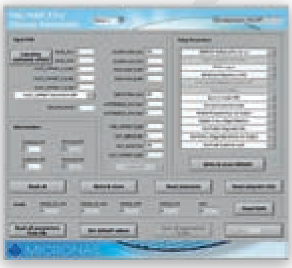
- HAL1820
- HAL/R24xy
- HAL28xy
- HAL36xy/38xy
- HAL/R/C37xy

Evaluation boards: **Extension board V4.0** **or** **TSSOP14 Extension board**



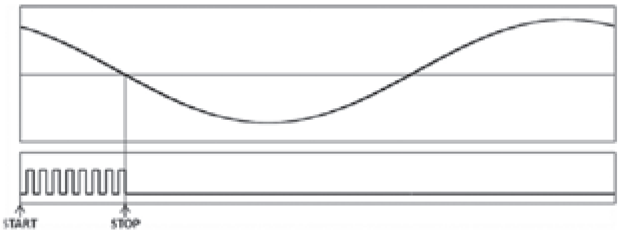


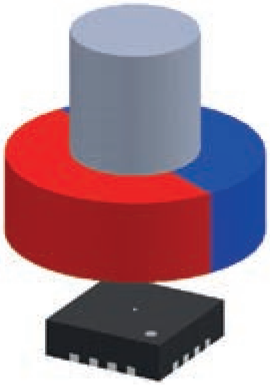
Programming software based on LabView:



4.5 MPS MAGNETIC ANGULAR POSITION SENSORS

MPS MagAlpha™ magnetic angle position sensors offer a revolutionary way to measure angles. MagAlpha™ sensors use the patented "SpinAxisTM" measurement system in which the phase angle output from a Hall sensor array is compared against time to give the instantaneous angle position in digital format. See Fig 1.





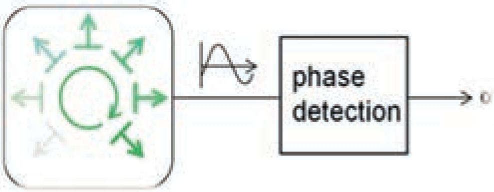


Figure 1: SpinAxis™ Technique

The "SpinAxis™" technique has allowed MPS to develop a range of angle sensors fitting different types of end application from low cost consumer rotary knobs to high speed motor commutation, position control, and general high resolution angle measurement.

MagAlpha™ Angle Sensors offer the following advantages:

- Instantaneous angle sensing: up to 1 µs sample rate, 3 µs latency at 100 k RPM
- High resolution up to 14 bit
- Support for shaft rotation speeds from 0 to over 100 K RPM
- Wide magnetic field range support from 15 … 150 mT working range
- End and side shaft magnet positioning
- Low power consumption: 3.3 V 12 mA
- Small package form factor: 3 x 3 QFN16 package
- Cost effect solutions

4.5.1 MAGALPHA™ ROTARY HUMAN-MACHINE-INTERFACE APPLICATIONS

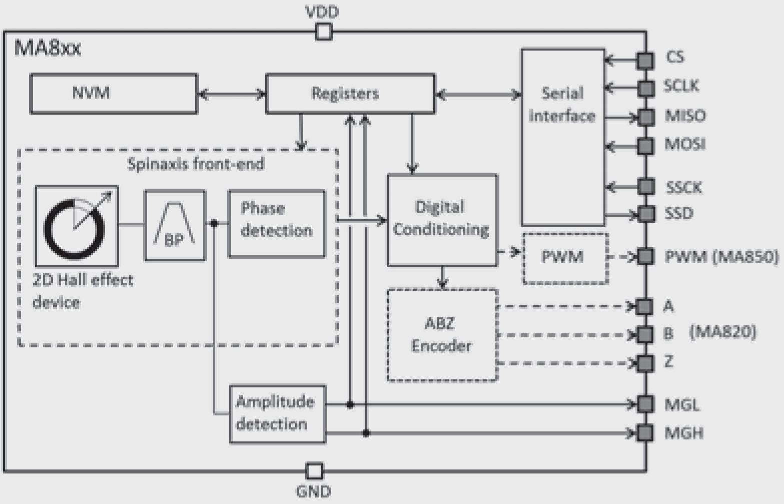
MA8xx Family

The MagAlpha™ MA8xx family is a new simple product way to use digital magnetic sensor range designed to replace analog potentiometers or rotary switches in user interface applications. Contactless sensing eliminates the lifetime issues of conventional potentiometers or mechanical switches. The sensor detects the absolute angular position of a permanent magnet, attached to the rotating knob. Typically a simple diametrically magnetized cylinder of 3 … 8 mm diameter is suitable.

Different options are available including digital angle output via SPI/SSI bus, incremental ABZ interface or PWM output. Configuration parameters are stored in a non-volatile memory.

Programmable threshold magnetic field strength detection is built in to enable implementation of a contactless push or pull button. Detection is performed by reading the device registers or the logic state of the two output signals. In this way, a combined rotary knob with "push or pull to select" functionality can be created.

Block diagram of MA8xx family sensor



FEATURES	UNIT	MA800 DIGITAL OUT	MA820 ABZ OUT	MA850 PWM OUT
Rotary user interface sensor range		Rotary knob applications		
Effective angle resolution	bit	8	8	8
Magnetic field range	mT	30 ... 150	30 ... 150	30 ... 150
Zero setting		✓	✓	✓
SPI register configuration		✓	✓	✓
Absolute angle on SPI	bit	8	--	--
Absolute angle on SSI	bit	8	--	--
ABZ incremental			✓	
ABZ resolution - pulses per channel	PPR		1 .. 64	
PWM output				✓
Magnetic field detection		✓	✓	✓

4.5.2 BRUSHLESS DC MOTOR AND GENERAL POSITION ANGLE MEASUREMENT APPLICATIONS

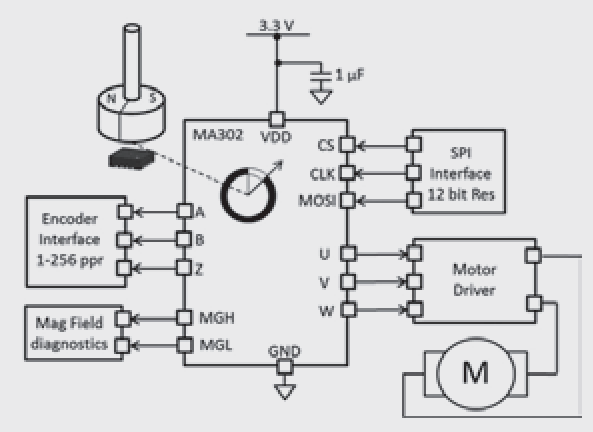
MPS offers a range of MagAlpha™ angle sensors optimized for brushless motor commutation (MA102), servo motor control (MA3xx family), and general angle measurement applications (MA7xx family). The MagAlpha™ sensors are able to generate the required signaling for each application, either as direct digital angle output over an SPI or SSI bus, UVW commutation signals or ABZ quadrature incremental encoder outputs.

MA302: 12 bit Fast Response Servo Motor Sensor

The MA302 is one of the latest generation of MagAlpha™ devices with higher resolution and additional features. It is optimised for high dynamic response and is suited for applications that experience rapid speed change and the need to support high rotation speeds. Examples include high speed brushless motors in servo applications.

The digital conditioning block is optimised to maintain the highest resolution over different operating conditions. Speeds of over 100k RPM are supported on the SPI, ABZ and UVW interfaces. End and side shaft topology is supported.

MA302

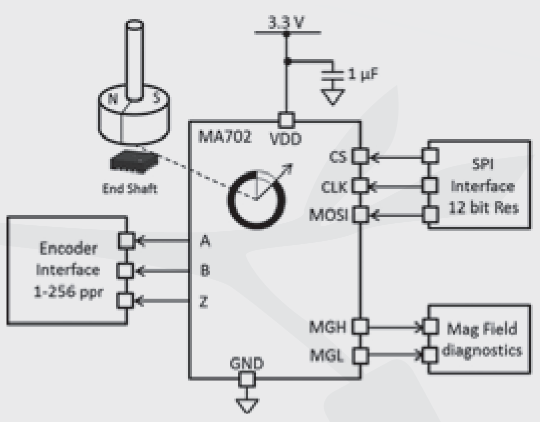


MA702: 12 bit Fast Response Angle Sensor

The MA702 is the latest generation of MagAlpha™ technology for general angle measurement. Example applications include position encoders on servo motor drives or industrial actuators. The internal signal conditioning is optimised to provide high resolution whilst maintaining low latency under rapid speed change. Speed ranges from 0 to over 100K RPM are supported.

12 bit absolute digital angle resolution has it's output via the SPI bus. A programmable ABZ quadrature encoder interface provides from 1 to 256 pulses per 360° rotation. End and side shaft magnet topologies are supported.

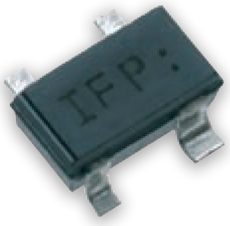
MA702



MagAlphaTM High Performance Application Devices

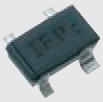
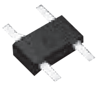
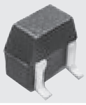
FEATURES BY PART	UNIT	MA102	MA302	MA310	MA702	MA704	MA710	MA730
		Motor commutation	Motor commutation + position control		Rotary angle sensors			
Effective angle resolution	bit	12	12	12	12	10	12	14
Dynamic response		High	High	Medium	High	Ultra-High	Medium	Medium
Magnetic field range	mT	30 ... 150	30 ... 150	15 ... 150	30 ... 150	30 ... 150	15 ... 150	40 ... 150
Zero setting		✓	✓	✓	✓	✓	✓	✓
Side-shaft compensation		✓	✓	✓	✓	✓	✓	✓
SPI register configuration		✓	✓	✓	✓	✓	✓	✓
Absolute angle on SPI	bit	8	12	12	12	10	12	14
Absolute angle on SSI	bit				12	10	12	14
ABZ incremental			✓	✓	✓	✓	✓	✓
ABZ resolution	PPR		1 ... 256	1 ... 256	1 ... 256	1 ... 64	1 ... 256	1 ...1024
PWM output					✓	✓	✓	✓
PWM resolution					12	10	12	14
UVW output 1-8 pole pair		✓	✓	✓	✓	✓	✓	✓
UVW resolution	bit	12	12	12				
Differential UVW		✓						
Magnetic field monitoring		✓	✓	✓	✓	✓	✓	✓

4.6 HALL SENSOR ELEMENTS – NHE SERIES



Digital hall sensors as described in the previous pages are a very convenient magnetic sensor solution because they include the Hall element, amplifier and the signal evaluation circuit on one single chip. In some special cases, however, it is necessary to develop an individual signal evaluation circuit, e.g. if very low electrical power consumption is required. For these applications we offer Hall elements in the very small SOT23 housing. In this case the vertical magnetic field component that is perpendicular to the PC board is measured. A vertical type is also available which detects horizontal magnetic field components parallel to the PC board (NHE529).

Specifications of hall sensor elements

SHAPE	PART NUMBER	DIMENSIONS AND DETECTION DIRECTION	HALL OUTPUT VOLTAGE V_H V_C = 1 V, B = 50 mT	OFFSET VOLTAGE V_O V_C = 1 V, B = 0 mT	INPUT/OUTPUT RESISTANCE R_{IN}/R_{OUT} @ 1 mA
	NHE520 NHE520R	SOT23 (2.9 × 2.9 × 1.1) mm (vertical field detection)	122 … 320 mV	-7 … 7 mV	240 … 550 Ω
	NHE520SR	(2.9 × 3.83 ×1.1) mm (vertical field detection)			
	NHE524	(2.9 ×2.9 × 2.67) mm (vertical field detection)			
	NHE528	(2.1 ×2.1 × 0.8) mm (vertical field detection)			
	NHE529	(2.7 ×2.1 × 1.57) mm (horizontal field detection)			

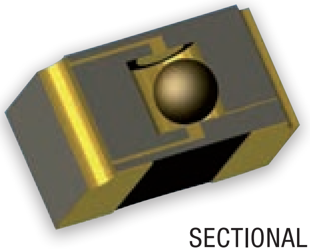
Features

- High sensitive type hall element of evaporated InSb film
- High sensitivity for effective performance in low magnetic fields
- Appropriate input and output resistances for transistor circuits
- Operating temperature: -20 … +110 °C
- Power dissipation: 150 mW
- Max. input current: 20 mA at 25 °C

Applications

- Brushless motors, e. g. CD-ROM drive
- Noncontacting magnetic sensors, e. g. position sensors, rotation sensors or other magnetic flux sensors

5.1 VIBRATION SENSORS VS1 AND VS2



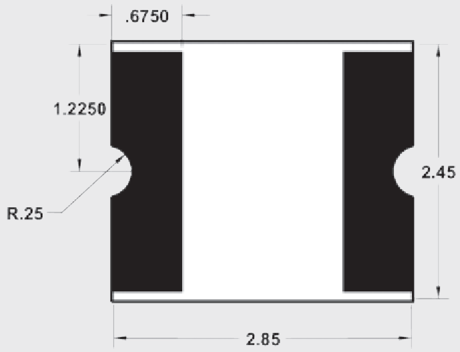
SECTIONAL VIEW VS2

2 CONTACT AREAS

Energy saving aspects of products (‚green products') get more and more important. A common method to achieve this, is to put the system in a low power state as long as the system is not used (sleep mode), and to wake up the system as soon as it is used. Normally a sensor is needed to switch from sleep mode to normal operation. Our VS1 and VS2 are perfectly suited to detect movements of handheld devices and to trigger the wake up of the system.

Endrich provides these surface mountable micro vibration sensors VS as replacement for mercury switches. The sensors detect vibrations by bridging a high ohmic gap in a P.C.B. with a micro ball (ø 0.8 mm). During vibration the resistance between both contact areas changes from some MΩ to less than 100 Ω. Compared to VS1 type, VS2 has contacts on both sides (top and bottom) of the cylindric tube, whereas VS1 only has a contact at the bottom side. Therefore VS2 has nearly omnidirectional sensitivity characteristics.

Dimensions (mm)



Height: 1.7 mm

of VS1/2

PARAMETER	SPECIFICATION
Rated voltage	+15 V max.
Reaction point	50 mg approx.
On-resistance	less than 100 Ω
Dimensions	2.45 × 2.85 × 1.7 mm
Operating temperature	-20 ... +70°C
Rec. soldering conditions	260°C, 10 s

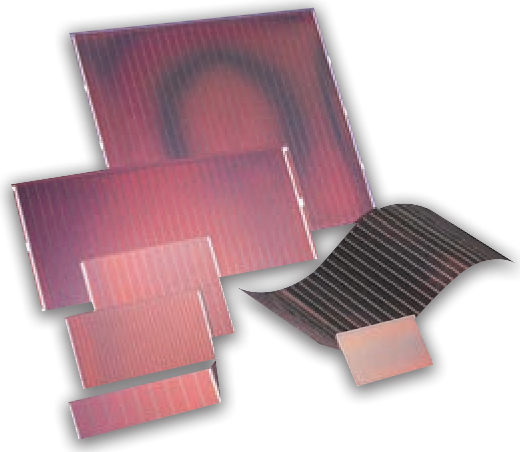
Features

- Small size 2.45 mm × 2.85 mm × 1.7 mm
- Mercury-free, RoHS compliant
- Low R_{ON}: 100 Ω
- Low noise
- Surface mountable
- Material:
  - housing: reinforced FR4 glass fibre
  - internal switching contact: Cu/Ni/Au
  - ball: steel, gold-plated
- Packaging: 1,000 pcs/reel or 2,000 pcs/reel
- Minimum order quantity: 100 pcs.

Applications

- Motion detection
- System wake up-low power
- Presence detection

5.2 AMORPHOUS SILICON SOLAR CELLS – AMORTON



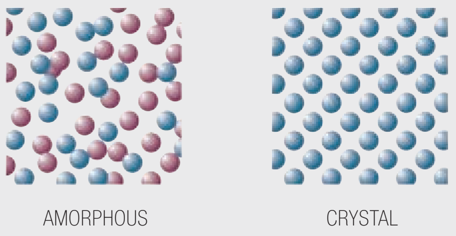
Solar cells are classified acc. to the material employed, i. e. crystal silicon, amorphous silicon, and compound semiconductor solar cells. Unlike crystal silicon, in which atomic arrangements are regular, amorphous silicon features irregular atomic arrangements as shown in the figures below.

Amorton is an integrated amorphous silicon solar cell which has been developed by SANYO. Amorton uses silane (SiH_4) as its source gas and is fabricated using a plasma CVD method. Three amorphous silicon layers – p-layer, i-layer, and n-layer – are formed consecutively on a glass substrate. This p-i-n junction corresponds to the p/n junction of a crystal silicon solar cell. In the process of this junction formation, a number of cells are connected in series on a substrate at one time. This allows any desired voltage to be obtained for a variety of equipment operation.

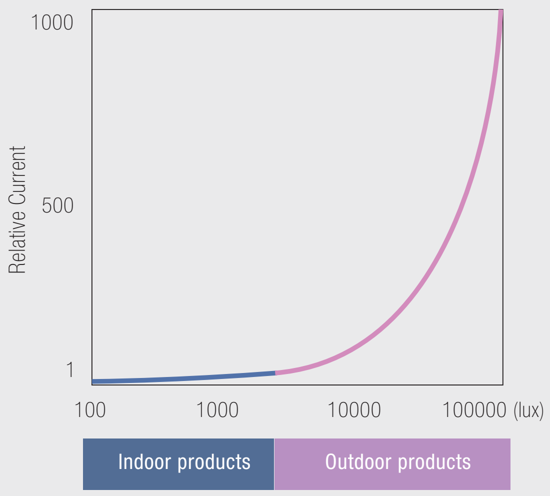
Features

- For indoor and outdoor use
- Glass substrate: low price (basic substrate)
- Stainless steel substrate:
  Thin, light weight, unbreakable, can easily be formed in arbitrary shapes, highly precise dimensions
- Film substrate:
  Thin, light weight, unbreakable, bendable, can easily be formed in arbitrary shapes
- Solar cells with a variety of voltages can be created
- Solar cells with a variety of shapes can be created

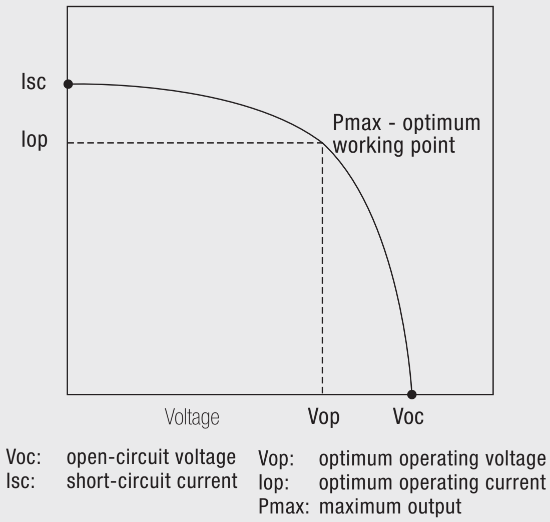
Amorphous atomic arrangement



Relationship between illumination level and output



Current-voltage curve



5.3 AMORTON – INDOOR & OUTDOOR

Amorton Products for Clocks (Application Example)


STAINLESS STEEL GLASS FILM

Output characteristics — indoor use Amorton

Indoors, artifical light, such as fluorescent and incandescent light, is used. The illuminance of these light sources ranges from 20 lux to 1,000 lux. Indoors, therefore, Amorton is most suitable for small equipment such as electronic calculators. Please use indoor the Amorton solar cells under 1,000 lux.

Typical cell characteristics

OPEN-CIRCUIT VOLTAGE	SHORT-CIRCUIT CURRENT	MAX. OUTPUT	LIGHT SOURCE
0.63 V/cell	17.0 μA/cm^2	7.0 μW/cm^2	FL200 lux

Output characteristics – Outdoor use Amorton

Natural light ranges in illuminance from 10,000 lux to 100,000 lux (AM-1.5, 100mW/cm^2) or more.

Typical cell characteristics

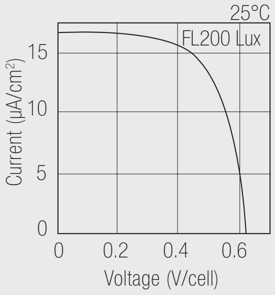
OPEN-CIRCUIT VOLTAGE	SHORT-CIRCUIT CURRENT	MAX. OUTPUT	LIGHT SOURCE
0.84 V/cell	13.3 mA/cm^2	7.48 mW/cm^2	AM-1.5 100 mW/cm^2

Applications

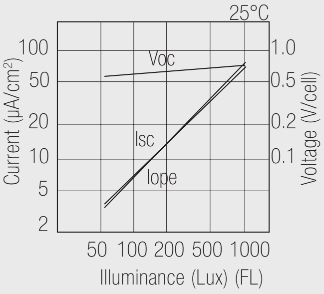
- Wrist watches (solar watches)
- Sensor lights
- Battery chargers
- Clocks
- LED blinkers (curbstone markers)
- Solar driven GSM/GPS modules

Output characteristics

Current - voltage characteristics of a cell

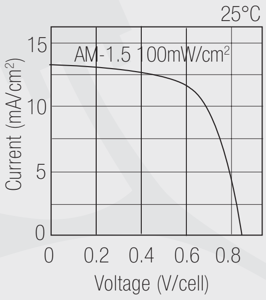


Output illuminance depency characteristics

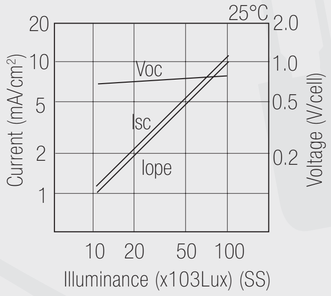


Output characteristics

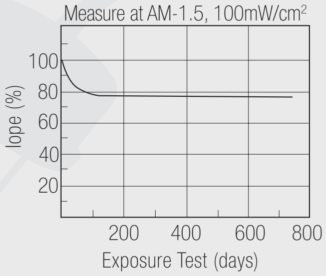
Current - Voltage Characteristics of a Cell



Output Illuminance Depency Characteristics



Lightproof (Leaving Outdoors)



Specifications of Amorton glass substrate – indoor products

PART NUMBER	TYPICAL OPERATING CHARACTERISTICS (FL-200 lux)	TYPICAL OPERATING CHARACTERISTICS (Ref:FL-50 lux)	EXTERNAL DIMENSIONS (mm)	WEIGHT (g)
AM-1407	1.5 V / 11.5 µA	1.4 V / 2.85 µA	38.0 × 12.5	1.30
AM-1417	1.5 V / 12.5 µA	1.4 V / 3.10 µA	35.0 × 13.9	1.30
AM-1424	1.5 V / 20.0 µA	1.4 V / 5.00 µA	53.0 × 13.8	2.00
AM-1437	1.5 V / 8.0 µA	1.4 V / 2.00 µA	29.6 × 11.8	1.00
AM-1454	1.5 V / 31.0 µA	1.4 V / 7.75 µA	41.6 × 26.3	3.00
AM-1456	1.5 V / 5.3 µA	1.4 V / 1.30 µA	25.0 × 10.0	0.70
AM-1513	1.8 V / 15.0 µA	1.6 V / 3.75 µA	55.0 × 13.5	2.00
AM-1801	3.0 V / 18.5 µA	2.6 V / 4.60 µA	53.0 × 25.0	3.60
AM-1805	3.0 V / 15.5 µA	2.6 V / 3.85 µA	55.0 × 20.0	3.00
AM-1815	3.0 V / 42.0 µA	2.6 V / 10.50 µA	58.1 × 48.6	7.80
AM-1816	3.0 V / 84.0 µA	2.6 V / 21.00 µA	96.7 × 56.7	15.6

Specifications of Amorton glass substrate – outdoor products

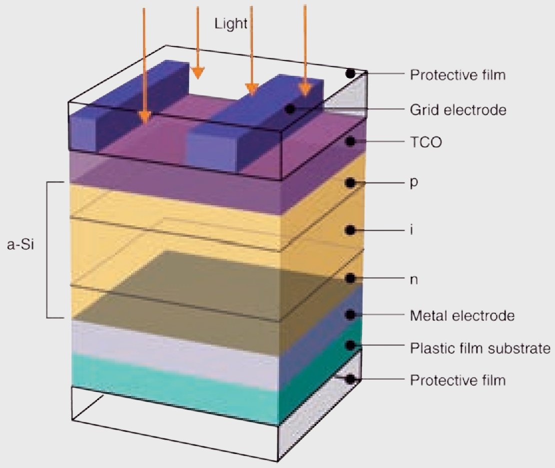
PART NUMBER	TYPICAL OPERATING CHARACTERISTICS (100 mW/cm^2)	TYPICAL OPERATING CHARACTERISTICS (Ref:SS 50 klux)	EXTERNAL DIMENSIONS (mm)	WEIGHT (g)
AM-5302	1.5 V / 105.0 mA	1.5 V / 47.0 mA	31.2 × 117.8	16.3
AM-5412	2.0 V / 39.0 mA	2.0 V / 17.2 mA	50.1 × 33.1	7.30
AM-5413	2.0 V / 16.3 mA	2.0 V / 7.2 mA	33.0 × 23.9*	2.10
AM-5416	2.0 V / 49.9 mA	2.0 V / 22.0 mA	60.1 × 36.7	9.80
AM-5605	3.0 V / 113.0 mA	3.0 V / 51.0 mA	62.3 × 117.8	32.5
AM-5608	3.0 V / 36.0 mA	3.0 V / 16.0 mA	60.1 × 41.3	11.0
AM-5610	3.0 V / 5.0 mA	3.0 V / 2.2 mA	25.0 × 20.0	2.20
AM-5611	3.0 V / 3.2 mA	3.0 V / 1.4 mA	33.4 × 10.0*	0.90
AM-5613	3.0 V / 31.5 mA	3.0 V / 14.0 mA	60.1 × 36.7	9.80
AM-5706	3.5 V / 45.0 mA	3.5 V / 20.0 mA	70.0 × 60.0	15.5
AM-5710	3.5 V / 32.0 mA	3.5 V / 14.0 mA	62.3 × 37.0*	6.30
AM-5812	4.0 V / 19.5 mA	4.0 V / 8.5 mA	59.0 × 28.7	4.60
AM-5902	4.5 V / 60.0 mA	4.5 V / 27.0 mA	150.0 × 37.5	25.0
AM-5904	4.5 V / 10.0 mA	4.5 V / 4.3 mA	40.1 × 33.1	5.90
AM-5907	4.5 V / 44.7 mA	4.5 V / 19.7 mA	75.0 × 55.0	18.3
AM-5909	4.5V / 22.2 mA	4.5 V / 9.8 mA	60.1 × 41.3	11.0
AM-5910	4.5 V / 88.5 mA	4.5 V / 9.8 mA	60.1 × 41.3	11.0
AM-5912	4.5 V / 15.4 mA	4.5 V / 6.8 mA	42.9 × 47.2*	5.60
AM-5913	4.5 V / 30.1 mA	4.5 V / 13.3 mA	60.1 × 55.1	14.7
AM-5914	4.5 V / 23.2 mA	4.5 V / 10.2 mA	50.1 × 55.1*	7.50
AM-5C03	6.0 V / 28.0 mA	6.0V / 12.5 mA	75.0 × 55.0	18.3
AM-5D01	6.5 V / 11.0 mA	6.5 V / 4.8 mA	100.0 × 18.0	8.00
AM-5E02	7.0 V / 23.3 mA	7.0 V / 10.3 mA	75.0 × 55.0	18.3
AM-5S04	15.0 V / 22.0 mA	15.0 V / 9.7 mA	124.5 × 57.0*	19.3
AM-5S05	15.0 V / 15.0 mA	15.0 V / 6.5 mA	124.5 × 39.3*	13.4
AM-5S06	15.0 V / 11.0 mA	15.0 V / 4.9 mA	124.5 × 29.5*	10.0
AM-7A03	5.3 V / 250.0 mA	5.3 V / 113.0mA	150.0 × 165.0	110
AM-7D08	7.0 V / 190.0 mA	7.0 V / 85.0 mA	150.0 × 165.0	110
AM-7E04	7.5 V / 115.0 mA	7.5 V / 50.0 mA	150.0 × 110.0	74.0
AM-7S03	15.0 V / 77.0 mA	15.0 V / 34.5 mA	150.0 × 165.0	110

Glass thickness with * is 1.1 mm, glass thickness without * is 1. 8 mm

5.4 AMORTON – FILM

Amorton flexible film is an exceptionally thin, light and flexible amorphous silicon solar cell fabricated on plastic film. In addition to these advantages, Amorton film is also resistant to cracks. Its standard configuration includes a protective film covering the amorphous silicon solar cell which measures about 0.4 mm in overall thickness.

Amorton film configuration



Specifications of Amorton flexible film

PART NUMBER	TYPICAL OPERATING CHARACTERISTICS (100 mW/cm^2)	TYPICAL OPERATING CHARACTERISTICS (Ref:SS 50 klux)	EXTERNAL DIMENSIONS (mm)	WEIGHT (g)
AT-7664	3.0V / 104 mA	3.0V / 46.5 mA	73..0 × 112.0 × 0.4	4
AT-7665	3.0V / 38.6 mA	3.0V / 17.3 mA	58..4 × 56.0 × 0.4	2
AT-7666	3.0V / 343.0 mA	3.0V / 154.0 mA	146.0 × 167.5 × 0.4	13
AT-7963	4.5V / 223.0 mA	4.5V / 100.0 mA	146.0 × 167.5 × 0.4	13
AT-7S63	15.0V / 134.0 mA	15.0V / 60.5 mA	292.0 × 168.0 × 0.4	25
AT-7S64	15.0V / 269.0 mA	15.0V / 121.0 mA	292.0 × 336.0 × 0.4	50

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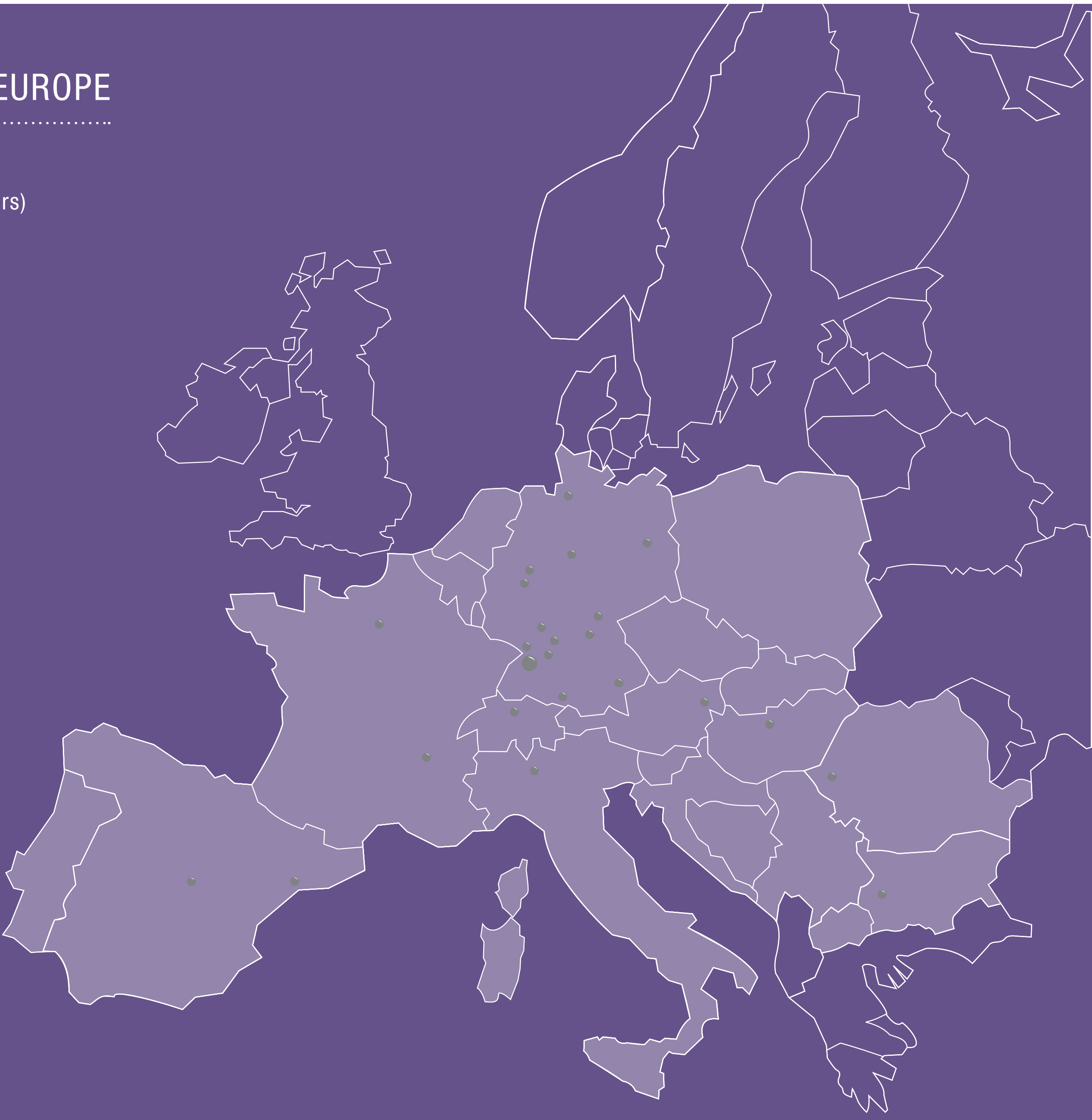

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www.endrich.com

ENDRICH Bauelemente Vertriebs GmbH · P.O.Box 1251 · D-72192 Nagold
Tel.: +49 (0) 7452 6007-0 · Fax: +49 (0) 7452 6007-70 · endrich@endrich.com · www.endrich.com

NOVITRONIC AG · Thurgauerstrasse 74 · CH-8050 Zürich
Tel.: +41 (0)44 306 91 91 · Fax +41 (0)44 306 91 81 · info@novitronic.ch · www.novitronic.ch