Industrial Sensors I & II

Choose yourself and new technologies

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[3] Burr-Brown products from Texas Instruments, XTR105 4-20mA CURRENT TRANSMITTER with sensor exitation and linearization, Texas Instruments Application Note, 2004, (www.ti.com)

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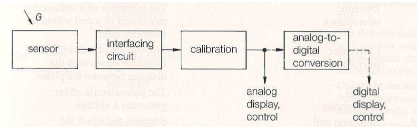
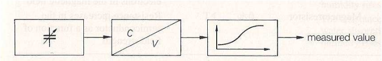
Introduction



Conversion of a physical quantity G into a calibrated electrical signal



A humidity sensor as an example of how the measured value is obtained

* Taken from [1]

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Introduction

Measurand	Sensor	Measurement range	Principle
Temperature	PTC metal	− 200 … + 800°C	Positive temperature coefficient of the resistance of metals; e.g., platinum
	PTC thermistor	− 50 … + 150°C	Positive temperature coefficient of the resistance of semiconductors; e.g., silicon
	NTC thermistor	− 50 … + 150°C	Negative temperature coefficient of the resistance of metal-oxide ceramic
	Transistor	− 50 … + 150°C	Negative temperature coefficient of the base–emitter voltage of a transistor
	Thermocouple	− 200 … + 2,800°C	Thermo-electric voltage at contact of different metals
	Crystal oscillator	− 50 … + 300°C	Temperature coefficient of the resonant frequency of specially cut quartz crystals

* Taken from [1]

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Introduction

Measurand	Sensor	Measurement range	Principle
Temperature via heat radiation	Pyrometer	− 100 … + 3,000°C	The spectral distribution of the luminance is temperature-dependent
	Pyroelement	− 50 … + 2,200°C	The increase in temperature due to radiated heat generates a polarization voltage
Light intensity	Photodiode Phototransistor	$10^{-2} \ldots 10^{5}$ lx	Current increases with light intensity due to optically released charge carriers
	Photoresistor	$10^{-2} \ldots 10^{5}$ lx	Electrical resistance reduces as the illumination increases
	Photomultiplier	$10^{-6} \ldots 10^{3}$ lx	Light releases electrons from a photocathode, which are multiplied by subsequent dynodes

* Taken from [1]

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Measurand	Sensor	Measurement range	Principle
Sound	Dynamic microphone		The induction of a voltage by movement of a coil within a magnetic field
	Condenser microphone		The voltage of a charged capacitor varies with the distance between the plates
	Crystal microphone		The piezoelectric effect generates a voltage
Magnetic field	Induction coil		Supplies voltage if the magnetic field changes or the coil moves within the field
	Hall-effect device	0.1 m … 1 T	Produces a voltage across the semiconductor by deflection of electrons in the magnetic field
	Magnetoresistor	0.1 … 1 T	Resistance increases in the semiconductor as a function of field strength

* Taken from [1]

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Measurand	Sensor	Measurement range	Principle
Force	Strain gauge	10^{-2} … 10^{7}N	Force causes elastic elongation of a thin-film resistor, thereby increasing its resistance
Pressure	Strain gauge	10^{-3} … 10^{3} bar	The bridge circuit of the strain gauge on the diaphragm is detuned by pressure
Acceleration	Strain gauge	1 … 5,000 g	The strain-gauge bridge is detuned by acceleration force on weighted diaphragm
Linear displacement	Potentiometric displacement transducer	µm … m	The potentiometer tap is shifted
	Inductive displacement transducer	µm … 10^{-1} m	The inductive bridge is unbalanced by displacement of a ferrite core
	Incremental displacement transducer, optical	µm … m	The reticle pattern is scanned. The number gives the displacement

* Taken from [1]

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Measurand	Sensor	Measurement range	Principle
Angle	Incremental angular displacement transducer, optical	1 … 20,000 per revolution	The reticle pattern is scanned. The number gives the angle of rotation
	Incremental angular displacement transducer, magnetic	1 … 1,000 per revolution	Magnetic scanning of a toothed-wheel sensor
	Incremental angular displacement transducer, capacitive	1 … 1,000 per revolution	Capacitive scanning of a toothed-wheel sensor
Flow velocity	Windmill-type anemometer		The rotational speed increases with the flow speed
	Heated-wire anemometer		Cooling increases with the flow rate
	Ultrasound transceiver		The Doppler shift increases with the flow rate

* Taken from [1]

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Measurand	Sensor	Measurement range	Principle
Gas concentration	Ceramic resistor		The resistance changes with the adsorption of the test substance
	MOSFET		Change in threshold voltage during adsorption of the test substance under the gate
	Absorption spectrum		Absorption lines are characteristic for each gas
Humidity	Capacitor	1 … 100%	The dielectric constant increases due to water absorption as the relative humidity rises
	Resistor	5 … 95%	The resistance decreases due to water absorption as the relative humidity rises

* Taken from [1]

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Metals as PTC thermistors

Metals posses a positive temperature coefficient.

'Pt...' – platinum temperature detectors. R_0 of the detector is specified at 0^0 C (Pt100, Pt200,…Pt1000).

In the temperature range $0^0C \le \vartheta \le 850^0C$

$$R_\vartheta = R_0\left[1 + 3.90802\cdot 10^{-3}\frac{\vartheta}{^0C} - 0.58095\cdot 10^{-6}\left(\frac{\vartheta}{^0C}\right)^2\right]$$

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Metals as PTC thermistors

In the temperature range $-200^0C \le \vartheta \le 0^0C$

$$R_\vartheta = R_0[1 + 3.90802\cdot 10^{-3}\frac{\vartheta}{^0C} - 0.58095\cdot 10^{-6}\left(\frac{\vartheta}{^0C}\right)^2$$

$$+ 0.42735\cdot 10^{-9}\left(\frac{\vartheta}{^0C}\right)^3 - 4.2735\cdot 10^{-12}\left(\frac{\vartheta}{^0C}\right)^4]$$

With nickel-iron temperature detectors R_0 is specified at 20^0C.

For the temperature range $-50^0C \le \vartheta \le 150^0C$

$$R_\vartheta = R_{20}\left[1 + 3.83\cdot 10^{-3}\frac{\vartheta}{^0C} - 4.64\cdot 10^{-6}\left(\frac{\vartheta}{^0C}\right)^2\right]$$

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Silicon-based PTC Thermistors

Uniformly doped silicon posses a positive temperature coefficient.

$$R_\vartheta = R_{25}\left[1 + 7.95\cdot 10^{-3}\,\frac{\vartheta}{{}^0C} + 1.95\cdot 10^{-5}\left(\frac{\vartheta}{{}^0C}\right)^2\right]$$

Where R_{25} is a nominal resistance at 25^0C.

This equation is valid only for sensor of KTS-series from Infineon and Philips and is only approximate for other manufacturers.

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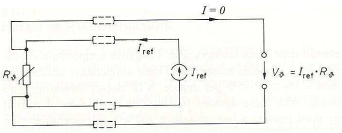
Temperature coeffiecient

Temperature coeffiecient: $TC = \frac{1}{R}\cdot\frac{dR}{d\vartheta}$



A four-wire resistance measuring circuit that provides independence from lead resistance

* Taken from „Electronic circuits : handbook for design and application" Tietze U., Schenk C. [1]

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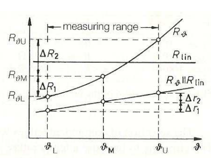
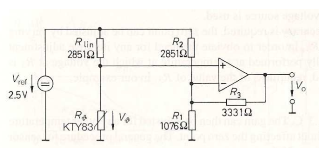
Linearization of the PTC thermistors





Principle of linearized operation and the example of linearization, zero shift and gain for a silicon PTC sensors

* Taken from [1]

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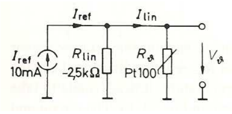
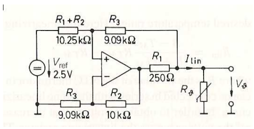
Linearization of the PTC thermistors





Principle of linearized operation of Pt... Sensors, and implementation of a current source that has a negative output resistance

* Taken from [1]

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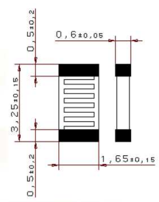
Temperature range	- 50 °C to + 130 °C (Possible working temperatures using volume expansion aligned conductor board material: 150°C)
Temperature coefficient	TCR = 3850 ppm/K
Soldering connection	end-termination galvanic tin plated with Ni-barrier
Long term stability	max. R_0-drift 0.06 % after 1000 h at 130 °C
Environmental conditions	unhoused for dry environments only
Insulation resistance	> 100 MΩ at 20 °C; > 2 MΩ at 130 °C (glass covering)
Measuring current	100Ω: 0.3 to 1.0 mA 1000Ω: 0.1 to 0.3 mA (self heating has to be considered)
Self heating	0.4 K/mW at 0 °C
Response time	water current (v = 0.4 m/s): $t_{0.5}$ = 0.15 s; $t_{0.9}$ = 0.30 s air stream (v = 2 m/s): $t_{0.5}$ = 3.5 s; $t_{0.9}$ = 10 s



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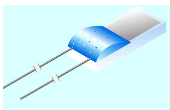
Examples of Pt100/1000 packeges

PT1000-SOT223

PT100-TO92



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Industrial thermometer housing

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Industrial thermometer housing

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NTC Thermistors

NTC thermistors are temperature-dependent resistors with a very large, negative temperature coefficient. They are made of metal-oxide ceramic materials.

If the temperature of interest T is close to nominal temperature T_N:

$$R_T = R_N \exp\left[B\left(\frac{1}{T}-\frac{1}{T_N}\right)\right]$$

Temperature in Kelvin $T = \vartheta + 273$

B is between 1500K and 7000K.

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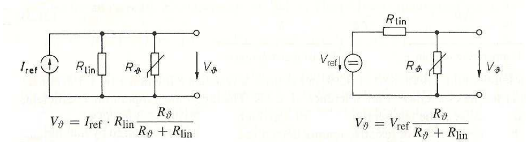
Linearization of the NTC thermistors



Linearization of NTC thermistors characteristic using R_{lin}.

* Taken from [1]

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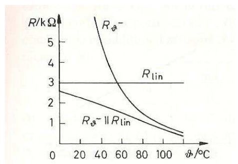
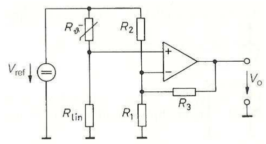
Linearization of the NTC thermistors



Linearization of an NTC thermistor using a parallel resistor



An interfacing circuit that provides linearization, zero shift, and gain for NTC thermistor

* Taken from [1]

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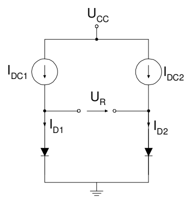
Diodes and Transistors as Temperature Sensors



$$U(T) = m\varphi_T(T)\ln\left(\frac{I_D}{I_R(T)}\right)$$

$$\varphi_T(T) = \frac{kT}{q}$$

$$U_R = U_{D2} - U_{D1} = m\varphi_T \ln\left(\frac{I_{D2}}{I_{D1}}\right)$$

$$\frac{dU_R}{dT} = \frac{nk}{q}\ln\left(\frac{I_{D2}}{I_{D1}}\right)$$

$$\frac{dU_D}{dT} \approx -2mV/\deg\_ \ for\_I_D = 2mA$$

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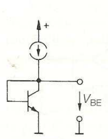
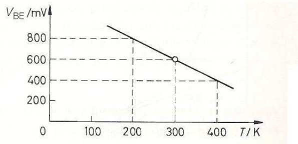
Diodes and Transistors as Temperature Sensors



The use of the base-emitter voltage for temperature measurement



Base-emitter voltage as a function of temperature

* Taken from [1]

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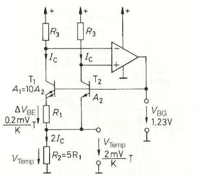
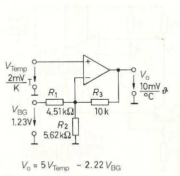
Diodes and Transistors as Temperature Sensors



Use of a bandgap reference for temperature measurement (e. g. LT1019)



A supplementary circuit for implementing a Celsius zero point

* Taken from [1]

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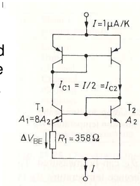
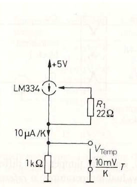
Diodes and Transistors as Temperature Sensors

A temperature controlled current source using the bandgap principle (e. g. AD592)





A temperature controlled current source with a freely selectable output current (e. g. LM344)

* Taken from [1]

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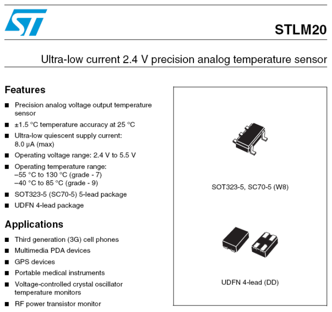
Transistor Temperature Sensors example


STLM20

Ultra-low current 2.4 V precision analog temperature sensor

Features

- Precision analog voltage output temperature sensor
- ±1.5 °C temperature accuracy at 25 °C
- Ultra-low quiescent supply current: 8.0 µA (max)
- Operating voltage range: 2.4 V to 5.5 V
- Operating temperature range: −55 °C to 130 °C (grade - 7) −40 °C to 85 °C (grade - 9)
- SOT323-5 (SC70-5) 5-lead package
- UDFN 4-lead package

Applications

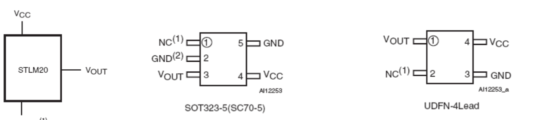
- Third generation (3G) cell phones
- Multimedia PDA devices
- GPS devices
- Portable medical instruments
- Voltage-controlled crystal oscillator temperature monitors
- RF power transistor monitor

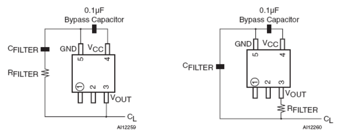
SOT323-5, SC70-5 (W8)

UDFN 4-lead (DD)

* Taken from „STLM20 – Ultra-low current 2.4V precision analog temperature sensor", Technical Data Sheet, ST microelectronics, 2009 [8]

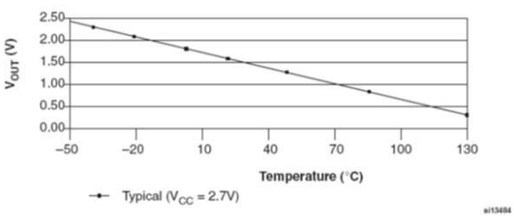
Transistor Temperature Sensors example





* Taken from „STLM20 – Ultra-low current 2.4V precision analog temperature sensor", Technical Data Sheet, ST microelectronics, 2009 [8]

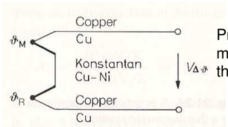
Transistor Temperature Sensors example



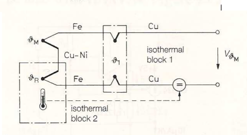
STLM20 V_{OUT} vs temperature

* Taken from „STLM20 – Ultra-low current 2.4V precision analog temperature sensor", Technical Data Sheet, ST microelectronics, 2009 [8]

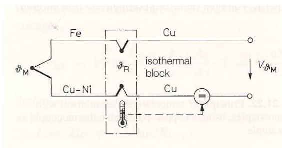
Thermocouples



Principle of temperature measurement with thermocouples



Compensation of the reference junction temperature



A practical configuration for a thermocouple systems

* Taken from [1]

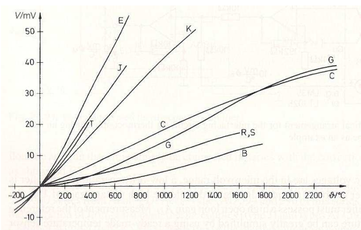
Thermocouples

Ty	Metal 1, positive terminal	Metal 2, negative terminal	Temperature coefficient, average	Usable temperature range
T	Copper	Constantan	42.8 μV/°C	− 200 to + 400°C
J	**Iron**	**Constantan**	51.7 μV/°C	− 200 to + 700°C
E	Chromel	Constantan	60.9 μV/°C	− 200 to +1, 000°C
K	**Chromel**	**Alumel**	40.5 μV/°C	− 200 to +1, 300°C
S	Platinum	Platinum– 10% rhodium	6.4 μV/°C	0 to +1, 500°C
R	Platinum	Platinum– 13% rhodium	6.4 μV/°C	0 to +1, 600°C
B	Platinum– 6% rhodium	Platinum– 30% rhodium		0 to +1, 800°C
G	Tungsten	Tungsten– 26% rhenium		0 to +2, 800°C
C	Tungsten– 5% rhenium	Tungsten– 26% rhenium	15 μV/°C	0 to +2, 800°C

Overview of thermocouples. The most widely used types. Types B and G are so nonlinear that no average temperature coefficient ca be specified Constantan = copper-nickel, Cromel = nickel-chromium, Alumel = aluminium - nickel

* Taken from „Electronic circuits : handbook for design and application" Tietze U., Schenk C. [1]

Thermocouples



Thermoelectric voltage versus temperature for various thermocouples, at a reference temperature of 0^0C

* Taken from [1]

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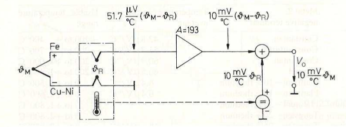
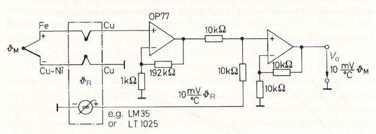
Thermocouples



An example of the amplification and reference point compensation for thermocouples (iron-constantan)



A practical arrangement for the interface circuit

* Taken from [1]

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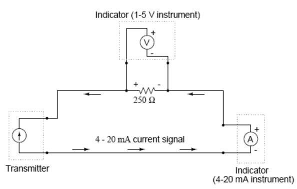
Measuring signal transmission



* Taken from „ Lessons In Electric Circuits, Volume I – DC, Kuphaldt T. R., Open Book Project, 2006 [4]

Percent of measurement	4-20 mA signal	1-5 V signal
0	4.0 mA	1.0 V
10	5.6 mA	1.4 V
20	7.2 mA	1.8 V
25	8.0 mA	2.0 V
30	8.8 mA	2.2 V
40	10.4 mA	2.6 V
50	12.0 mA	3.0 V
60	13.6 mA	3.4 V
70	15.2 mA	3.8 V
75	16.0 mA	4.0 V
80	16.8 mA	4.2 V
90	18.4 mA	4.6 V
100	20.0 mA	5.0 V

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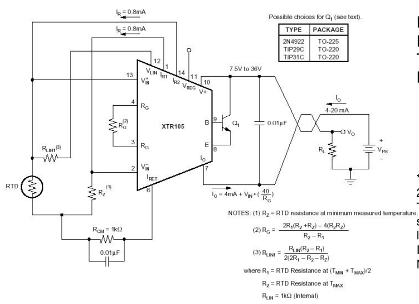
Thermocouples



RTD – Resistive Temperature Detector

* Taken from „XTR105 4-20mA CURRENT TRANSMITTER with sensor exitation and linearization", Texas Instruments Application Note, 2004 [2]

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Thermocouples

MEASUREMENT TEMPERATURE SPAN ΔT (°C)

T_{MIN}	100°C	200°C	300°C	400°C	500°C	600°C	700°C	800°C	900°C	1000°C
–200°C	18.7/86.6 15000 16500	18.7/169 9760 11500	18.7/255 8060 10000	18.7/340 6650 8870	18.7/422 5620 7870	18.7/511 4750 7150	18.7/590 4020 6420	18.7/665 3480 5900	18.7/750 3090 5360	18.7/845 2740 4990
–100°C	60.4/80.6 27400 29400	60.4/162 15400 17800	60.4/243 10500 13000	60.4/324 7870 10200	60.4/402 6040 8660	60.4/487 4990 7500	60.4/562 4220 6490	60.4/649 3570 5900	60.4/732 3090 5360	
0°C	100/78.7 33200 35700	100/158 16200 18700	100/237 10500 13000	100/316 7680 10000	100/392 6040 8250	100/475 4870 7150	100/549 4020 6340	100/634 3480 5620		
100°C	137/75 31600 34000	137/150 15400 17800	137/226 10200 12400	137/301 7500 9760	137/383 5760 8060	137/453 4750 6810	137/536 3920 6040			
200°C	174/73.2 30900 33200	174/147 15000 17400	174/221 9760 12100	174/294 7150 9310	174/365 5620 7680	174/442 4530 6490				
300°C	210/71.5 30100 32400	210/143 14700 16500	210/215 9530 11500	210/287 6980 8870	210/357 5360 7320					
400°C	249/68.1 28700 30900	249/137 14000 16200	249/205 9090 11000	249/274 6650 8450						
500°C	280/66.5 28000 30100	280/133 13700 15400	280/200 8870 10500							
600°C	316/64.9 26700 28700	313/130 13000 14700								
700°C	348/61.9 26100 27400									
800°C	374/60.4 24900 26700									

[R_Z/R_G, R_{LIN1}, R_{LIN2}]

NOTE: The values listed in this table are 1% resistors (in Ω). Exact values may be calculated from the following equations:

R_Z = RTD resistance at minimum measured temperature.

$$R_G = \frac{2(R_2 - R_Z)(R_1 - R_Z)}{(R_2 - R_1)}$$

$$R_{LIN1} = \frac{R_{LIN}(R_2 - R_1)}{2(2R_1 - R_2 - R_Z)}$$

$$R_{LIN2} = \frac{(R_{LIN} + R_G)(R_2 - R_1)}{2(2R_1 - R_2 - R_Z)}$$

where: R_1 = RTD resistance at $(T_{MIN} + T_{MAX})/2$
R_2 = RTD resistance at T_{MAX}
R_{LIN} = 1kΩ (Internal)

* Taken from „XTR105 4-20mA CURRENT TRANSMITTER with sensor exitation and linearization", Texas Instruments Application Note, 2004 [2]

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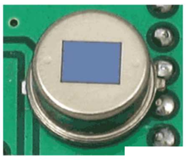
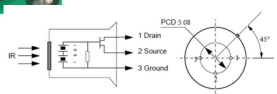
pyroelectric sensor





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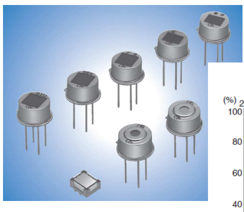
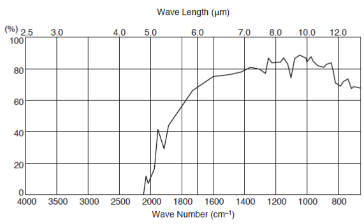
pyroelectric sensor by muRata





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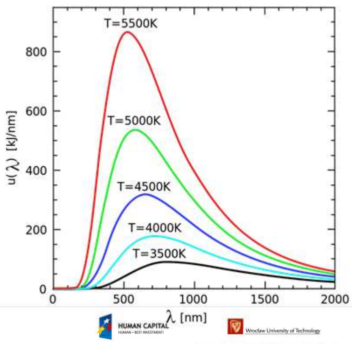


Temperature Sensors Summary (RTD)

Type	Manufacturer	Output signal nominal value	Temperature range
Metal PTC thermistor			
Pt 100…1000	Heraeus	100…1000 Ω	− 50 …+ 500°C
Fk 100…2000	Heraeus	100…2000 Ω	− 200 …+ 500°C
1 Pt 100…1000	Omega	100…1000 Ω	− 70 …+ 500°C
Pt 100…1000	Murata	100…1000 Ω	− 50 …+ 600°C
Pt 100…1000	Sensycon	100…1000 Ω	− 50 …+ 600°C
Silicon PTC thermistor			
AD 22100[1]	Analog D.	22 mV/K	− 50 …+ 150°C
KTY-Series	Infineon	1…2 kΩ	− 50 …+ 150°C
KTY-Series	Philips	1…2 kΩ	− 50 …+ 300°C
Metal-ceramic NTC thermistors			
M-Series	Infineon	1 k…100 kΩ	− 50 …+ 200°C
NTH-Series	Murata	100 Ω…100 kΩ	− 50 …+ 120°C
Thermistors	Philips	1 kΩ…1 MΩ	− 50 …+ 200°C

* Taken from [1]

Temperature Sensors Summary (other)

Type	Manufacturer	Output signal nominal value	Temperature range
Bandgap sensors			
AD 7818[2]	Analog Dev.	4 LSB/K	− 55 …+ 125°C
TMP 04	Analog Dev.	PWM-Output	− 40 …+ 100°C
TMP 17	Analog Dev.	1μA/K	− 40 …+ 105°C
TMP 36	Analog Dev.	10 mV/K	− 40 …+ 125°C
LT 1025[3]	Lin. Tech.	10 mV/K	0 … + 60°C
MAX 6607	Maxim	10 mV/K	−20 … + 85°C
DS 18B 20[2]	Maxim	20 LSB/K	−55 …+ 125°C
LM 45	National	10 mV/K	−20 …+ 100°C
LM 60	National	6 mV/K	−40 …+ 125°C
LM 74[2]	National	16 LSB/K	−55 …+ 150°C
LM 134	National	0.1 … 10 μA/K	−40 …+ 125°C
TMP 125	Texas Inst.	4 LSB/K	−40 …+ 125°C
Thermocouples			
J, K, S, R, B	Heraeus	Fig. 21.26	Fig. 21.26
J, K, S, R, B, T, E, C, G	Omega	Fig. 21.26	Fig. 21.26
J, K, S	Philips	Fig. 21.26	Fig. 21.26
J, K, S, R, B	Sensycon	Fig. 21.26	Fig. 21.26
Thermocouple amplifiers			
AD 594	Analog Dev.	type J 10 mV/°C	− 55°C …+ 125°C
AD 595	Analog Dev.	type K 10 mV/°C	− 55°C …+ 125°C

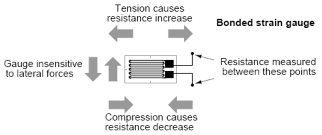
[1] Amplifier integrated
[2] ADC integrated
[3] Additional outputs for reference junction compensation of thermocouples

- crystal oscillator
- pyrometer (bolometer, thermocouple…)
- -pyroelement

* Taken from [1]

Strain guages

If a strip of conductive metal is stretched, it will become skinnier and longer, both changes resulting in an increase of electrical resistance end-to-end. Conversely, if a strip of conductive metal is placed under compressive force (without buckling), it will broaden and shorten.



$$R\uparrow = \rho \frac{l\uparrow}{s\downarrow}$$

$$U\uparrow = R\uparrow \cdot I$$

* Taken from [1]

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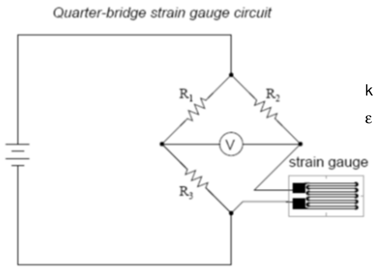
Strain guages



$$\frac{\Delta R_T}{R_T} = k\varepsilon$$

k – strain guage constant

ε - unit elongation

$$R_T = (30 - 3000)\Omega$$

* Taken from „ Lessons In Electric Circuits, Volume I – DC, Kuphaldt T. R., Open Book Project, 2006 [4]

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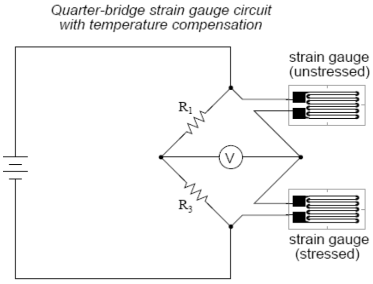
Strain guages



* Taken from [4]

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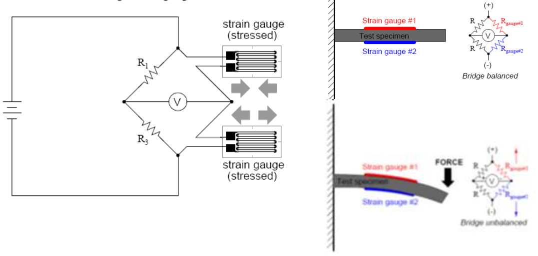
Strain guages

Half-bridge strain gauge circuit



* Taken from [4]

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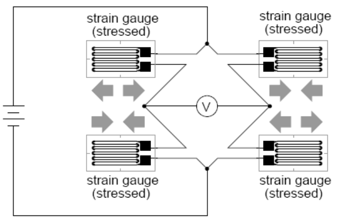
Strain guages

Full-bridge strain gauge circuit



* Taken from [4]

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Strain guages

Prime Strain Gage Selection Considerations

- Gage Length
- Number of Gages in Gage Pattern
- Arrangement of Gages in Gage Pattern
- Grid Resistance
- Strain Sensitive Alloy
- Carrier Material
- Gage Width
- Solder Tab Type
- Configuration of Solder Tab
- Availability

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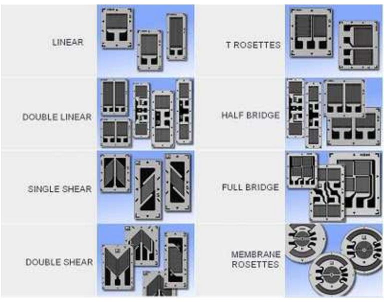

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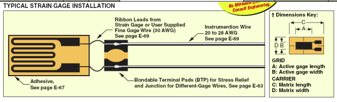
Strain guages

To Order (Specify Model Number)

	MODEL NO.	PRICE PER PKG OF 10	NOM. RESISTANCE (Ω)	DIMENSIONS mm (in)† GRID A	GRID B	CARRIER C	CARRIER D	MAX V* (Vrms)	TERMINATION	TEMP COMP	TERM PAD
Shown actual size 4.70 mm; Leads not shown	SGD-1.5/120-LY11	$49	120	1.50 (0.059)	1.20 (0.047)	4.70 (0.185)	3.40 (0.134)	2.5	Ribbon Leads	ST	BTP-1
	SGD-1.5/120-LY13	49	120	Miniature linear pattern Measurement of stress concentration 120 Ω				3.5	Ribbon Leads	AL	
	SGD-1.5/120-LY41	45	120					2.5	Solder Pads	ST	
	SGD-1.5/120-LY43	45	120					3.5	Solder Pads	AL	
Shown actual size 7.60 mm; Leads not shown	SGD-2/350-LY11	$55	350	2.00 (0.079)	2.50 (0.098)	7.60 (0.299)	5.80 (0.228)	7.5	Ribbon Leads	ST	BTP-2
	SGD-2/350-LY13	55	350	Miniature linear pattern Measurement of stress concentration, higher resistance, reduced heat generation 350 Ω				10	Ribbon Leads	AL	
	SGD-2/350-LY41	45	350					7.5	Solder Pads	ST	
	SGD-2/350-LY43	45	350					10	Solder Pads	AL	

TYPICAL STRAIN GAGE INSTALLATION



* Taken from [5]

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Economic ctrain gauge

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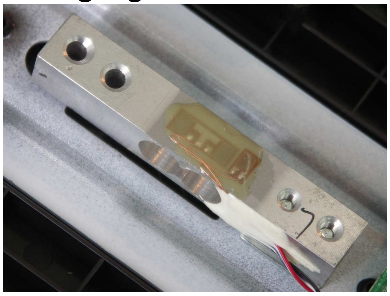
Strai gauge – mechanical construction



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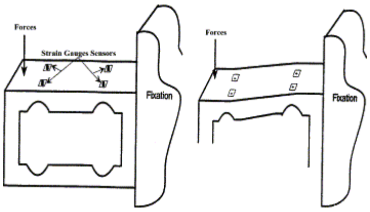
deformation of a mechanical transducer



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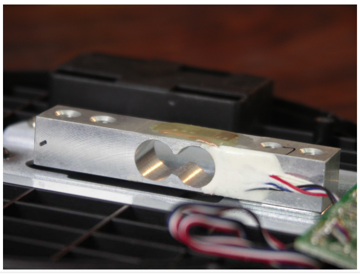
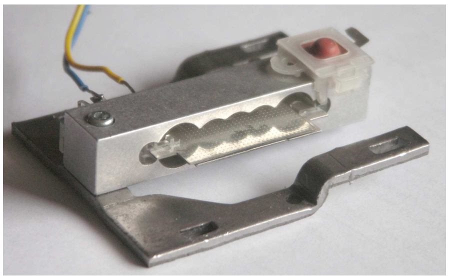
Strain gauge – mechanical construction



Strain gauge - capacitive



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Pressure Measurement

Pressure range	Application
< 40 mbar	Water level in a washing machine, dishwashert
100 mbar	Vacuum cleaner, filtration monitoring, flow measurement
200 mbar	Blood pressure measurement
1 bar	Barometer, motor vehicle (correction for ignition and fuel injection)
2 bar	Motor vehicle (tire pressure)
10 bar	Expresso machinery
50 bar	Pneumatics, industrial robots
500 bar	Hydraulics, construction machinery
2000 bar	Car motor with fuel injection

Pressures that occur in practical applications

* Taken from [1]

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Pressure Measurement

Definisions: $1\_Pascal = \frac{1\_Newton}{1\_Square\_meter}$

1 bar = 100 kPa 1 mbar = 1 hPa

$$1\_cmH_2O = 98.1\_Pa = 0.981\_mbar$$
$$1\_mmHg = 133\_Pa = 1.33\_mbar$$

$$1\_psi = punds\_per\_square\_inch$$
$$1\_psi = 6.98\_kPa = 68.9\_mbar$$

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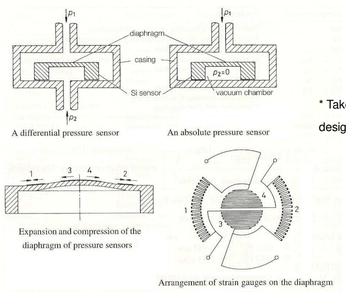
Pressure Measurement



* Taken from „Electronic circuits : handbook for design and application" Tietze U., Schenk C. [1]

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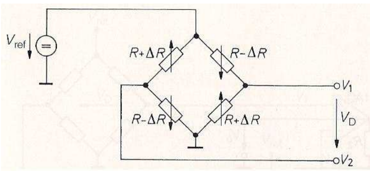
Pressure Measurement



Measuring bridge of a pressure sensor

$$\frac{V_D}{V_{ref}} = \frac{R+\Delta R}{2R} - \frac{R-\Delta R}{2R} = \frac{\Delta R}{R}$$

$$S = \frac{\Delta V_D}{\Delta p V_{ref}} = \frac{\Delta R}{\Delta p \cdot R}$$

* Taken from „Electronic circuits : handbook for design and application" Tietze U., Schenk C. [1]

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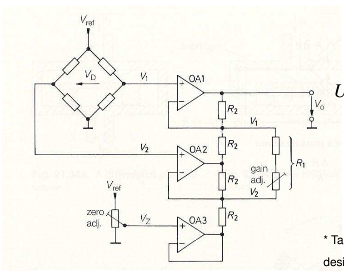
Pressure Measurement

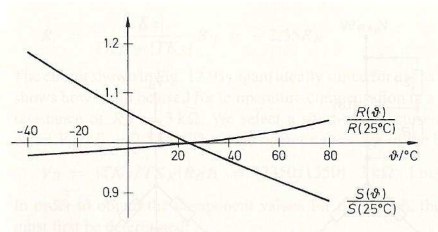


An interfacing circuit for pressure sensor

$$U_{out} = \underbrace{2\left(1+\frac{R_2}{R_1}\right)}_{GAIN}\underbrace{(U_1-U_2)}_{U_D}+\underbrace{U_Z}_{U_0}$$

* Taken from „Electronic circuits : handbook for design and application" Tietze U., Schenk C. [1]

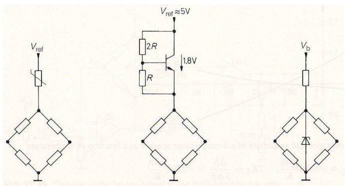
Pressure Measurement



Resistance and sensitivity of silicon pressure sensors as a function of temperature

* Taken from „Electronic circuits : handbook for design and application" Tietze U., Schenk C. [1]

Pressure Measurement



Temperature compensation method for pressure sensors

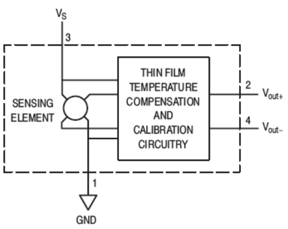
An NTC thermistor - an example; SDX-series from SenSym

Approximately three diodes - an example; KP100A1 from Philips

A badgap temperature sensor - an example; LM335 from National

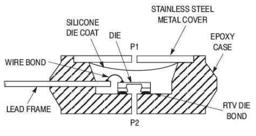
* Taken from [1]

Pressure Measurement

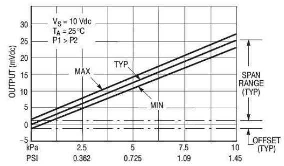


* Taken from „MPX2010 10kPa on-chip temperature compensated & calibrated silicon pressure sensor", Motorola Technica Data, 2002 [3]

Pressure Measurement



Unibody Package — Cross–Sectional Diagram (not to scale)



Output versus Pressure Differential

* Taken from „MPX2010 10kPa on-chip temperature compensated & calibrated silicon pressure sensor", Motorola Technica Data, 2002 [3]

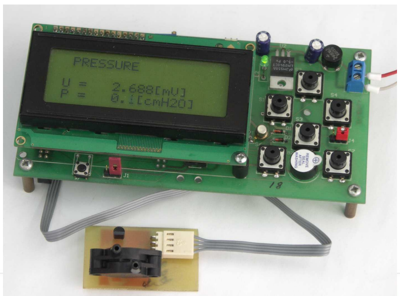
Pressure Measurement

Type	Manufacturer	Pressure range	Measurement range	Zero point error	Bridge resistance	Temp. compensation
MPX 10	Freescale	0.1…0.5 bar	35 mV	50%	1 kΩ	—
MPX 2000	Freescale	0.1…2 bar	40 mV	3%	2 kΩ	internal
MPX 5000*	Freescale	40 m…10 bar	4.5 V	1%	—	internal
40PC*	Honeywell	1…17 bar	4 V	2%	—	internal
170PC	Honeywell	17…70 mbar	30 mV	10%	6 kΩ	21.41a
180PC*	Honeywell	0.3…10 bar	5 V	2%	—	internal
240PC*	Honeywell	1…35 bar	5 V	1%	—	internal
KP100*	Infineon	1 bar	14 bit	10 %	—	internal
KP120*	Infineon	1 bar	4 V	2 %	—	internal
NPC 12xx	Novasensor	70 m…7 bar	75 mV	3 %	4 kΩ	internal
NPH	Novasensor	25 m…0.4 bar	100 mV	3 %	4 kΩ	internal
ASDX*	SenSym	70 m…7 bar	4 V	2 %	—	internal
SDX	SenSym	70 m…7 bar	90 mV	3 %	4 kΩ	21.41a
SX	SenSym	70 m…20 bar	110 mV	40 %	4 kΩ	—
Sensor Amplifiers						
MAX 1450	Maxim		4.5 V	1 %		21.42

* Integrated amplifier

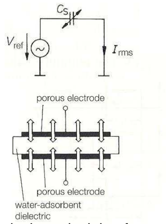
* Taken from „Electronic circuits : handbook for design and application" Tietze U., Schenk C. [1]

Lab setup of pressure sensor

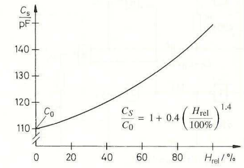


Humidity Sensors

$$H_{abs} = \frac{mass\_of\_water}{volume\_of\_air}\left[\frac{g}{m^3}\right]$$



Internal design principle of a capacitive humadity sensor and the452 principle of operation



Sensor capacitance versus relative humadity. Example: No.232691 90001 from Philips

* Taken from [1]

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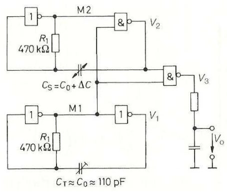
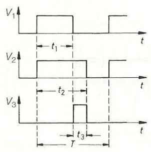
Humidity Sensors



Determining the increase in capacitance by measuring the increase in oscillation period (Gates: CMOS; for example CD4001)



Output signal resulting from the difference in switching times

Sensor example: SHT10, SHT11, SHT15 (www.sensirion.com/humidity)

* Taken from [1]

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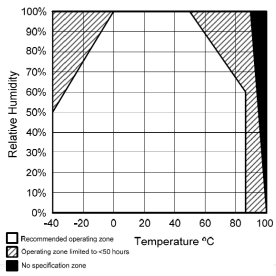
Honeywell humidity sensors



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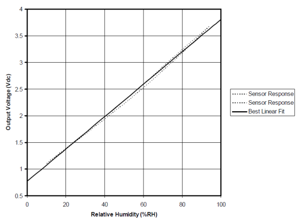
Honeywell humidity sensors



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The HIH-5031 is a covered, condensation-resistant, integrated circuit humidity sensor that is factory-fitted with a hydrophobic filter allowing it to be used in many condensing environments including industrial, medical and commercial applications.

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Oxygen sensors

Water quality control – KDS25B.


FIGARO PRODUCT INFORMATION

GS Yuasa Dissolved Oxygen Sensor KDS-25B

Features:

* Long life
* Virtually no influence from CO_2
* No external power supply required for sensor operation
* No warmup time is required

Applications:

* Water quality control

The GS Yuasa Dissolved Oxygen Sensor KDS-25B is a unique galvanic cell type sensor which was developed for water quality control. Its most notable features are long life expectancy and it is not influenced by CO_2.

* Taken from „ Product information – GS Yuasa Dissolved Oxygen Sensor KDS-25B", Technical Data Sheet, Figaro Engineering Inc., 2007 [6]

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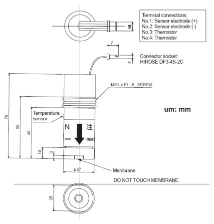
Oxygen sensors

Water quality control – KDS25B.



Specifications

Item		Model KDS-25B
Measurement range		0~80mg/L dissolved oxygen
Accuracy in water at 25˚C±1˚C		±5% (full scale)
Operating conditions	Atmospheric pressure	81~203kPa (corresponds to 10m of water depth)
	Temperature	5~35˚C
	Relative humidity	10 ~ 90%R.H. (no condensation)
Thermal time constant		10 min. or less
Initial output voltage in clean air under standard test conditions		8.0~15.0mV
Standard test conditions	Atmospheric pressure	1013±5hPa
	Temperature	25˚C±1˚C
	Relative humidity	60±5%

* Taken from „ Product information – GS Yuasa Dissolved Oxygen Sensor KDS-25B", Technical Data Sheet, Figaro Engineering Inc., 2007 [6]

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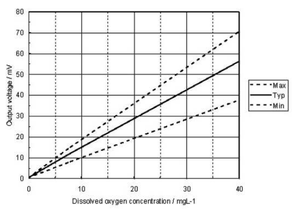
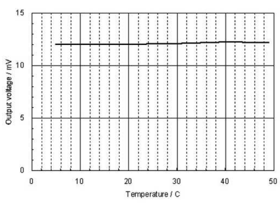
Oxygen sensors

Water quality control – KDS25B.





* Taken from „ Product information – GS Yuasa Dissolved Oxygen Sensor KDS-25B", Technical Data Sheet, Figaro Engineering Inc., 2007 [6]

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Oxygen sensors

Percent oxygen present in a particular atmosphere – KE25/50

Features

* Long life (KE-25 - 5 years / KE-50 - 10 years)
* Virtually no influence from CO_2, CO, H_2S, NO_x, H_2
* Low cost
* Operates in normal ambient temperatures
* Stable output signal
* No external power supply required for sensor operation
* No warm-up time is required

Applications

* Medical - Anesthetic instruments, respirators, oxygen-enrichers
* Biotechnology - Oxygen incubators
* Food industry - Refrigeration, greenhouses
* Safety - Air conditioners, oxygen detectors, fire detectors

*Taken from „Technical information for GS Oxygen sensor KE series", Technical Data Sheet, Figaro Engineering Inc., 2007 [7]

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Oxygen sensors

Theory of operation of the KE25/50 - the KE series sensor is a lead-oxygen battery which incorporates a lead anode, an oxygen cathode made of gold, and a weak acid electrolyte. Oxygen molecules enter the electrochemical cell through a non-porous fluorine resin membrane and are reduced at the gold electrode with the acid electrolyte. The current which flows between the electrodes is proportional to the oxygen concentration in the gas mixture being measured. The terminal voltages across the thermistor (for temperature compensation) and resistor are read as a signal, with the change in output voltages representing the change in oxygen concentration.

*Taken from „Technical information for GS Oxygen sensor KE series", Technical Data Sheet, Figaro Engineering Inc., 2007 [7]

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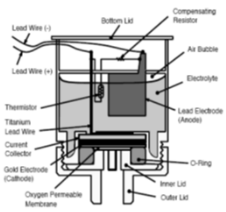
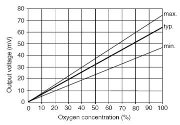
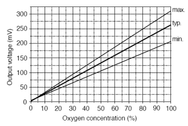
Oxygen sensors



Structure of KE25/50



KE25



KE50

*Taken from „Technical information for GS Oxygen sensor KE series", Technical Data Sheet, Figaro Engineering Inc., 2007 [7]

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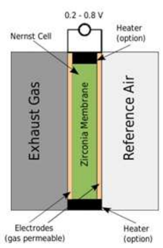
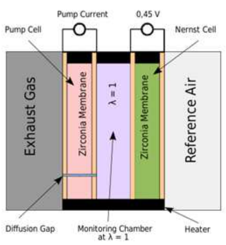
The zirconium dioxide lambda sensor



A planar zirconia sensor



A planar wideband zirconia sensor

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Titania sensor

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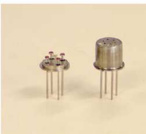
Air quality sensors

Air quality control sensor – TGS 2600

Technical Information for Air Quality Control Sensors

The Figaro 2600 series is a new type thick film metal oxide semiconductor, screen printed gas sensor which offers miniaturization and lower power consumption. The TGS2600 displays high selectivity and sensitivity to low concentrations of various air contaminants such as those found in cigarette smoke.



Features

- High selectivity to low gas concentrations
- Low power consumption
- Small size
- Long life

Applications

- Air cleaners for indoor air cleaners
- Air cleaners for vehicles
- Air quality monitors

*Taken from „Technical information for air quality control sensor TGS 2600", Technical Data Sheet, Figaro Engineering Inc., 2004, [9]

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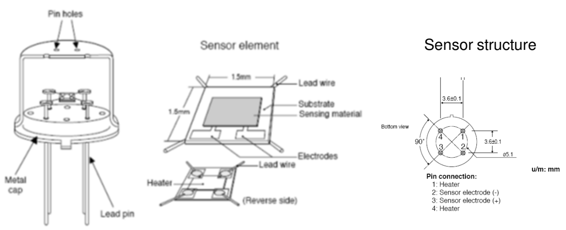
Air quality sensors

Air quality control sensor – TGS 2600



*Taken from „Technical information for air quality control sensor TGS 2600", Technical Data Sheet, Figaro Engineering Inc., 2004, [9]

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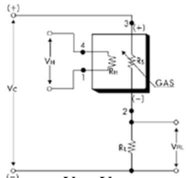
Air quality sensors

The structure of TGS2600. Using thick film techniques, the sensor material is printed on electrodes (noble metal) which have been printed onto an alumina substrate. The main sensing material of the sensor element is tin dioxide (SnO2). One electrode is connected to pin No.2 and the other is connected to pin No.3. An RuO2 heater printed onto the reverse side of the substrate and connected to pins No.1 and No.4 heats the sensing material. Lead wires are Pt-W and connected to sensor pins which are made of Ni-plated Ni-Fe 50%. The sensor base is made of Ni-plated steel. The sensor cap is made of stainless steel and contains 6 pin holes on the sensor's top.



$$R_S = \frac{V_C - V_{out}}{V_{out}} R_L$$

*Taken from „Technical information for air quality control sensor TGS 2600", Technical Data Sheet, Figaro Engineering Inc., 2004, [9]

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Air quality sensors

Item	Specification
Circuit voltage (Vc)	5.0V ± 0.2V DC
Heater voltage (VH)	5.0V ± 0.2V DC/AC
Heater resistance (room temp.)	83Ω at room temp. (typical)
Load resistance (RL)	Variable (0.45kΩ min.)
Sensor power dissipation (Ps)	≤ 15mW
Operating & storage temperature	-10°C ~ +50°C
Optimal detection concentration	1~30ppm

Item	Specification
Sensor resistance (air)	10kΩ ~ 90kΩ
Sensor resistance gradient (β)	0.3 ~ 0.6
β = Rs(10ppm hydrogen)/Rs(air)	
Heater current	42 ± 4mA
Heater power consumption	210mW (typical)

*Taken from „Technical information for air quality control sensor TGS 2600", Technical Data Sheet, Figaro Engineering Inc., 2004, [9]

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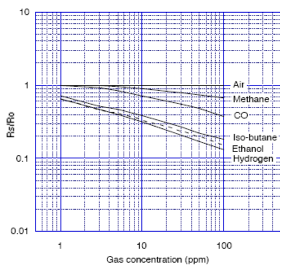
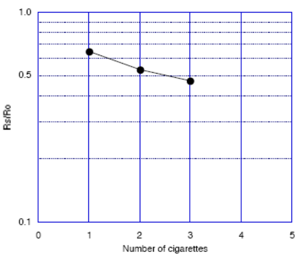
Air quality sensors





*Taken from „Technical information for air quality control sensor TGS 2600", Technical Data Sheet, Figaro Engineering Inc., 2004, [9]

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Carbon monoxide sensors

Carbon monoxide sensor – TGS 2442

The Figaro TGS2442 sensor is a new type thick film metal oxide semiconductor, screen printed sensor which offers miniaturization and utilizes pulse heating for achieving low power consumption. The TGS2442 displays high selectivity to carbon monoxide together with improved humidity dependency and durability.

Features

* Miniature size and low power consumption
* High sensitivity / selectivity to carbon monoxide (CO)
* Low sensitivity to alcohol vapor
* Reduced influence by various interference gases
* Long life and low cost

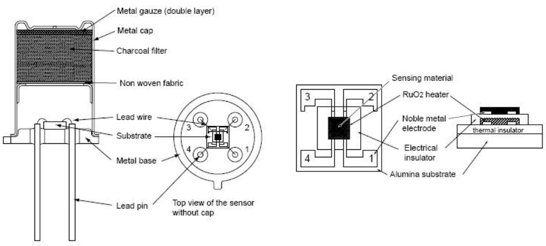
Applications

* Residential and commercial CO detectors
* Air quality controllers
* Ventilation control for indoor parking garages

*Taken from „ Technical information for TGS2442", Technical Data Sheet, Figaro Engineering Inc., 2007, [10]

Carbon monoxide sensors

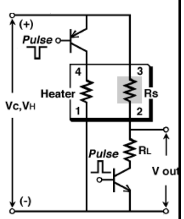
Carbon monoxide sensor – TGS 2442



*Taken from „ Technical information for TGS2442", Technical Data Sheet, Figaro Engineering Inc., 2007, [10]

Carbon monoxide sensors

The structure of TGS2442. The sensor utilizes a multilayer structure. A glass layer for thermal insulation is printed between a ruthenium oxide (RuO_2) heater and an alumina substrate. A pair of Au electrodes for the heater are formed on a thermal insulator. The gas sensing layer, which is formed of tin dioxide (SnO_2), is printed on an electrical insulation layer which covers the heater. A pair of Pt electrodes for measuring sensor resistance is formed on the electrical insulator. An activated charcoal filter is used for the purpose of reducing the influence of noise gases.



*Taken from „ Technical information for TGS2442", Technical Data Sheet, Figaro Engineering Inc., 2007, [10] Wrocław University of Technology | Master programmes in English at Wrocław University of Technology

Carbon monoxide sensors

Model number			TGS 2442
Sensing element type			M1
Standard package			TO-5 metal can
Target gases			Carbon monoxide
Typical detection range			30 ~ 1000 ppm
Standard circuit conditions	Heater voltage cycle	V_H	V_{HH}=4.8V±0.2V DC, 14ms V_{HL}=0.0, 986ms
	Circuit voltage cycle	V_C	V_C=0V for 995ms, V_C=5.0V±0.2V DC for 5ms
	Load resistance	R_L	variable (≥10kΩ)
Electrical characteristics under standard test conditions	Heater resistance	R_H	17 ± 2.5Ω at room temp.
	Heater current	I_H	approx. 203mA(in case of V_{HH})
	Heater power consumption	P_H	approx. 14mW (ave.)
	Sensor resistance	R_S	13.3kΩ ~ 133kΩ in 100ppm of carbon monoxide
	Sensitivity (change ratio of Rs)	β	0.13 ~ 0.31
Standard test conditions	Test gas conditions		Carbon monoxide in air at 20±2°C, 65±5%RH
	Circuit conditions		Same as Std. Circuit Condition (above)
	Conditioning period before test		2 days or more

$$R_S = \frac{V_C R_L}{V_{out}} - R_L$$

$$\beta = \frac{R_S(CO, 300\,ppm)}{R_S(CO, 100\,ppm)}$$

*Taken from „ Technical information for TGS2442", Technical Data Sheet, Figaro Engineering Inc., 2007, [10]

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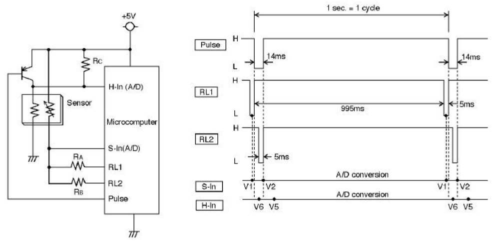
Carbon monoxide sensors



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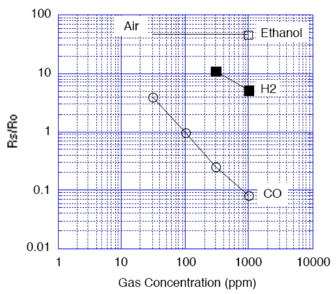

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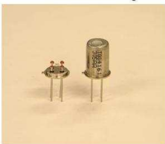
Carbon dioxide sensors

The Figaro TGS4161 is a new solid electrolyte type sensor which offers miniaturization, low power consumption, and long life. The TGS4161 displays high selectivity to carbon dioxide. Also, the TGS4161 displays good long term stability and shows excellent durability against the effects of high humidity through the application of innovative technology in the sensor's electrode design.



Carbon Dioxide sensor – TGS 4161

Features

* High selectivity to carbon dioxide
* Compact size
* Low dependency on humidity
* Low power consumption
* Long life and low cost

Applications

* Air quality control
* CO_2 monitors

*Taken from „Technical information for Carbon Dioxide Sensor TGS4161", Technical Data Sheet, Figaro Engineering Inc., 2006, [11]

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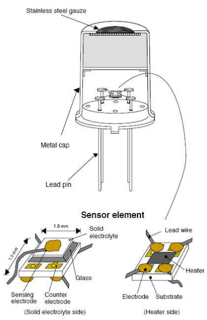
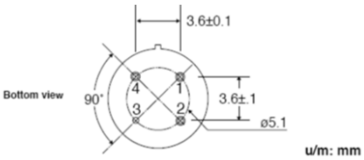
Carbon dioxide sensors





Pin connection:
1: Heater (+)
2: Sensor electrode (+)
3: Sensor electrode (-)
4: Heater (-)

*Taken from „Technical information for Carbon Dioxide Sensor TGS4161", Technical Data Sheet, Figaro Engineering Inc., 2006, [11]

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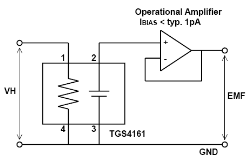
Carbon dioxide sensors

The structure of TGS4161. The CO2 sensing element consists of a cation (Na^+) solid electrolyte formed between two electrodes together with a printed heater (RuO2) substrate. The cathode (sensing element) consists of lithium carbonate and gold, while the anode (counter electrode) is made of gold. The anode is connected to sensor pin No.2 ("S(+)") while the cathode is connected to pin No.3 ("S(-)"). A RuO2 heater connected to pins No.1 ("H") and No.4 ("H") heats the sensing element. Lead wires are made of Pt and are connected to nickel pins.



*Taken from „Technical information for Carbon Dioxide Sensor TGS4161", Technical Data Sheet, Figaro Engineering Inc., 2006, [11]

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Carbon dioxide sensors

Item	Specification
Heater voltage (V_H)	5.0V ± 0.2V DC
Heater resistance (R_H) - *room temp.*	70±7Ω
Heater current	approx. 50mA
Heater power consumption	approx. 250mW
Operating conditions	-10°C ~ +50°C, 5 ~ 95%RH
Storage conditions	-20°C ~ +60°C, 5 ~ 90%RH (store in a moisture proof bag with silica gel)
Optimal detection concentration	350 ~ 10,000ppm

Item		Specification
EMF in 350ppm of CO_2		220 ~ 490mV
ΔEMF	EMF (350ppmCO2) - EMF (3500ppm CO2)	44 ~ 72mV

*Taken from „Technical information for Carbon Dioxide Sensor TGS4161", Technical Data Sheet, Figaro Engineering Inc., 2006, [11]

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Carbon dioxide sensors

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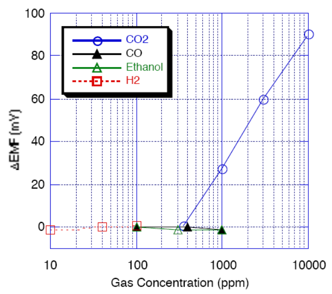

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Summary – gas sensors

- selectivity – ability to distinguish different gases or to be sensitive to one substance
- working conditions – temperature, acquisition time
- sensitivity

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Test questions (an example):

- Name 4 principles of temperature sensors.
- Name 4 examples of photonic sensors
- What are the basic modes of photodiode applications ?
- What is the difference between sensitivity and selectivity of a sensor ?

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