Instrumentação 1

Sensores de Temperatura, Deslocamento Pressão e Nível

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Sensores

Temperatura

Deslocamento

Pressão

Nível

Os **tipos de sensores industriais** podem ser: **Sensores** de Pressão, **Sensores** de Temperatura, **Sensores** de Nível, **Sensores** de Vazão e ainda os mais comuns: indutivo, capacitivo, fotoelétrico, magnético e ultrassônico.

Medição de Temperatura

Medição de Temperatura

Calibração

TABLE 32.7 Defining Fixed Points of the ITS-90

Material[a]	Equilibrium State[b]	Assigned value of temperature T_{90} (K)	t_{90} (°C)
He	VP	3–5	–270.15 to –268.15
e-H_2	TP	13.8033	–259.3467
e-H_2 (or He)	VP (or GT)	≈17	≈–256.16
e-H_2 (or He)	VP (or GT)	≈20.3	≈–252.85
Ne	TP	24.5561	–248.5939
O_2	TP	54.3584	–218.7916
Ar	TP	83.8058	–189.3442
Hg	TP	234.3156	–38.8344
H_2O	TP	273.16	0.01
Ga	MP	302.9146	29.7646
In	FP	429.7485	156.5985
Sn	FP	505.078	231.928
Zn	FP	692.677	419.527
Al	FP	933.473	660.323
Ag	FP	1234.93	961.78
Au	FP	1337.33	1064.18
Cu	FP	1357.77	1084.62

[a] e-H_2 indicates equilibrium hydrogen; that is, hydrogen with the equilibrium distribution of its *ortho* and *para* forms at the corresponding temperatures. Normal hydrogen at room temperature contains 25% *para* and 75% *ortho* hydrogen. The isotopic composition of all materials is that naturally occurring.

[b] VP indicates vapor pressure point or equation; GT indicates gas thermometer point; TP indicates triple point; FP indicates freezing point; MP indicates melting point.

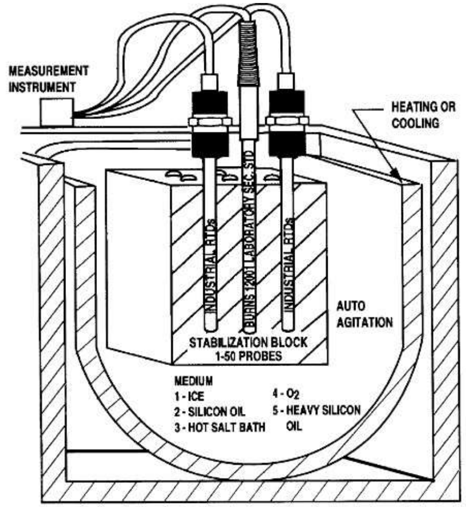
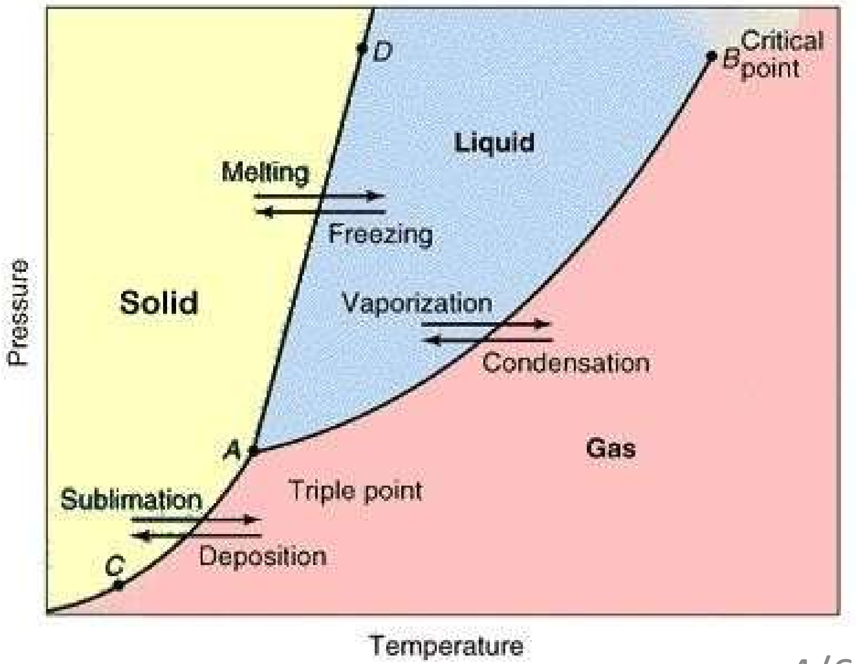


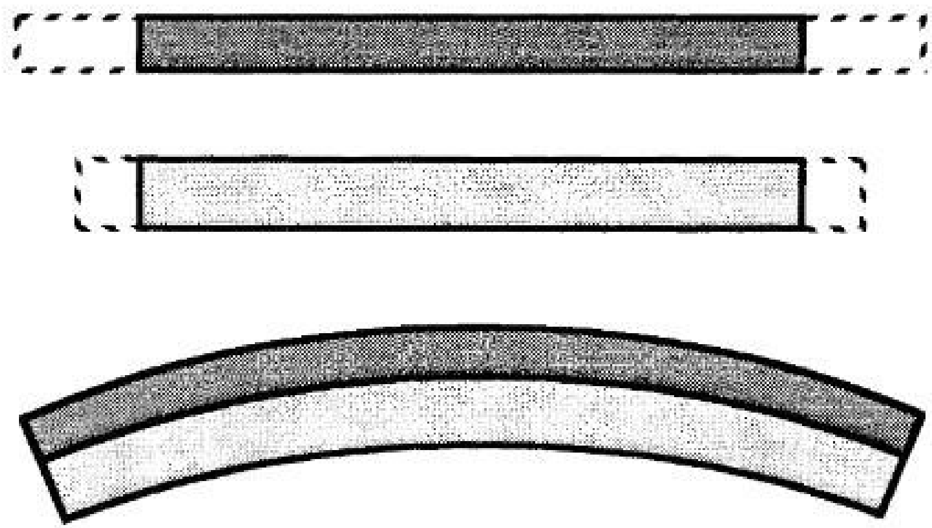
FIGURE 32.15 An isothermal bath permits calibration of industrial RTDs compared with a secondary standard.



Medição de Temperatura

Par bimetálico - termostato

- Materiais diferentes têm diferentes coeficientes de diatação
- Aplicados como sensores e também como atuadores



Medição de Temperatura

Par bimetálico - termostato

TABLE 32.1 Properties for Selected Materials Used in Bimaterial Elements

Material	Density (ρ) (kg m⁻³)	Young's Modulus (*E*) (GPa)	Heat capacity (*C*) (J kg⁻¹ K⁻¹)	Thermal expansion (10⁻⁶ K⁻¹)	Thermal conductivity (W m⁻¹ K⁻¹)
Al	2700[c]	61–71[b]	896[a]	24[b]	237[c]
	2707[a]	70.6[c]	900[c]	23.5[c]	204[a]
Cu	8954[a]	129.8[c]	383.1[a]	17.0[c]	386[a]
	8960[c]		385[c]		401[c]
Cr	7100[c]	279[c]	518[c]	6.5[c]	94[c]
Au	19300[b,c]	78.5[b,c]	129[b,c]	14.1[b,c]	318[b,c]
Fe	7870[c]	211.4[c]	444[c]	12.1[c]	80.4[c]
Ni	8906[a]	199.5[c]	446[a]	13.3[c]	90[a]
	8900[c]		444[c]		90.9[c]
Ag	10524[a]	82.7[c]	234.0[a]	19.1[c]	419[a]
	10500[c]		237[c]		429[c]
Sn	7304[a]	49.9[c]	226.5[a]	23.5[c]	64[a]
	7280[c]		213[c]		66.8[c]
Ti	4500[c]	120.2[c]	523[c]	8.9[c]	21.9[c]
W	19350[a]	411[c]	134.4[a]	4.5[c]	163[a]
	19300[c]		133[c]		173[c]
Invar (Fe64/Ni36)	8000[c]	140–150[c]	—	1.7-2.0[c]	13[c]
Si	2340[c]	113[c]	703[c]	4.7-7.6[c]	80–150[c]
n-Si	2328[b]	130–190[b]	700[b]	2.6[b]	150[b]
p-Si	2300[b]	150–170[b]	770[b]	—	30[b]
Si_3N_4	3100[a]	304[b]	600–800[b]	3.0[b]	9–30[b]
SiO_2	2200[b]	57-85[b]	730[b]	0.50[b]	1.4[b]

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Medição de Temperatura

Par bimetálico - termostato

TABLE 32.2 Table of Selected Industrially Available ASTM Thermostatic Elements

Type (ASTM)	Flexivity 10^{-6} (°C^{-1})	Max. sensitivity temp. range (°C)	Max. operating temp. (°C)	Young's Modulus (GPa)
TM1	27.0 ± 5%[a] 26.3 ± 5%[b]	–18–149	538	17.2
TM2	38.7 ± 5%[a] 38.0 ± 5%[b]	–18–204	260	13.8
TM5	11.3 ± 6%[a] 11.5 ± 6%[b]	149–454	538	17.6
TM10	23.6 ± 6%[a] 22.9 ± 6%[b]	–18–149	482	17.9
TM15	26.6 ± 5.5%[a] 25.9 ± 5.5%[b]	–18–149	482	17.2
TM20	25.0 ± 5%[a] 25.0 ± 5%[b]	–18–149	482	17.2

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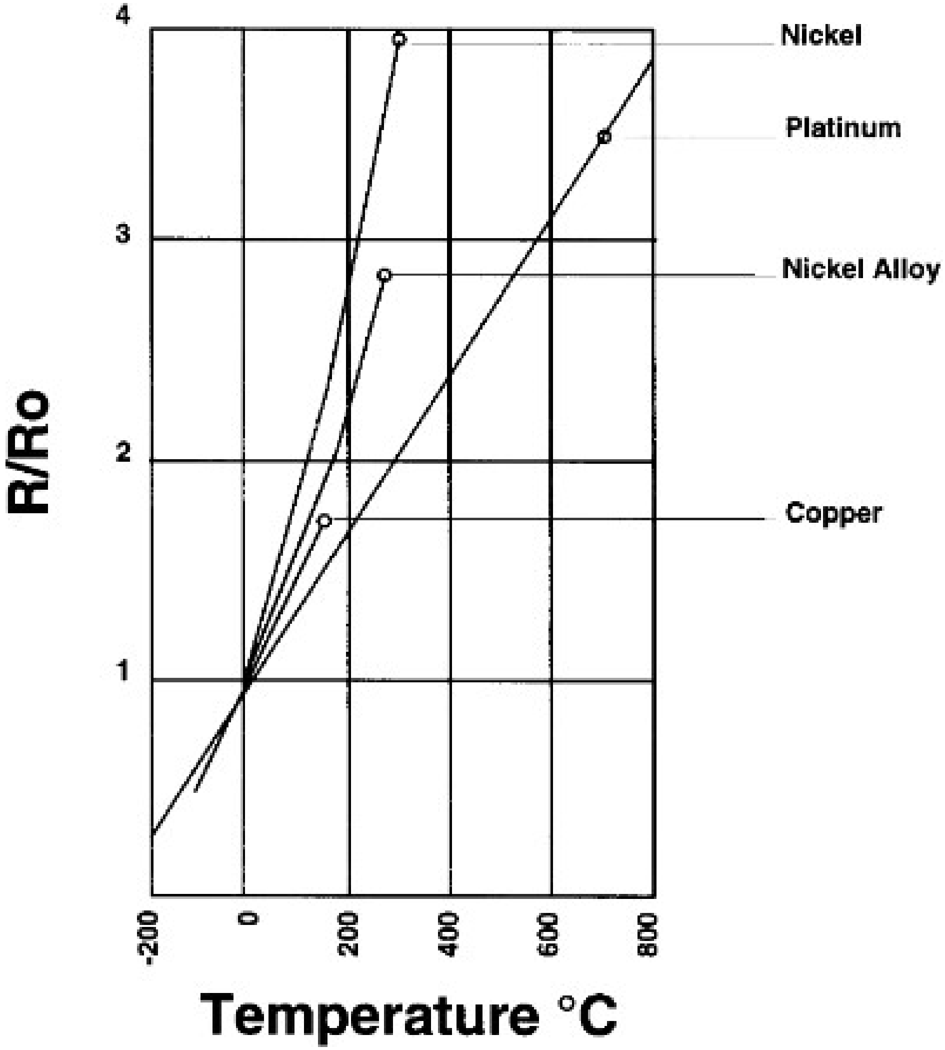
Medição de Temperatura

Termômetros resistivos

Resistive Temperature Detectors (RTDs)



Medição de Temperatura

Termômetros resistivos

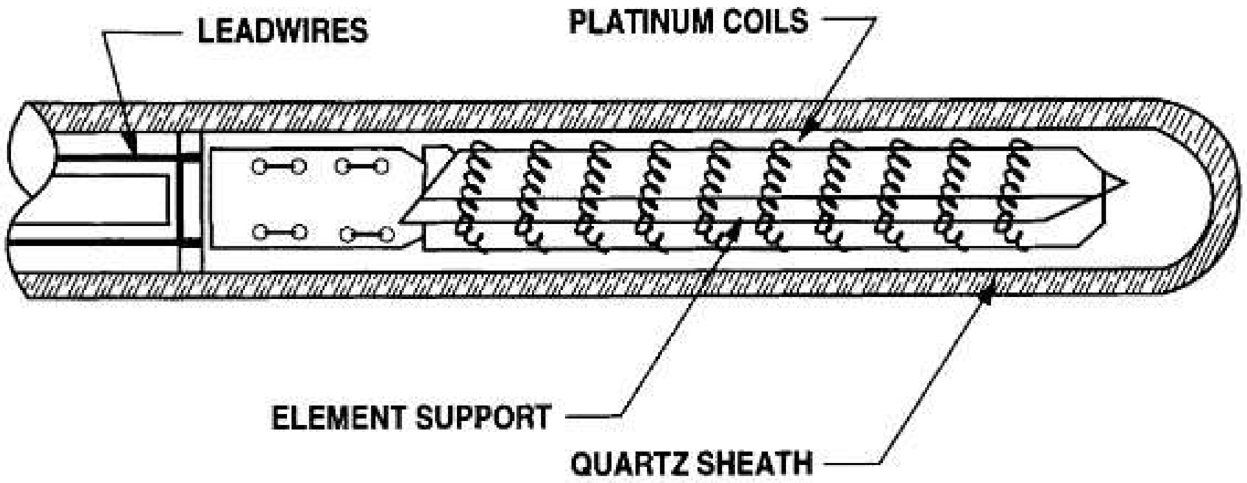


FIGURE 32.8 The Standard Platinum Resistance Thermometer is fragile and used only in laboratory environments.

Probe	Basic application	Temperature	Cost	Probe style[a]	Handling
SPRT	Calibration of Secondary SPRT	–200 to 1000°C (–328 to 1832°F)	$5000	I	Very fragile
Secondary SPRT	Lab use	–200 to 500°C (–328 to 932°F)	$700	I, A	Fragile
Wirewound IPRT	Industrial field use	–200 to 648°C (–328 to 1200°F)	$60–$180	I, S, A	Rugged
Thin-film IPRT	Industrial field use	–50 to 260°C (–200 to 500°F)	$40–$140	I, S, A	Rugged

[a] I = immersion; A = air; S = surface.

Termômetros resistivos

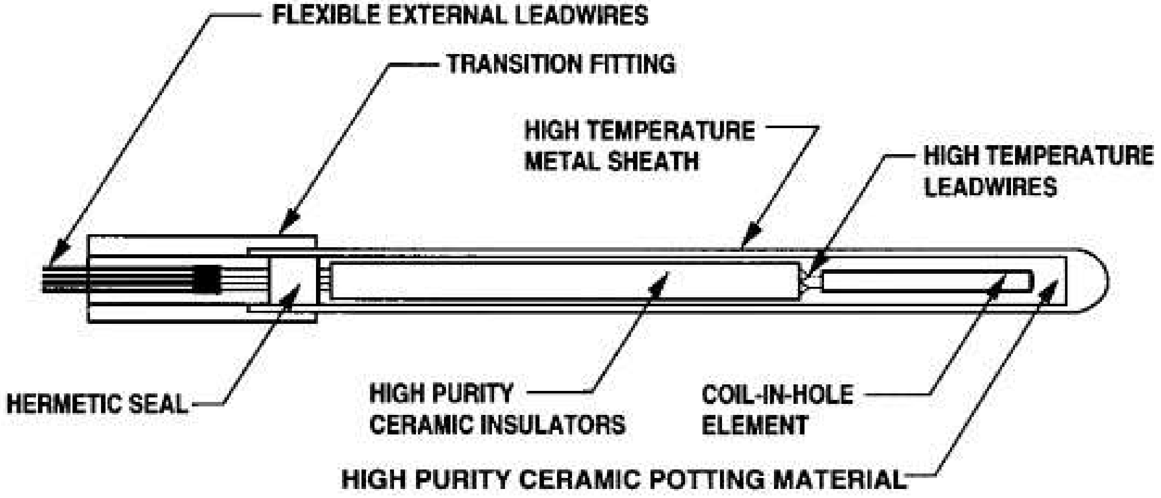


FIGURE 32.9 The Secondary Standard Platinum Resistance Thermometer is intended for laboratory environments.

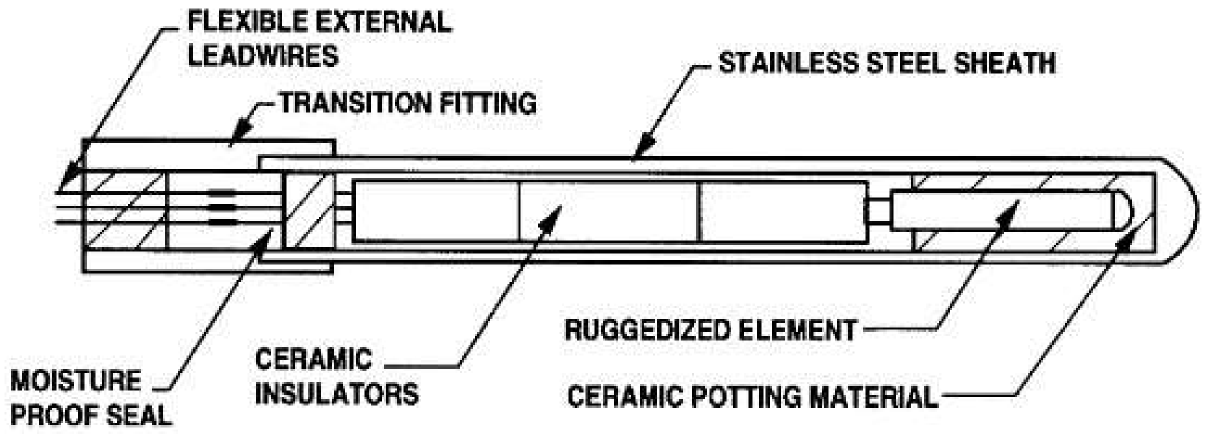


FIGURE 32.10 Industrial Platinum Resistance Thermometers are almost as durable as thermocouples.

Medição de Temperatura

Termômetros resistivos

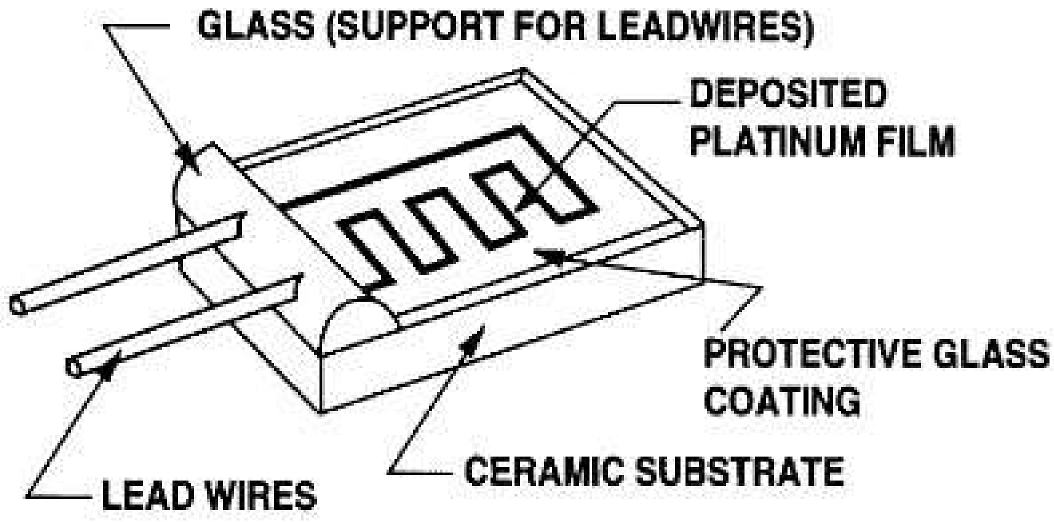


FIGURE 32.13 Thin-film elements have a thin film of platinum deposited onto a ceramic substrate.

Medição de Temperatura

Termopar

Efeito Seebeck

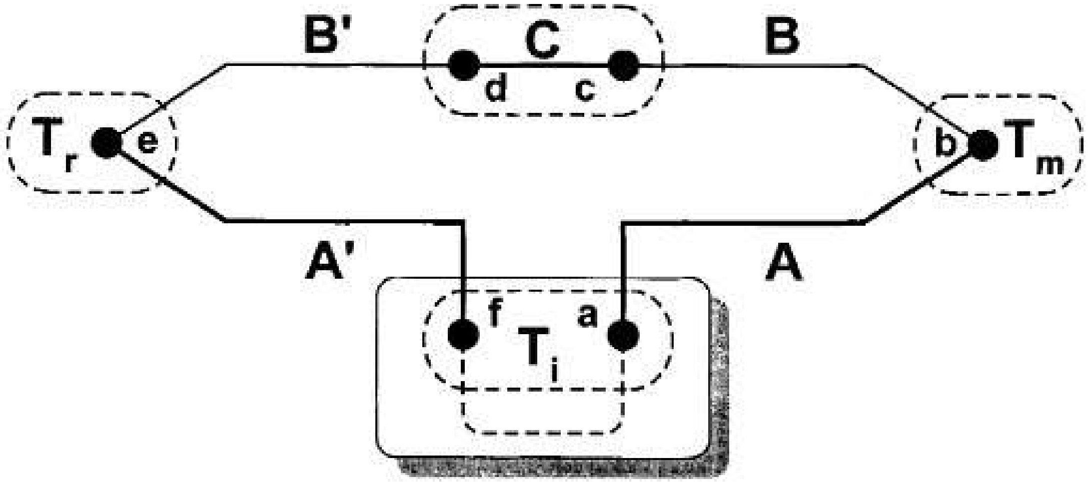
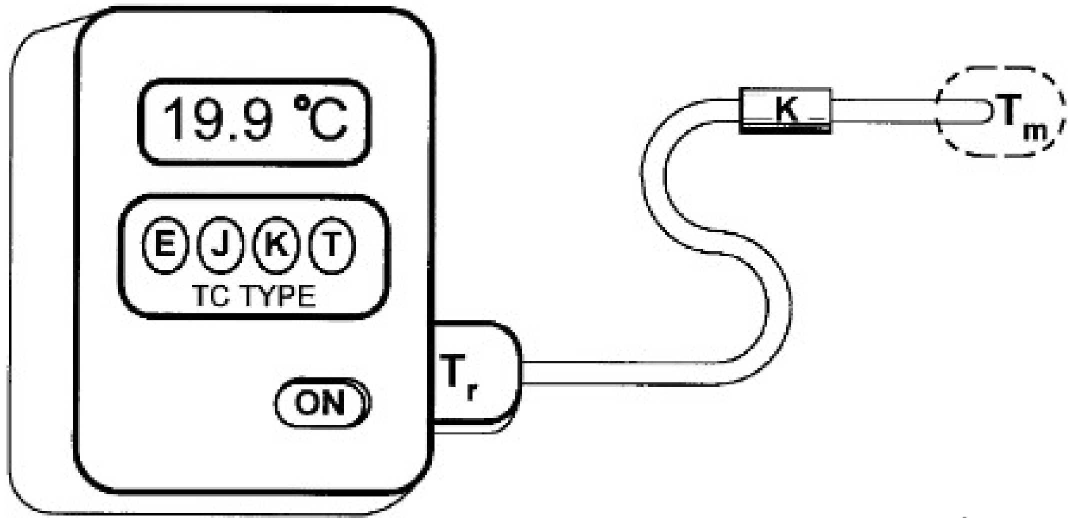


FIGURE 32.25 The basic thermocouple circuit with a *single* temperature reference junction, **e**. The Seebeck voltage measured in open-circuit mode at terminals **a** and **f** is proportional to the temperature difference between thermocouple *measuring junction* **b** and the necessary temperature *reference junction* **e**. For convenience, T_r is usually made to be 0°C. For thermometry, the zones at temperatures T_r and T_i must be isothermal.



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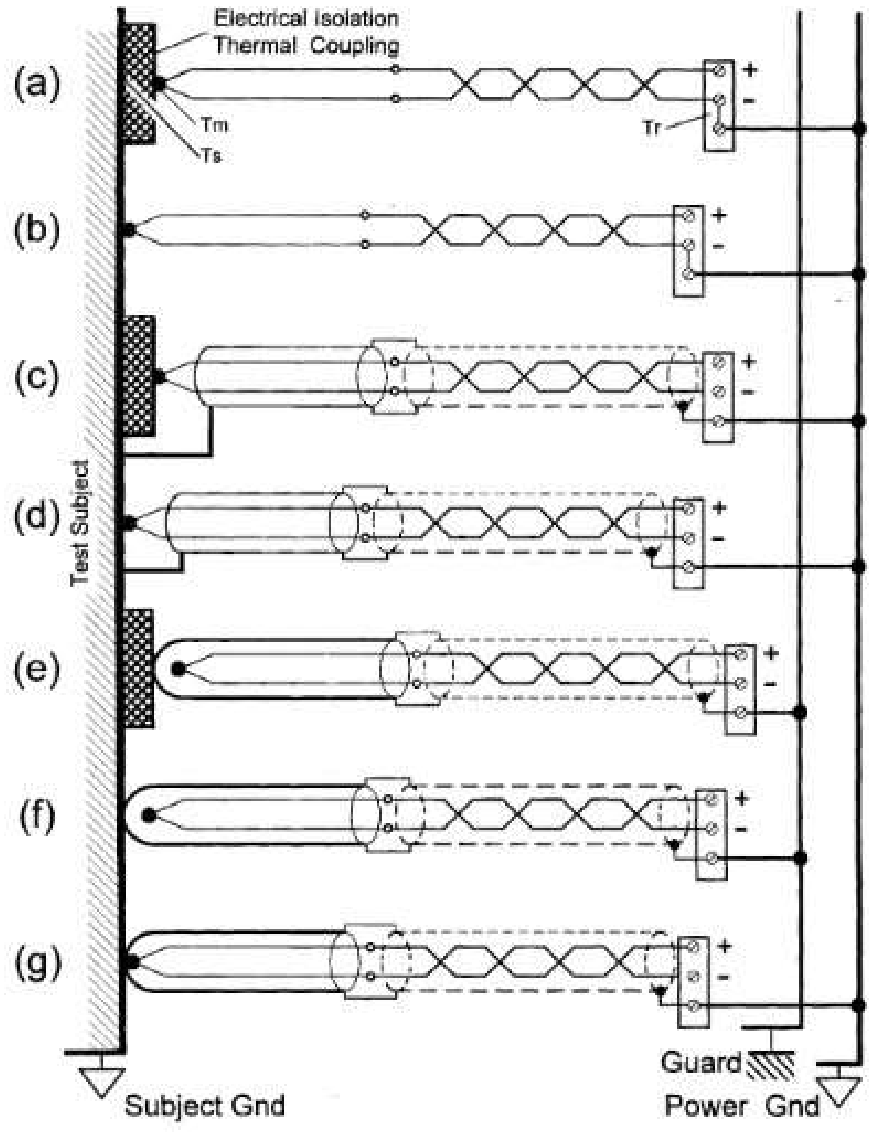

FIGURE 32.27 Preferred grounding and shielding for several thermometry situations. Electromagnetic (EM) and electrostatic (ES) noise must be controlled by different means. The design of the thermocouple monitoring instrument may dictate the grounding and shielding scheme that can be used.

Medição de Temperatura

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Type	Common name	Color code	M.P. (°C)	Recommended range, (°C)[d]	emf at 400°C, (mV)	Uncertainty, +/– Special tolerance Normal tolerance	ρ (μΩ-cm)
B	—	Brown[a]	1810	870 to 1700	0.787	0.25%	34.4
BX	—	Gray[a]	—	—	—	0.50%	—
BP	Pt30Rh	Gray	1910	—	—	—	18.6
BN	Pt6Rh	Red	1810	—	—	—	15.8
E	—	Brown[a]	1270	−200 to 870	28.946	1.0°C or 0.40%	127
EX	—	Purple[a]	—	—	—	1.7°C or 0.50%	—
EP	Chromel[b]	Purple	1430	—	—	—	80
EN	Constantan	Red	1270	—	—		46
J	—	Brown[a]	1270	0 to 760	21.848	1.1°C or 0.40%	56
JX	—	White[a]	—	—	—	2.2°C or 0.75%	—
JP	Iron	White	1536	—	—	—	10
JN	Constantan	Red	1270	—	—	—	46
K	—	Brown[a]	1400	−200 to 1260	16.397	1.1°C or 0.40%	112
KX	—	Yellow[a]	—	—	—	2.2°C or 0.75%	—
KP	Chromel	Yellow	1430	—	—	—	80
KN	Alumel[b]	Red	1400	—	—	—	31
N	—	Brown[a]	—	0 to 1260	12.974	1.1°C or 0.40%	
NX	—	Orange[a]	—			2.2°C or 0.75%	—
NP	Nisil	Orange			—	—	—
NN	Nicrosil	Red					
R	—	Brown[a]	1769	0 to 1480	3.408	0.6°C or 0.10%	29
RX	—	Green[a]	—	—		1.5°C or 0.25%	—
RP	Pt13Rh	Green	1840	—	—		19
RN	Pt	Red	1769	—		—	10
S	—	Brown[a]	1769	0 to 1480	3.259	0.6°C or 0.10%	30
SX	—	Green[a]	—	—		1.5°C or 0.25%	—
SP	Pt10Rh	Green	1830	—	—		20
SN	Pt	Red	1769	—		—	10
T	—	Brown[a]	1083	−200 to 370	20.810	0.5°C or 0.40%	48
TX	—	Blue[a]	—	—		1.0°C or 0.75%	—
TP	Copper	Blue	1083	—		—	2
TN	Constantan	Red	1270	—		—	46

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TABLE 32.15 Temperature Upper Limits For Different Wire Diameters

Dia., mm	0.025	0.127	0.254	0.406	0.813	1.600	3.175	
Dia., in.	0.001	0.005	0.010	0.016	0.032	0.063	0.125	
Dia., AWG	50	35	30	26	20	14	8	
Type	Temperature limit,°C							Type
E	290	325	370	400	510	775	855	E
J	230	275	305	350	460	600	750	J
K, N	690	730	790	840	950	1095	1250	K, N
T	90	110	150	185	270	370	375	T

Note: Recommended limits are guidelines for continual use of bead-insulated thermocouples in closed-end protection tubes in compatible environments. Mineral insulated metal-sheathed thermocouples can have slightly higher limits and tolerate longer exposure.

From References [1, 9, 13].

TABLE 32.16 Environmental Tolerance of Letter Designated Thermocouples

	Environment							
Type	Oxygen rich	Oxygen poor	Reducing	Vacuum	Humid	Below 0°C	Sulfur traces	Neutron radiation
B	Good	Good	Poor	Fair	Good	Poor	Poor	Fair
E	Good	Poor	Poor	Poor	Good	Good	Poor	Poor
J	Fair	Good	Good	Good	Poor	Poor	Fair	Poor
K	Good	Poor	Poor	Poor	Good	Fair	Poor	Good
N	Good	Fair	Poor	Poor	Good	Good	Fair	Good
R,S	Good	Good	Poor	Poor	Good	Fair	Poor	Poor
T	Fair	Fair	Good	Good	Good	Good	Fair	Poor

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Junções semicondutoras

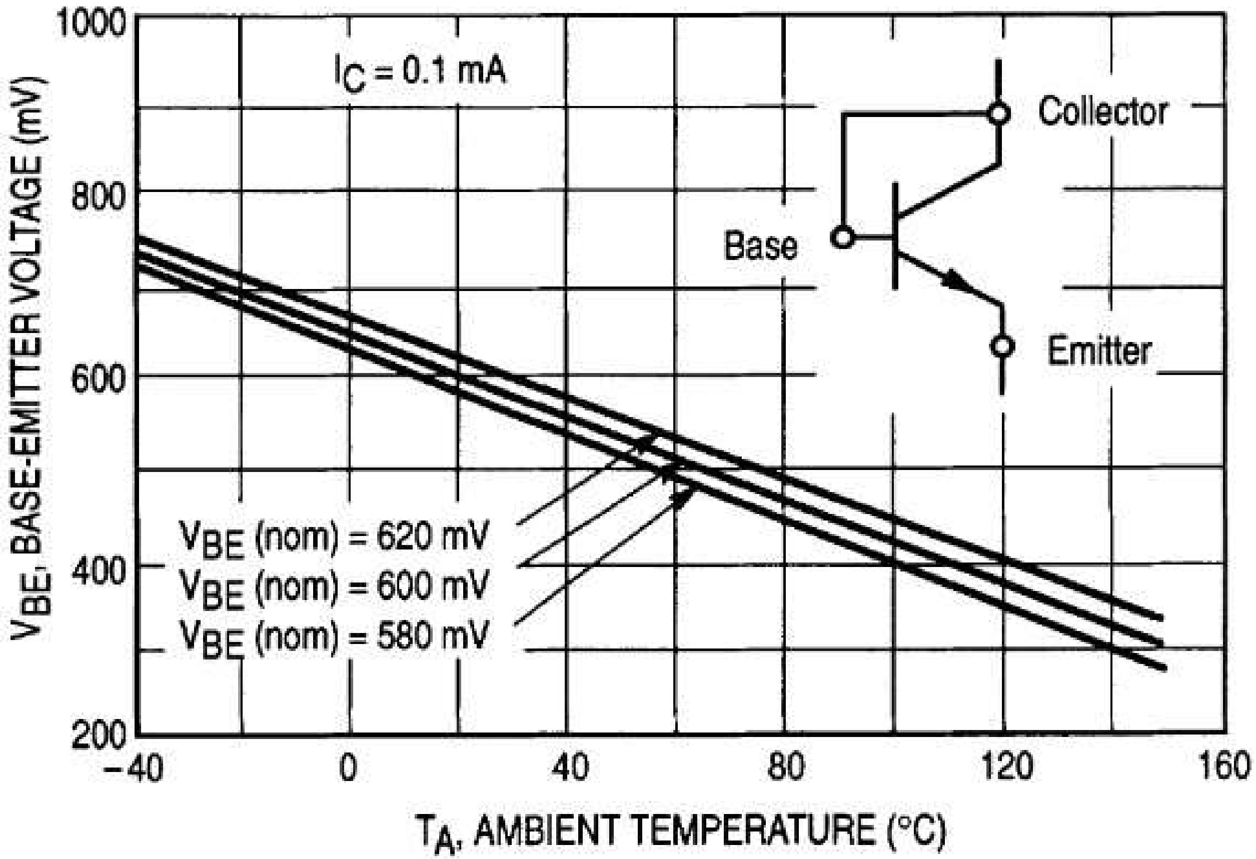
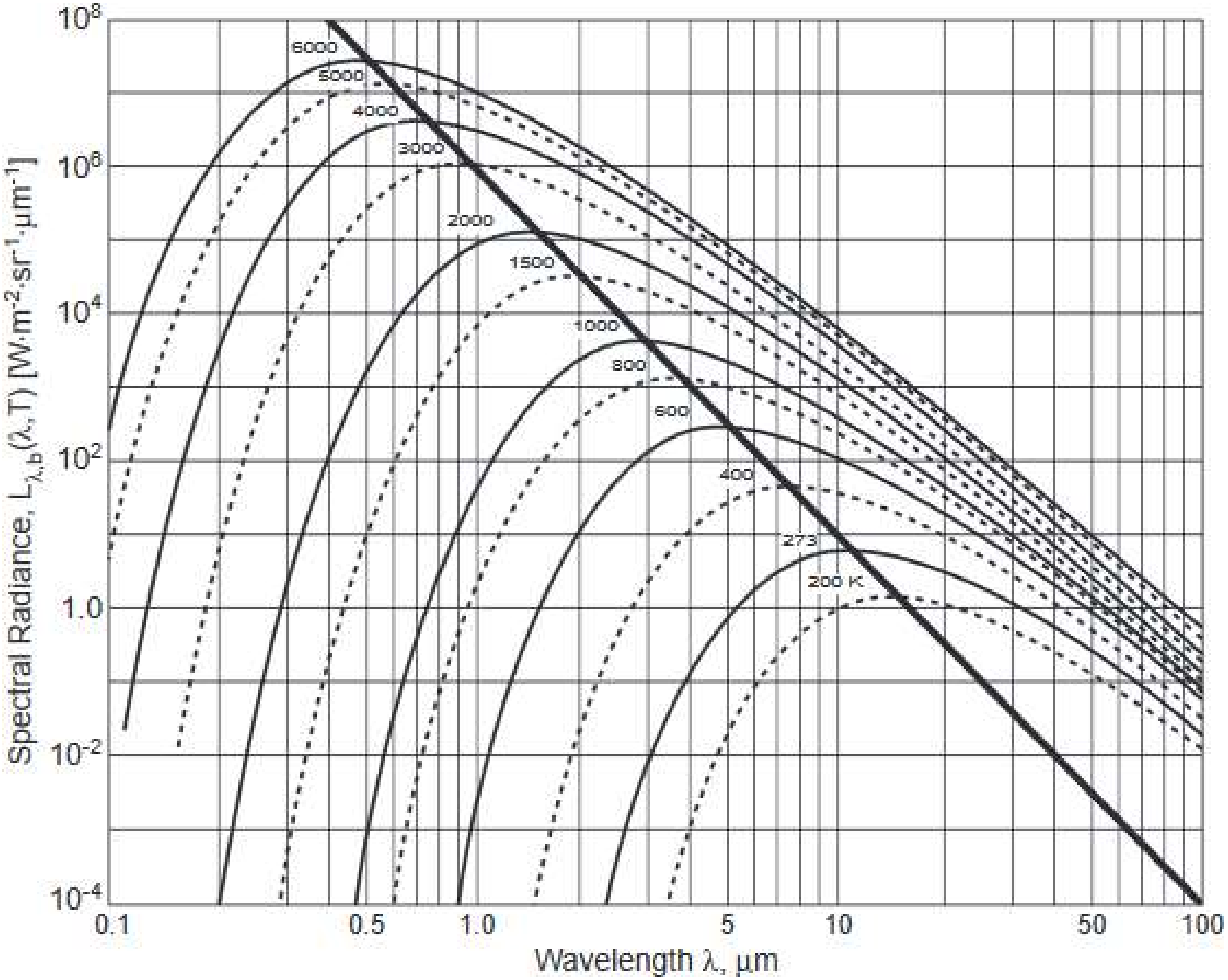


FIGURE 32.33 Base–emitter voltage vs. ambient temperature for a silicon temperature sensor.

Medição de Temperatura

Termômetros de infravermelho



Medição de Temperatura

Termômetros de infravermelho

TABLE 32.17 Typical Emissivities of Different Materials (from 0 to 100°C)

Material	Emissivity	Material	Emissivity
Blackbody (ideal)	1.00	Green leaves	0.88
Cavity radiator	0.99–1.00	Ice	0.96
Aluminum (anodized)	0.70	Iron or steel (rusted)	0.70
Aluminum (oxidized)	0.11	Nickel (oxidized)	0.40
Aluminum (polished)	0.05	Nickel (unoxidized)	0.04
Aluminum (rough surface)	0.06–0.07	Nichrome (80Ni-20Cr) (oxidized)	0.97
Asbestos	0.96	Nichrome (80Ni-20Cr) (polished)	0.87
Brass (dull tarnished)	0.61	Oil	0.80
Brass (polished)	0.05	Silicon	0.64
Brick	0.90	Silicone rubber	0.94
Bronze (polished)	0.10	Silver (polished)	0.02
Carbon-filled latex paint	0.96	Skin (human)	0.93–0.96
Carbon lamp black	0.96	Snow	0.85
Chromium (polished)	0.10	Soil	0.90
Copper (oxidized)	0.6–0.7	Stainless steel (buffed)	0.20
Copper (polished)	0.02	Steel (flat rough surface)	0.95–0.98
Cotton cloth	0.80	Steel (ground)	0.56
Epoxy resin	0.95	Tin plate	0.10
Glass	0.95	Water	0.96
Gold	0.02	White paper	0.92
Gold-black	0.98–0.99	Wood	0.93
Graphite	0.7–0.8	Zinc (polished)	0.04

Medição de Temperatura

Termômetros de infravermelho

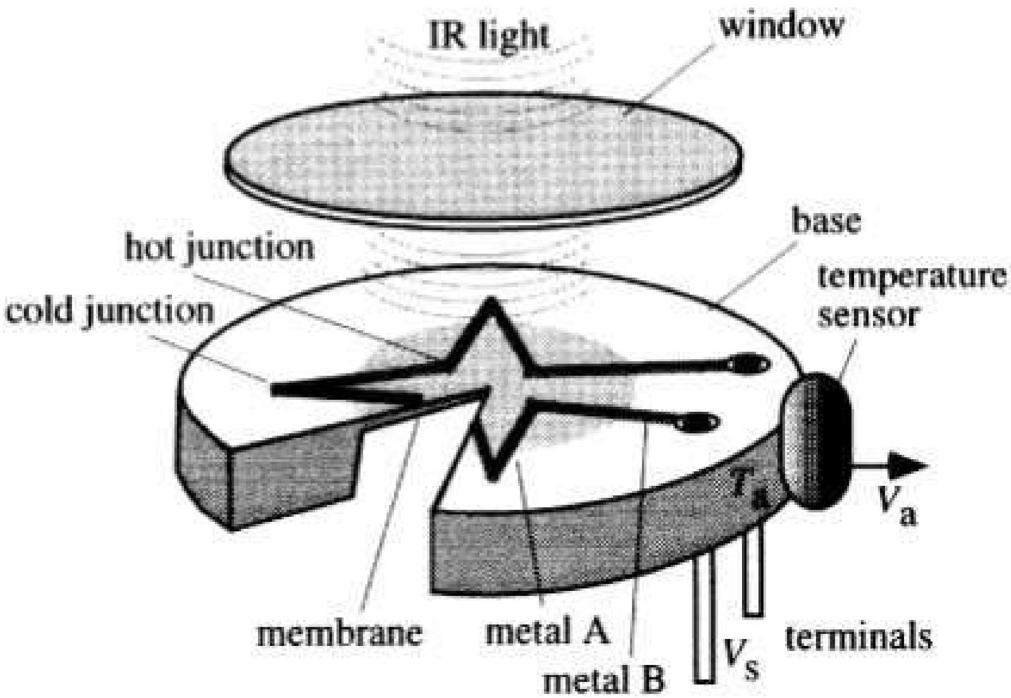


FIGURE 32.55 Thermopile sensor. "Hot" junctions are deposited on a membrane and "cold" junctions on the supporting ring.

Termômetros piroelétricos

Materiais piroelétricos são substâncias cristalinas capazes de gerar cargas elétricas em respostas ao fluxo de calor.

TABLE 32.19 Physical Properties of Pyroelectric Materials

Material	Curie temperature °C	Thermal conductivity W mK^{-1}	Relative permittivity ε_r	Pyroelectric charge coeff. C $(m^2K)^{-1}$	Pyroelectric voltage coeff. V $(mK)^{-1}$	Coupling k_p^2 (%)
Single Crystals						
TGS	49	0.4	30	3.5×10^{-4}	1.3×10^{6}	7.5
$LiTa0_3$	618	4.2	45	2.0×10^{-4}	0.5×10^{6}	1.0
Ceramics						
$BaTiO_3$	120	3.0	1000	4.0×10^{-4}	0.05×10^{6}	0.2
PZT	340	1.2	1600	4.2×10^{-4}	0.03×10^{6}	0.14
Polymers						
PVDF polycrystalline layers	205	0.13	12	0.4×10^{-4}	0.40×10^{6}	0.2
$PbTiO_3$	470	2 (monocrystal)	200	2.3×10^{-4}	0.13×10^{6}	0.39

Medição de Temperatura

Termômetros piroelétricos

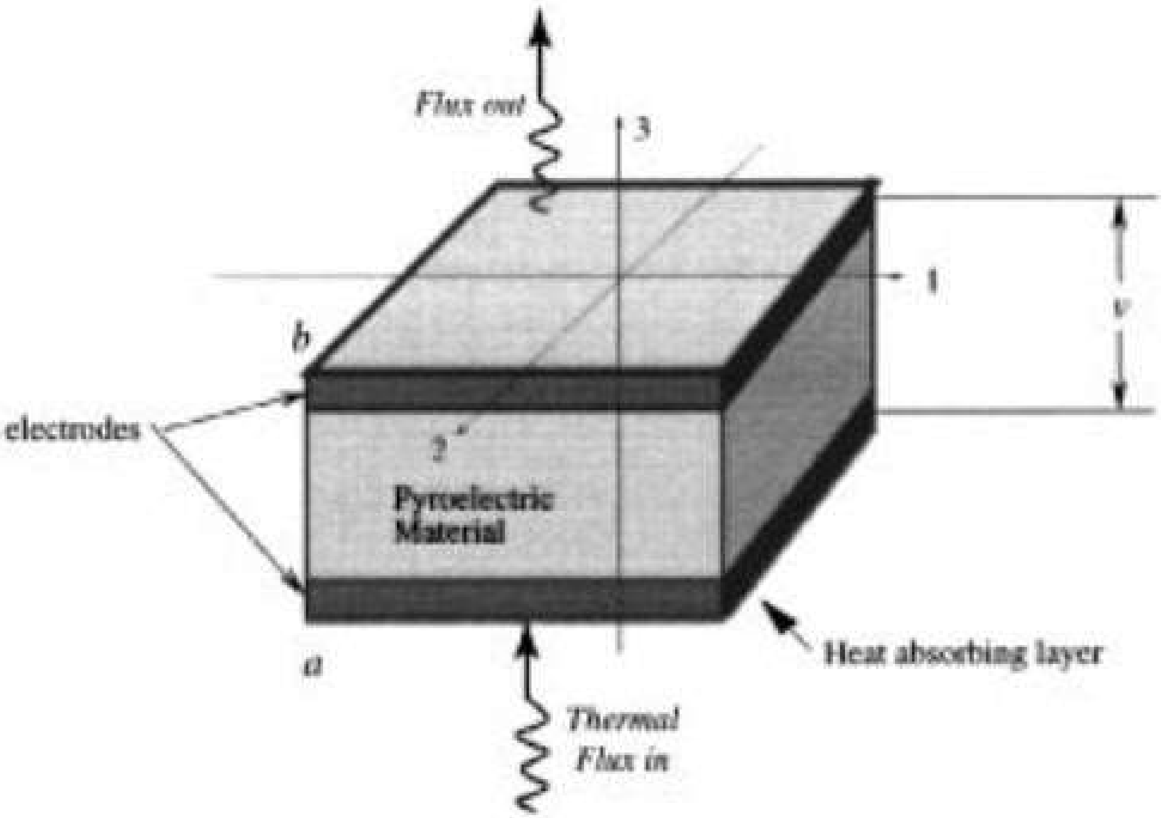


FIGURE 32.67 Pyroelectric sensor has two electrodes at the opposite sides of the crystalline material. Thermal radiation is applied along axis 3.

Medição de Temperatura

Termômetros piroelétricos

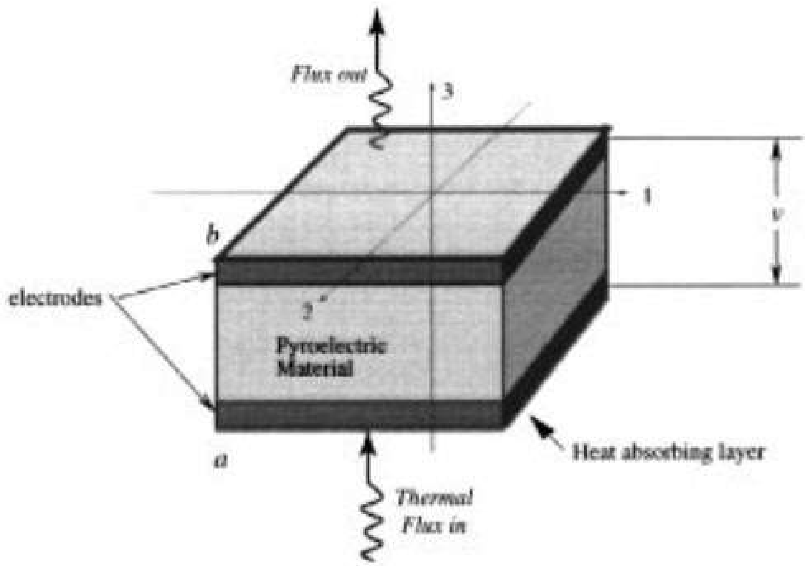


FIGURE 32.67 Pyroelectric sensor has two electrodes at the opposite sides of the crystalline material. Thermal

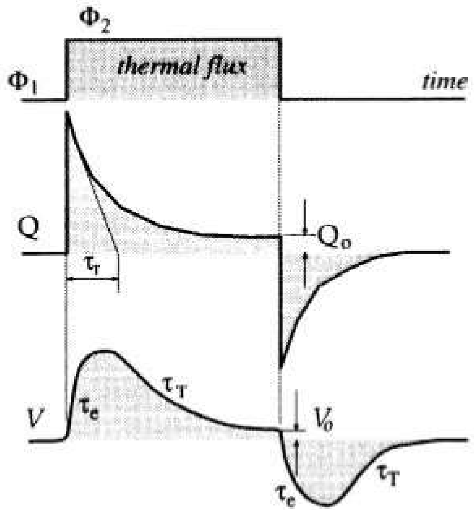


FIGURE 32.68 Response of a pyroelectric sensor to a thermal step function. The magnitudes of charge Q_0 and voltage v_0 are exaggerated for clarity.

Medição de Temperatura

Termômetros piroelétricos

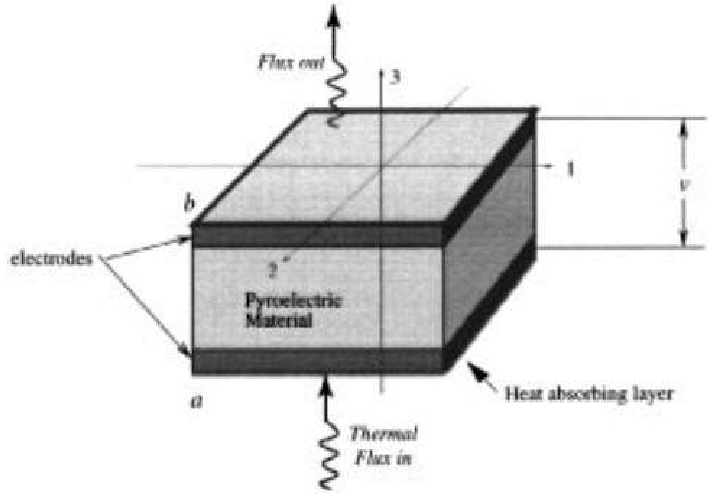
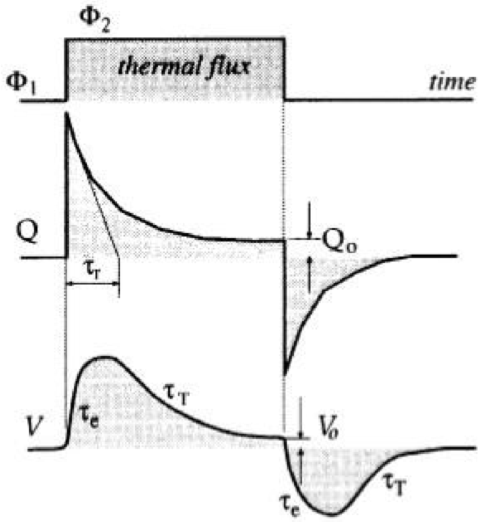


FIGURE 32.67 Pyroelectric sensor has two electrodes at the opposite sides of the crystalline material. Thermal radiation is applied along axis 3.



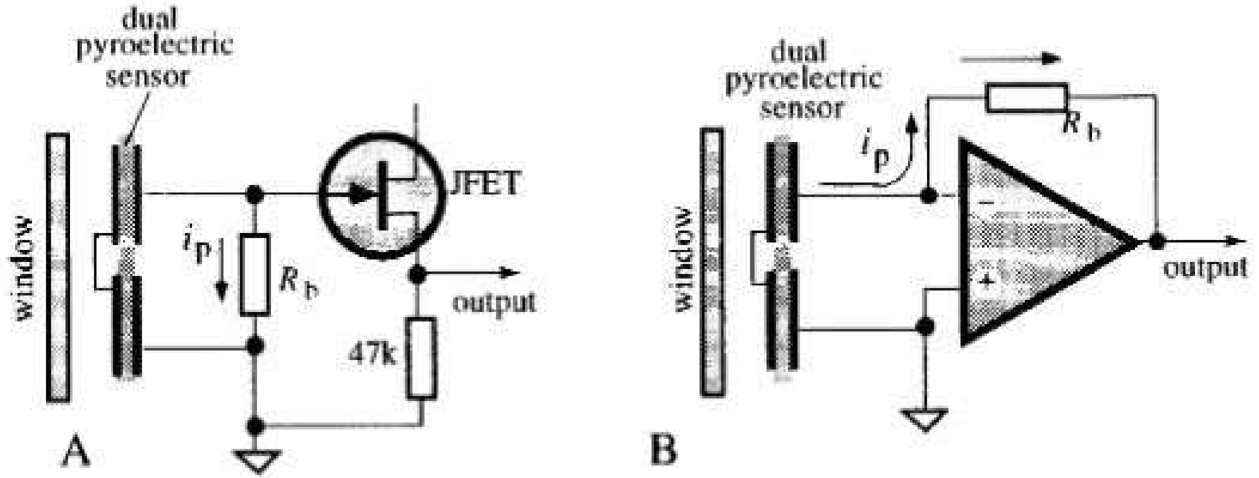
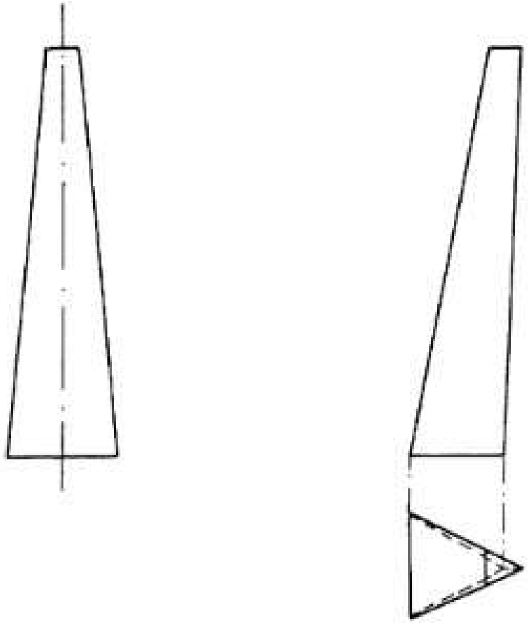


FIGURE 32.69 Interface circuits for pyroelectric sensors operating in voltage (A) and current (B) modes.

Medição de Temperatura

Indicadores de temperatura

a.



b.

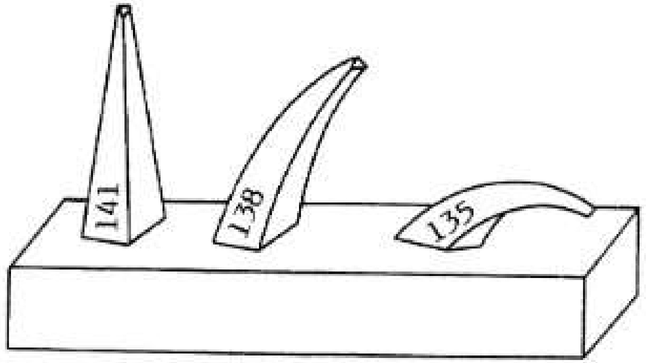


FIGURE 32.77 Pyrometric cones (a) in cross-sections; (b) on a plaque during firing.

TABLE 32.26a Approximate Touch-Down Temperatures of Pyrometric Cones (DIN 51063)

Cone no.	Temperature (°C)	Cone no.	Temperature (°C)	Cone no.	Temperature (°C)	Cone no.	Temperature (°C)
022	600	07a	960	9	1280	29	1650
021	650	06a	980	10	1300	30	1670
020	670	05a	1000	11	1320	31	1690
019	690	04a	1020	12	1350	32	1710
018	710	03a	1040	13	1380	33	1730
017	730	02a	1060	14	1410	34	1750
016	750	01a	1080	15	1435	35	1770
015a	790	1a	1100	16	1460	36	1790
014a	815	2a	1120	17	1480	37	1825
013a	835	3a	1140	18	1500	38	1850
012a	855	4a	1160	19	1520	39	1880
011a	880	5a	1180	20	1530	40	1920
010a	900	6a	1200	26	1580	41	1960
09a	920	7	1230	27	1610	42	2000
08a	940	8	1250	28	1630		

TABLE 32.26b Approximate Touch-Down Temperatures of Pyrometric Cones (BS 1041)

Cone no.	Temperature (°C)	Cone no.	Temperature (°C)	Cone no.	Temperature (°C)	Cone no.	Temperature (°C)
022	600	011	880	1	1135	11	1310
021	615	010	900	2	1150	12	1330
020	630	09	925	3	1165	13	1350
019	665	08	950	4	1180	14	1380
018	700	07	975	5	1195	15	1410
017	730	06	1000	6	1210	16	1435
016	760	05	1030	7	1230	17	1460
015	790	04	1060	8	1250	18	1485
014	810	03	1085	9	1270	19	1510
013	830	02	1105	10	1290	20	1535
012	860	01	1120				

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Medição de Deslocamento

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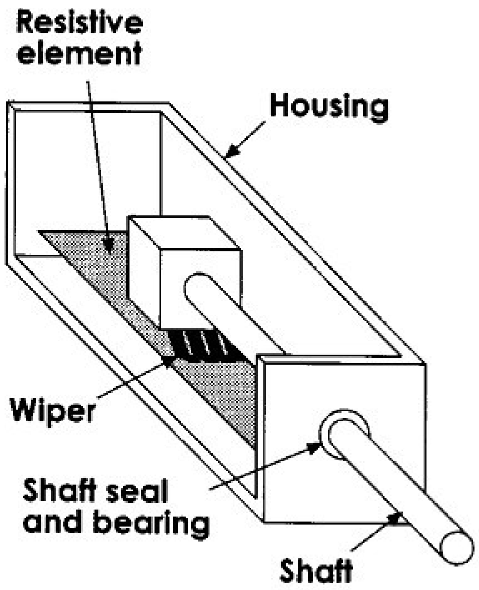
SENSOR DE DESLOCAMENTO RESISTIVO

Representação em corte de potenciômetros de precisão



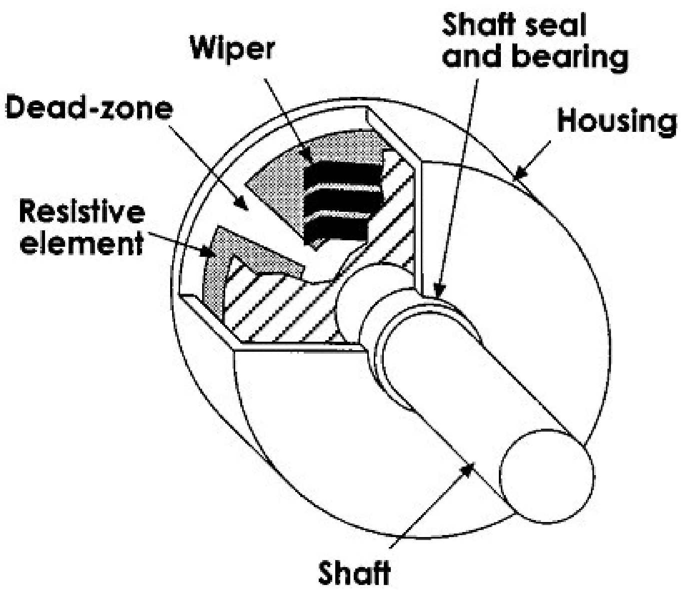
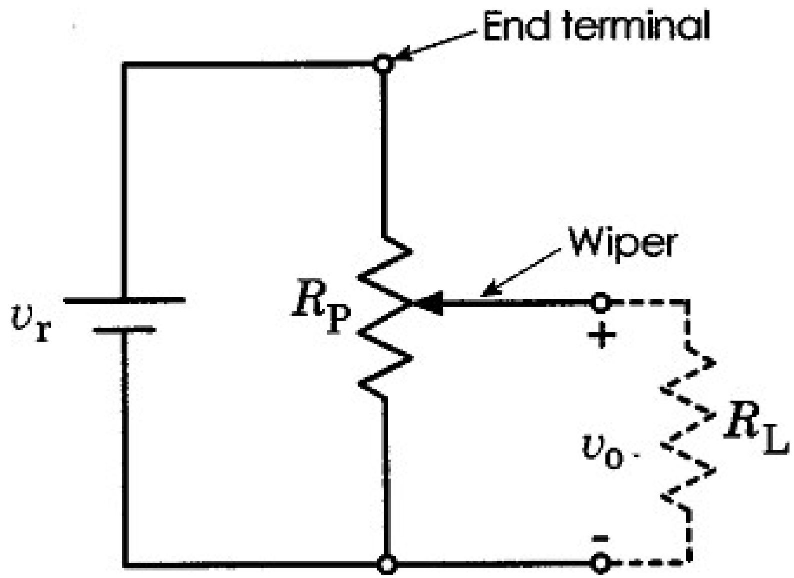


Diagrama esquemáticos do potenciômetro



SENSOR DE DESLOCAMENTO RESISTIVO

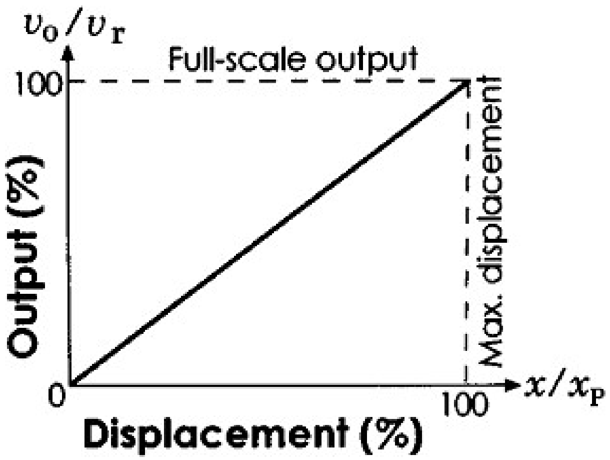
TABLE 6.1 Fundamental Potentiometer Characteristics

Advantages	Disadvantages
Easy to use	Limited bandwidth
Low cost	Frictional loading
Nonelectronic	Inertial loading
High-amplitude output signal	Wear
Proven technology	

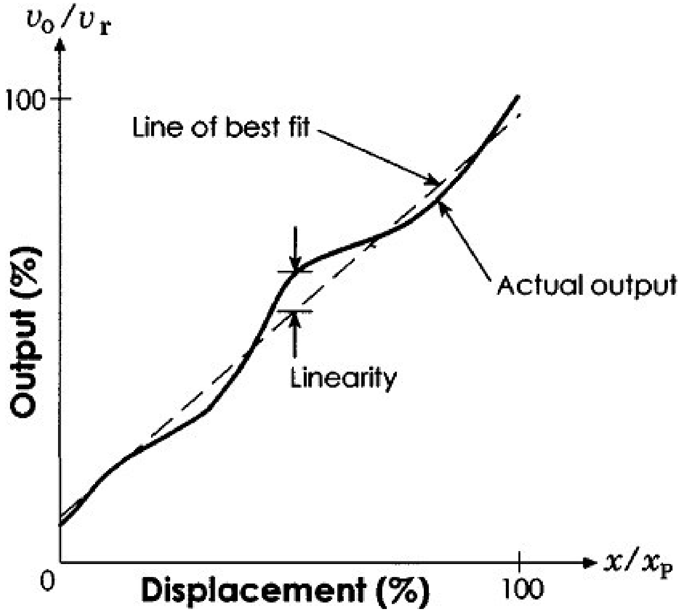
TABLE 6.2 Characteristics of Conductive Plastic, Wirewound, and Hybrid Resistive Elements

	Conductive plastic	Wirewound	Hybrid
Resolution	Infinitesimal	Quantized	Infinitesimal
Power rating	Low	High	Low
Temperature stability	Poor	Excellent	Very good
Noise	Very low	Low, but degrades with time	Low
Life	10^6–10^8 cycles	10^5–10^6 cycles	10^6–10^7 cycles

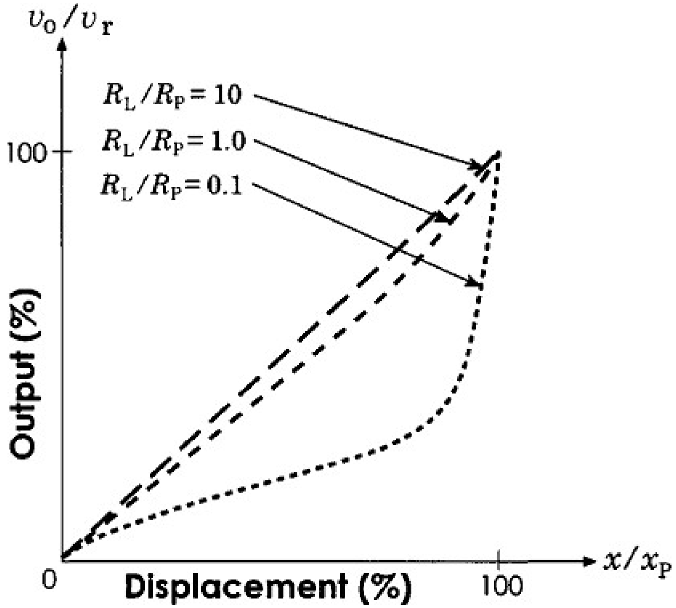
Função de saída linear ideal



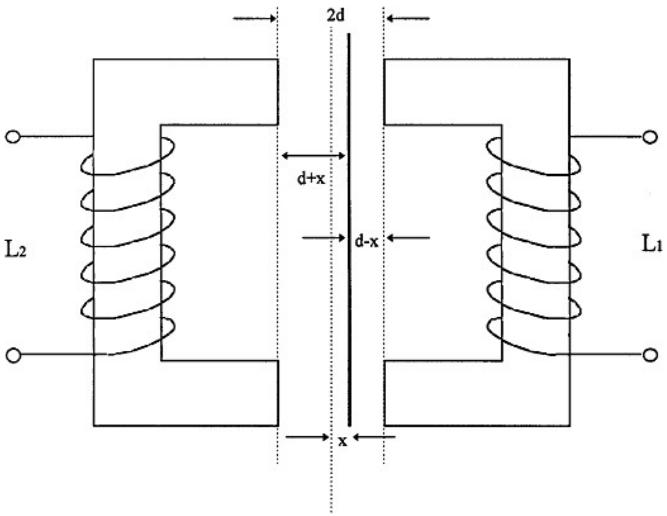
Linearidade da função de saída

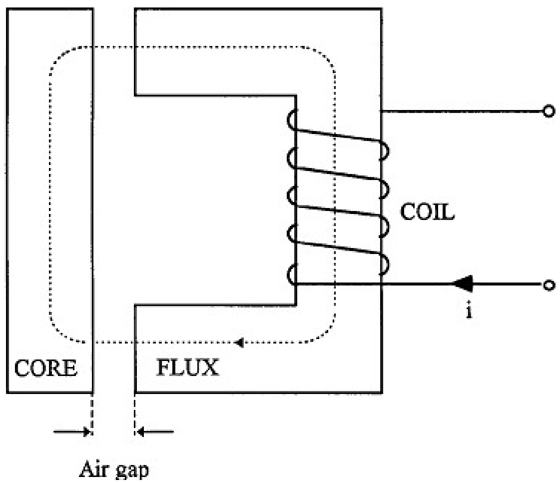


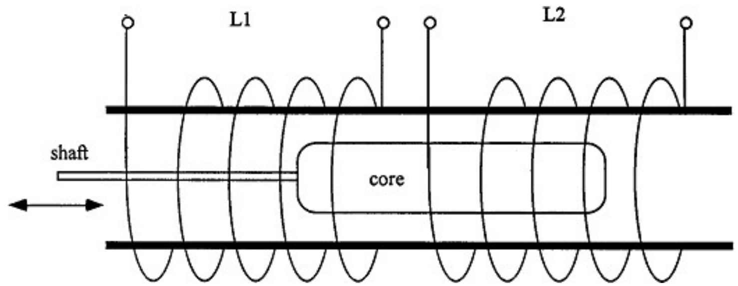
Função de saída em relação a carga

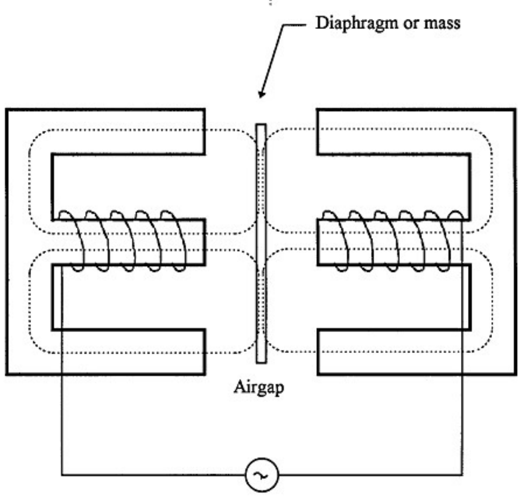


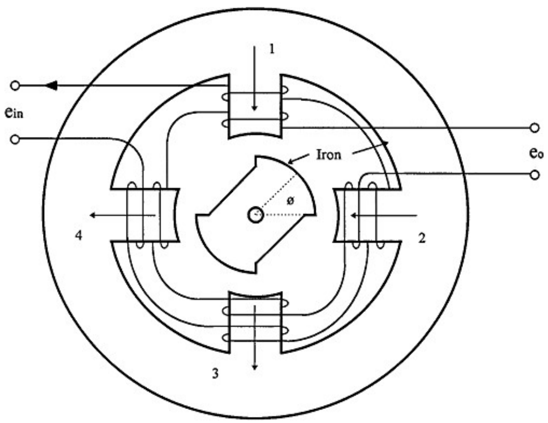
SENSOR DE DESLOCAMENTO RESISTIVO

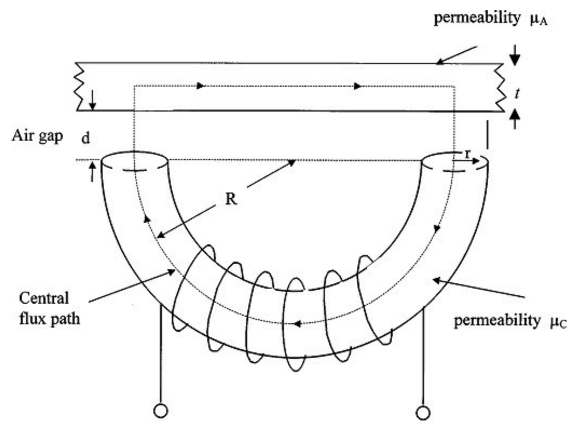




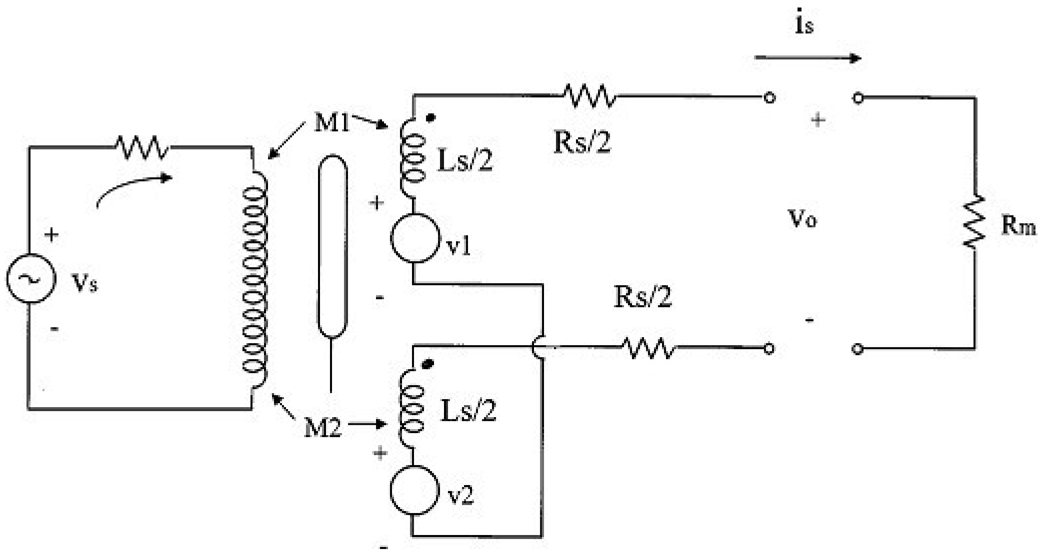


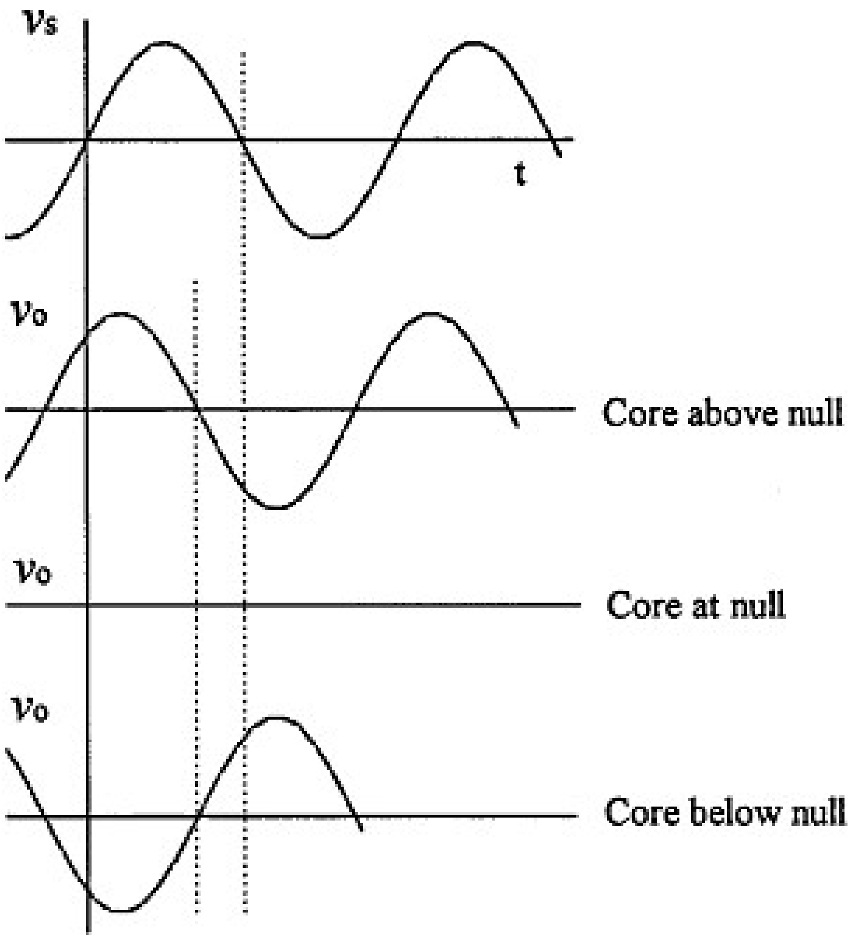




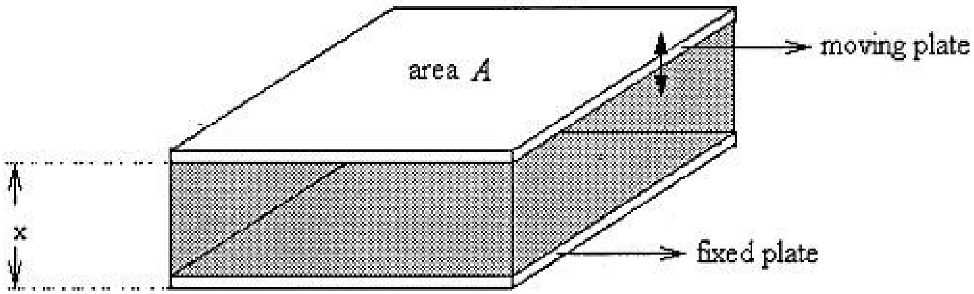


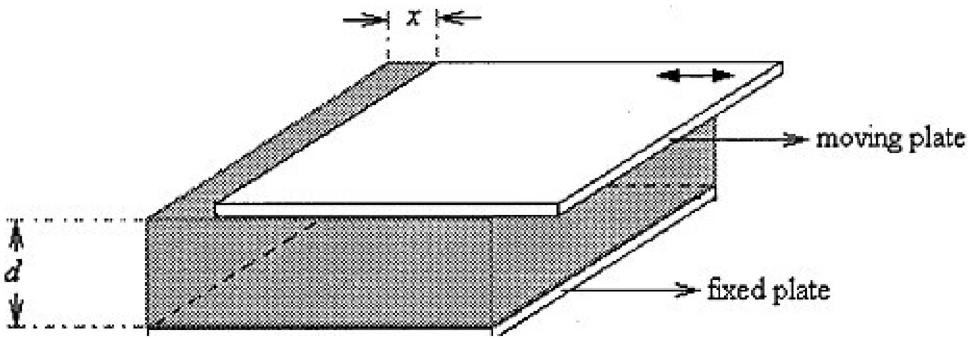
SENSOR DE DESLOCAMENTO RESISTIVO

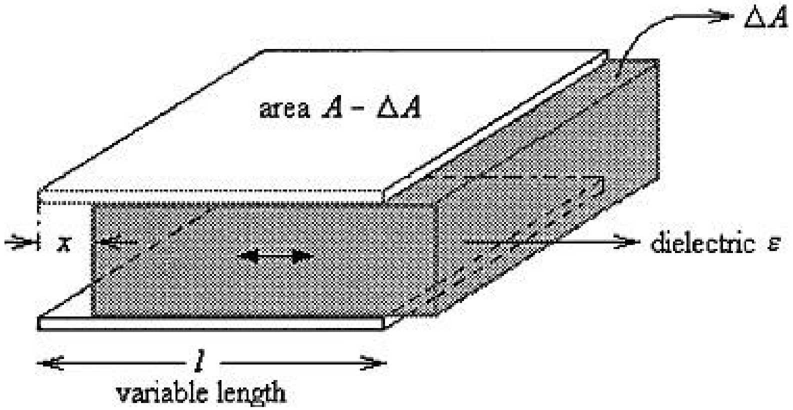


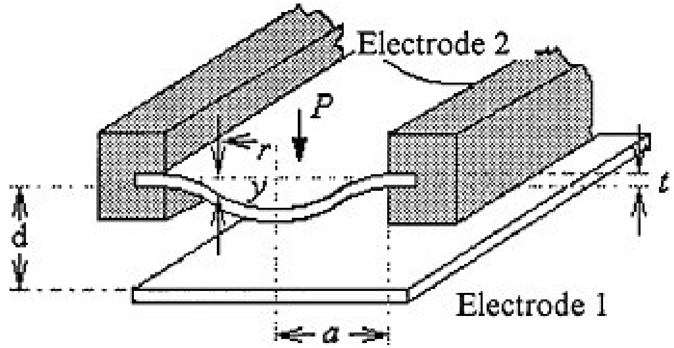


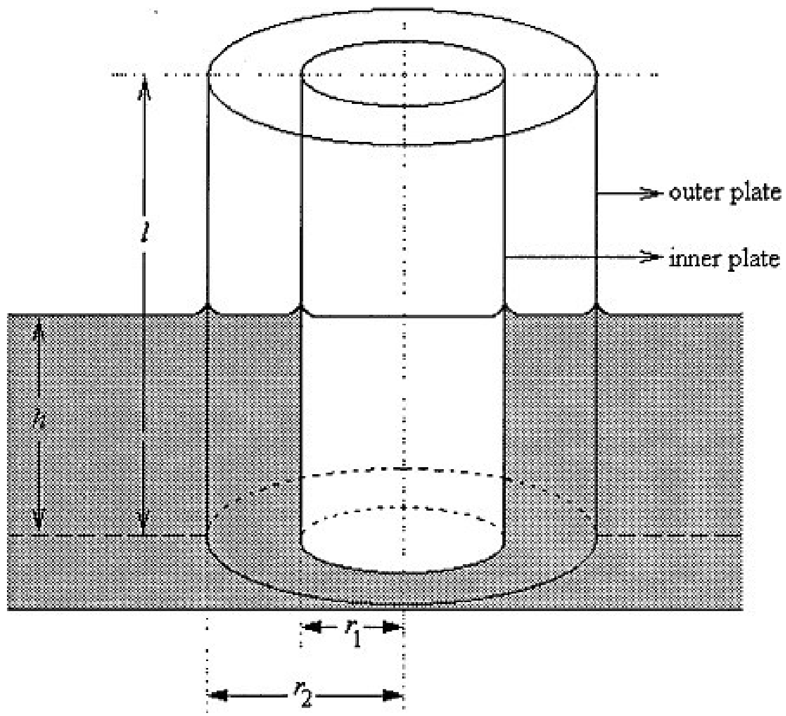
SENSOR DE DESLOCAMENTO CAPACITIVO



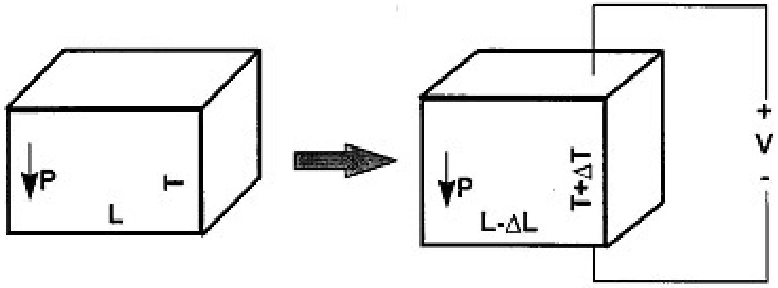




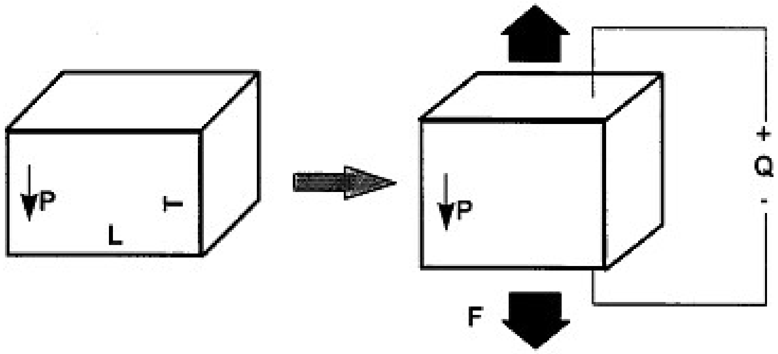




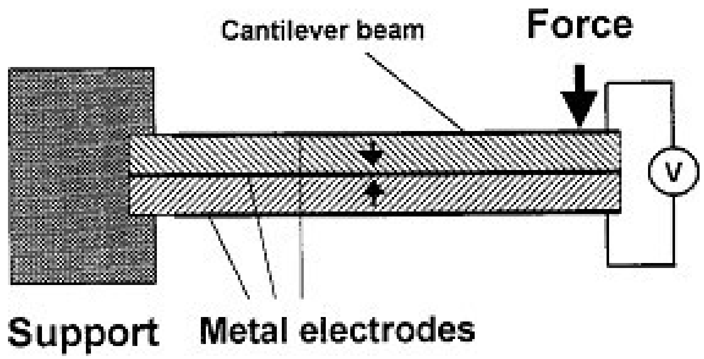
SENSOR DE DESLOCAMENTO PIEZOELÉTRICO

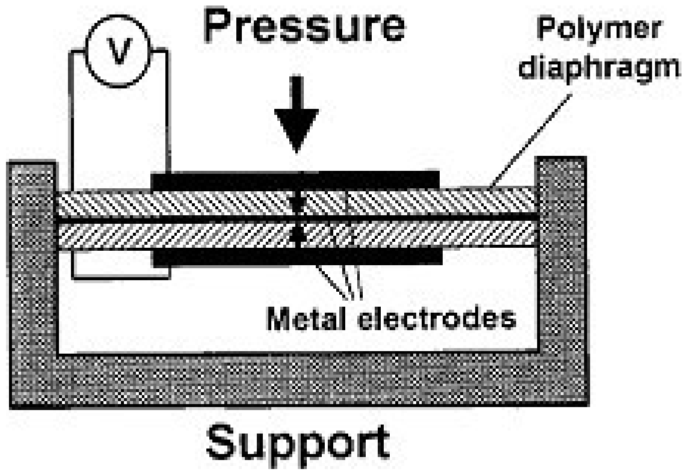


a)



b)





a) **Campo elétrico V aplicado ao material gera deformação**
b) **Deformação do material produz uma carga Q**

Fabry Perot

Interferometria

$$I = I_0 \cos\left(\frac{4\pi}{\lambda} d\right)$$

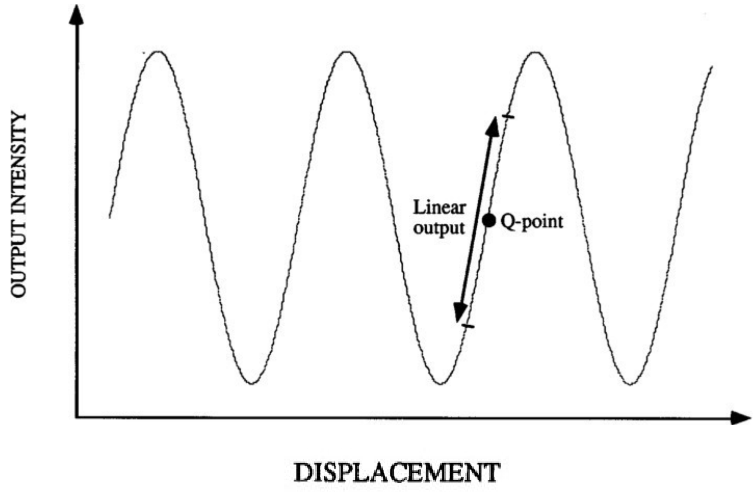
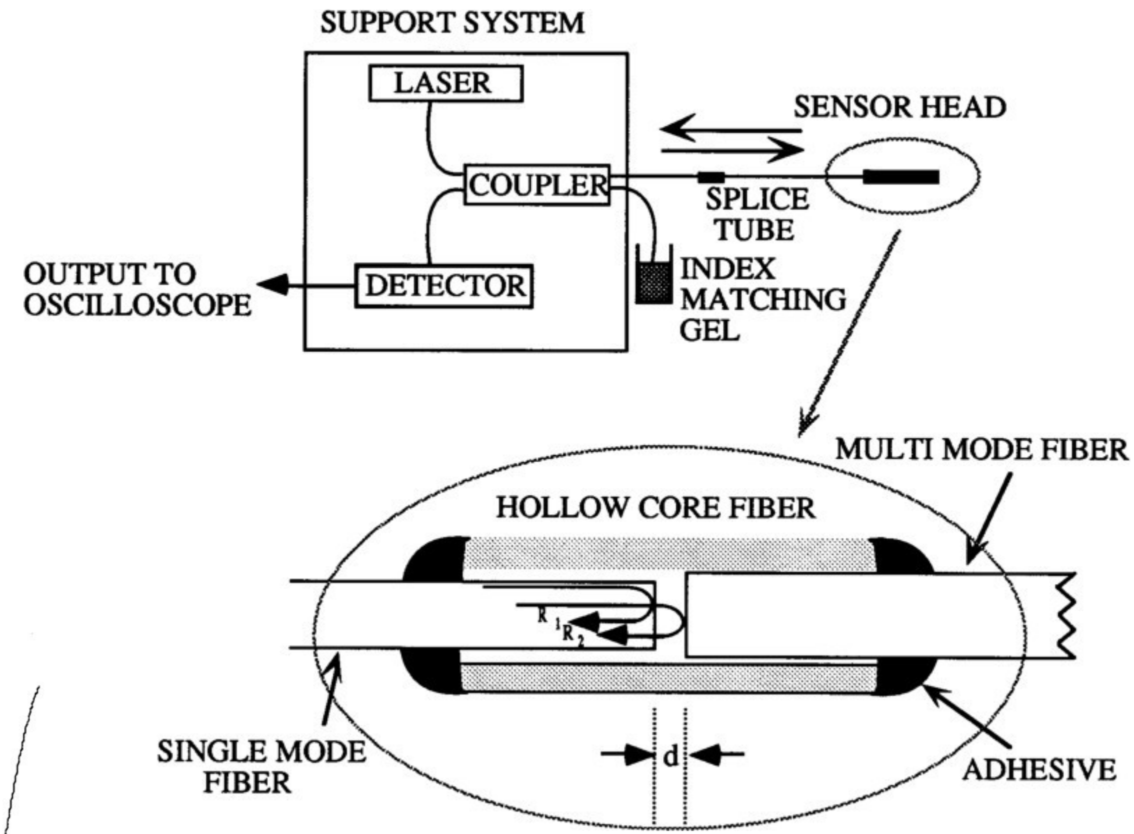


FIGURE 6.100 A typical EFPI transfer function curve.



EXEMPLO DE APLICAÇÃO

V. Bhatia. **Wavelength-tracked white light interferometry for highly sensitive strain and temperature measurements**, 1996.

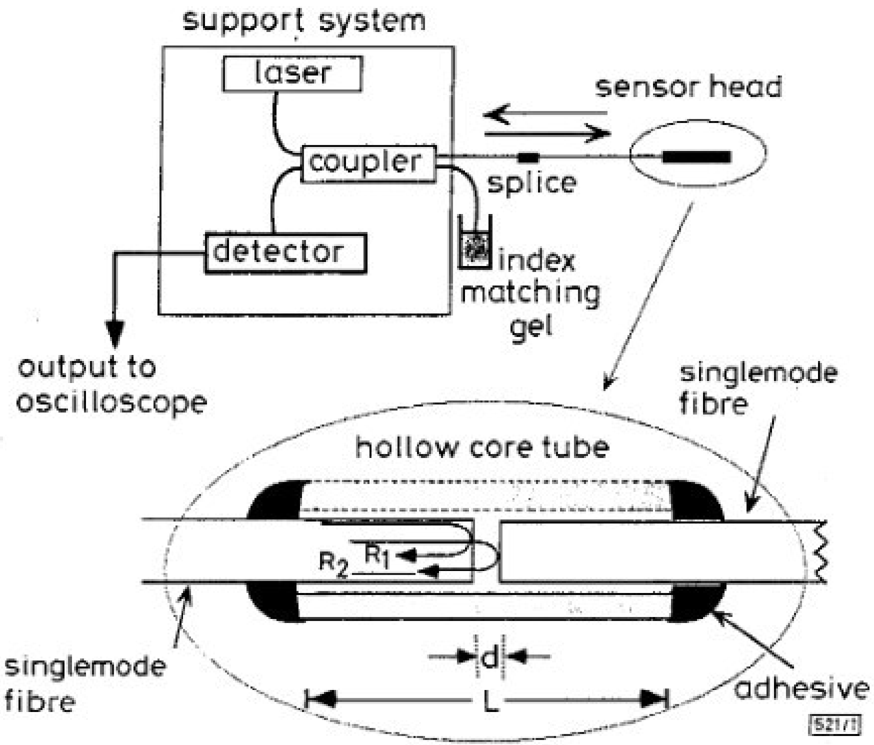


Fig. 1 *Extrinsic Fabry-Perot interferometric (EFPI) system with a magnified view of sensing head*

d = cavity length
L = gauge-length of sensor

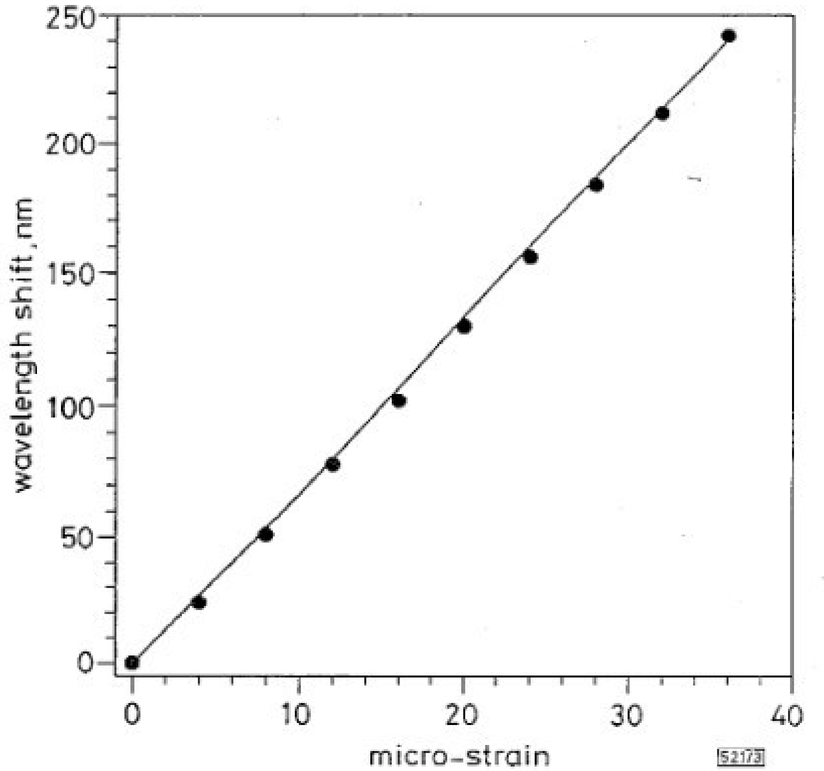
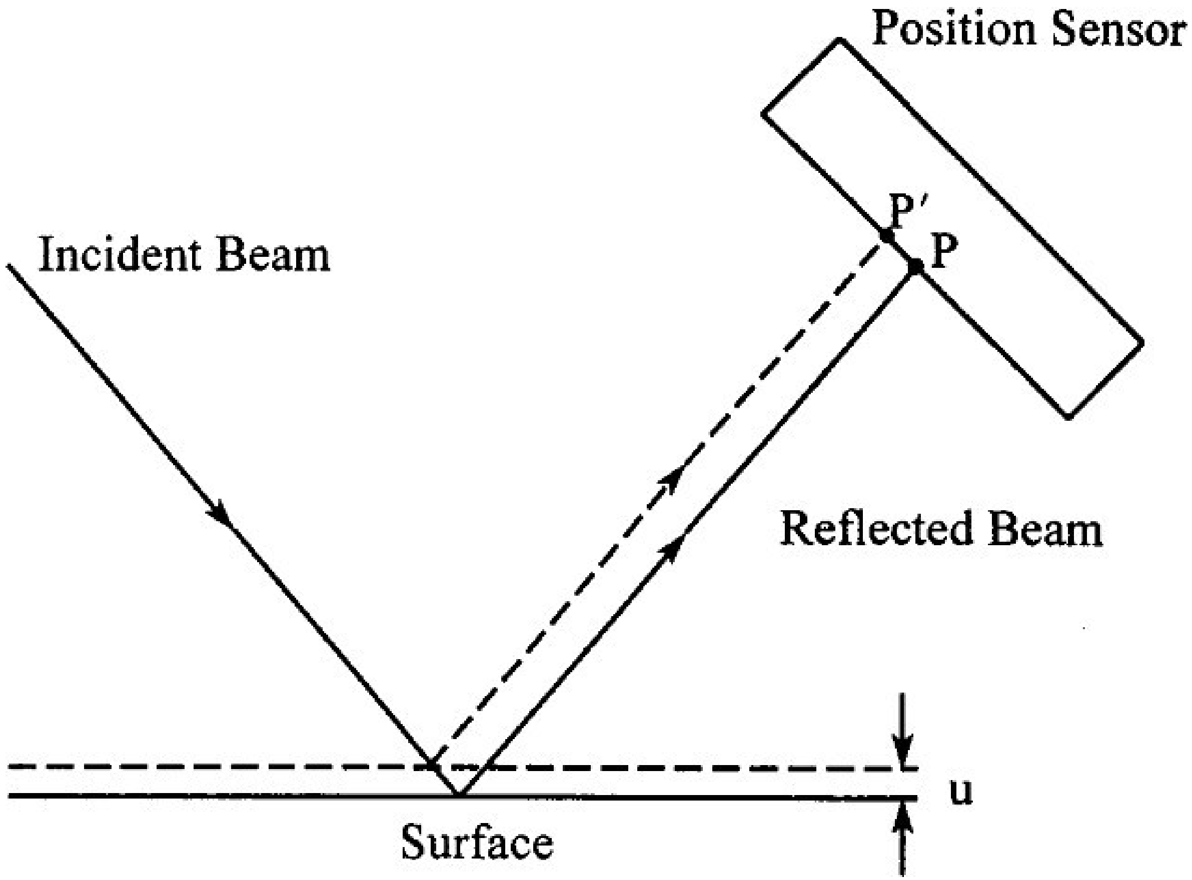


Fig. 3 *Theoretical and experimental shifts in resonance bands of sensor with d = 2μm and L = 1 cm in the 1.3μm region*

Reflexão de feixe óptico



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EXEMPLO DE APLICAÇÃO

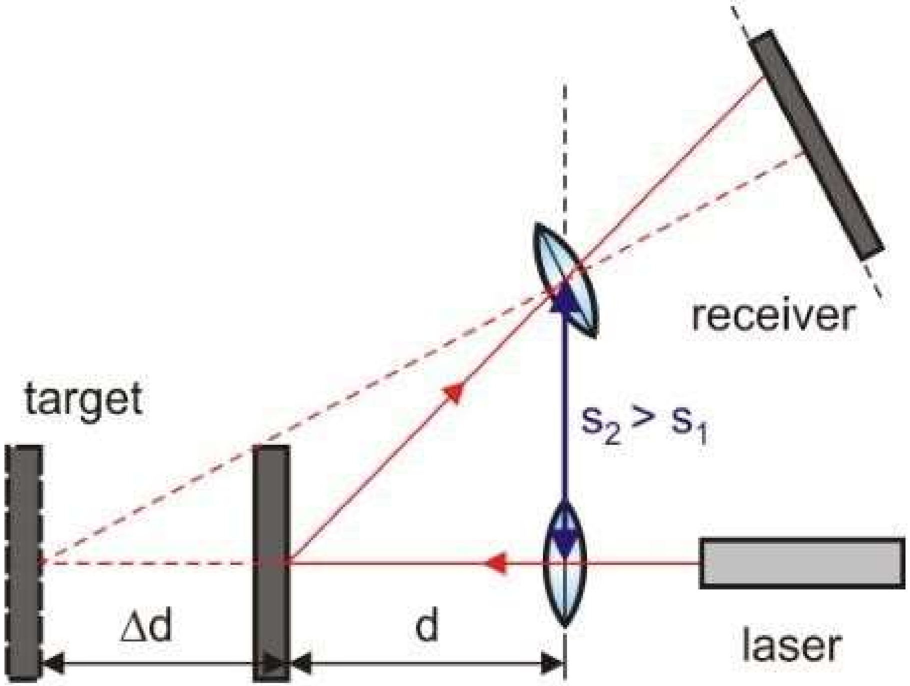


Fig. 1 principle setup of triangulation sensor

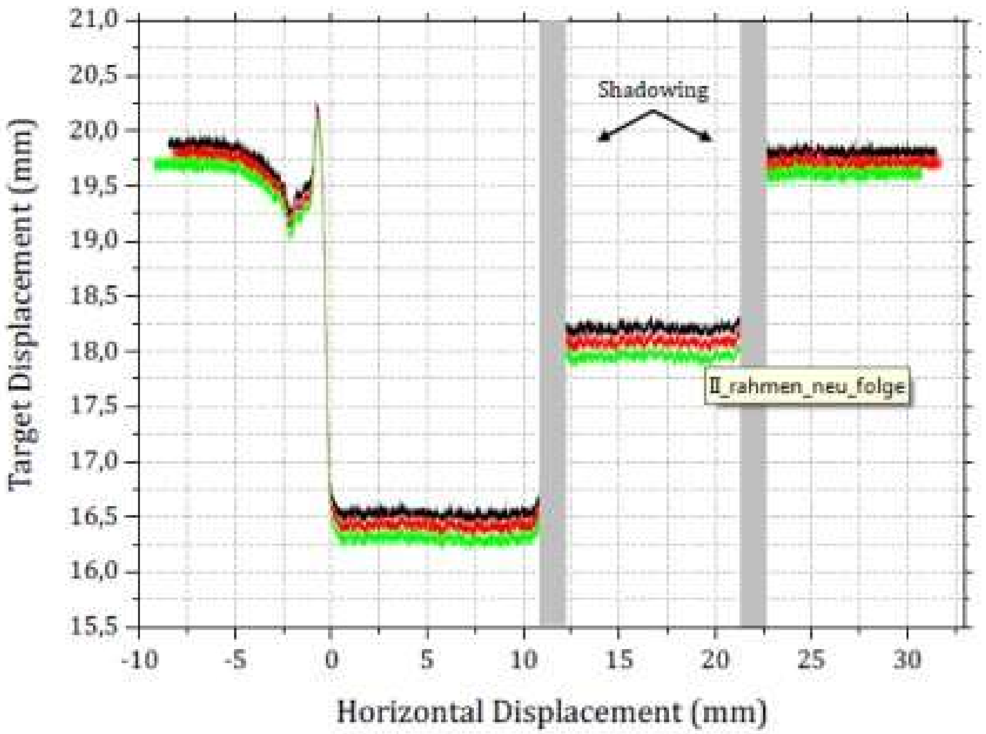
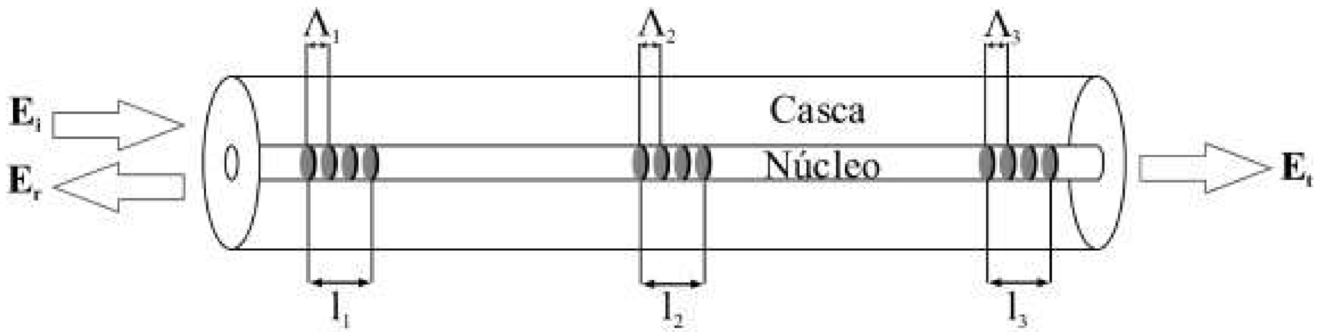
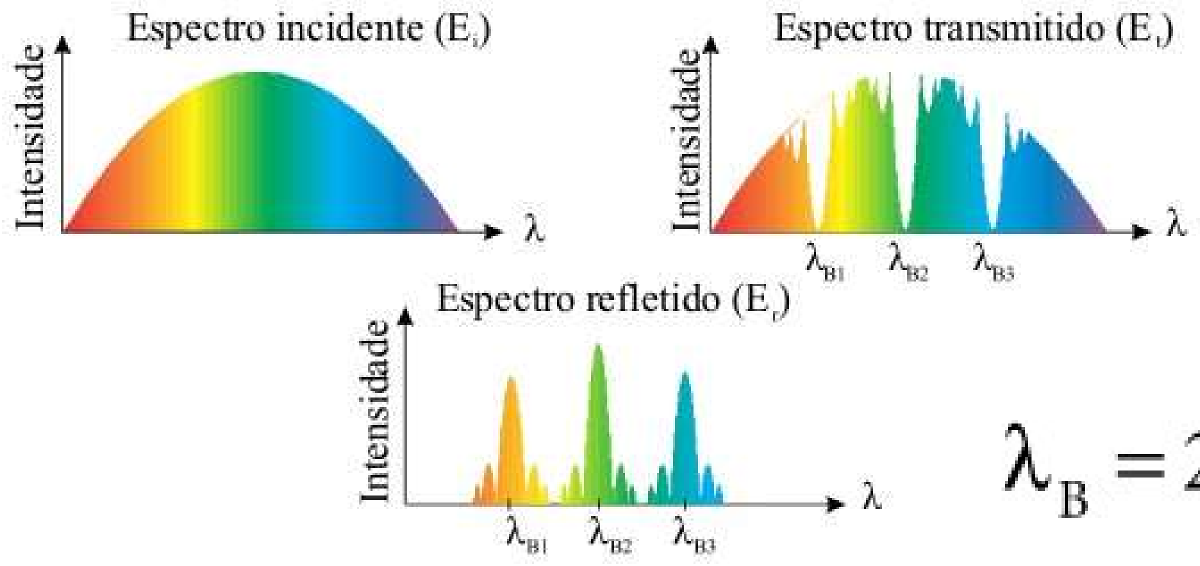


Fig. 6 fast distance measurement on moving target at different displacements

Redes de Bragg em Fibra Óptica



(a)



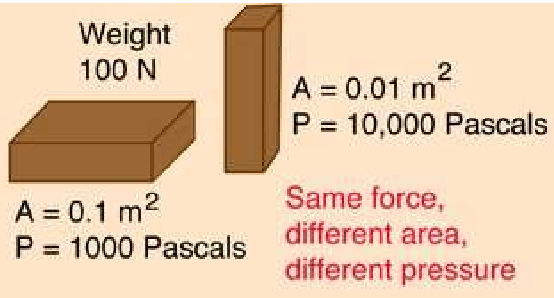
(b)

$$\lambda_B = 2\Lambda n_{eff}$$

Sensores de Pressão

Introdução - Pressão

$$Pressure = \frac{Force}{Area} = \frac{F}{A}$$

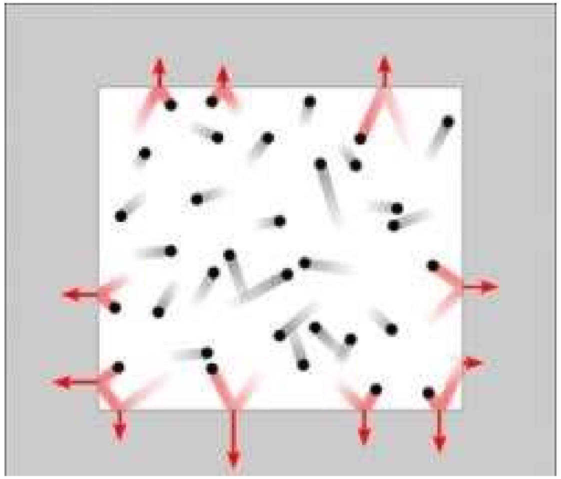


$$P = \frac{Force}{Area} = \frac{F}{A} = \frac{F \cdot d}{A \cdot d} = \frac{W}{V} = \frac{Energy}{Volume}$$

Pressure Units

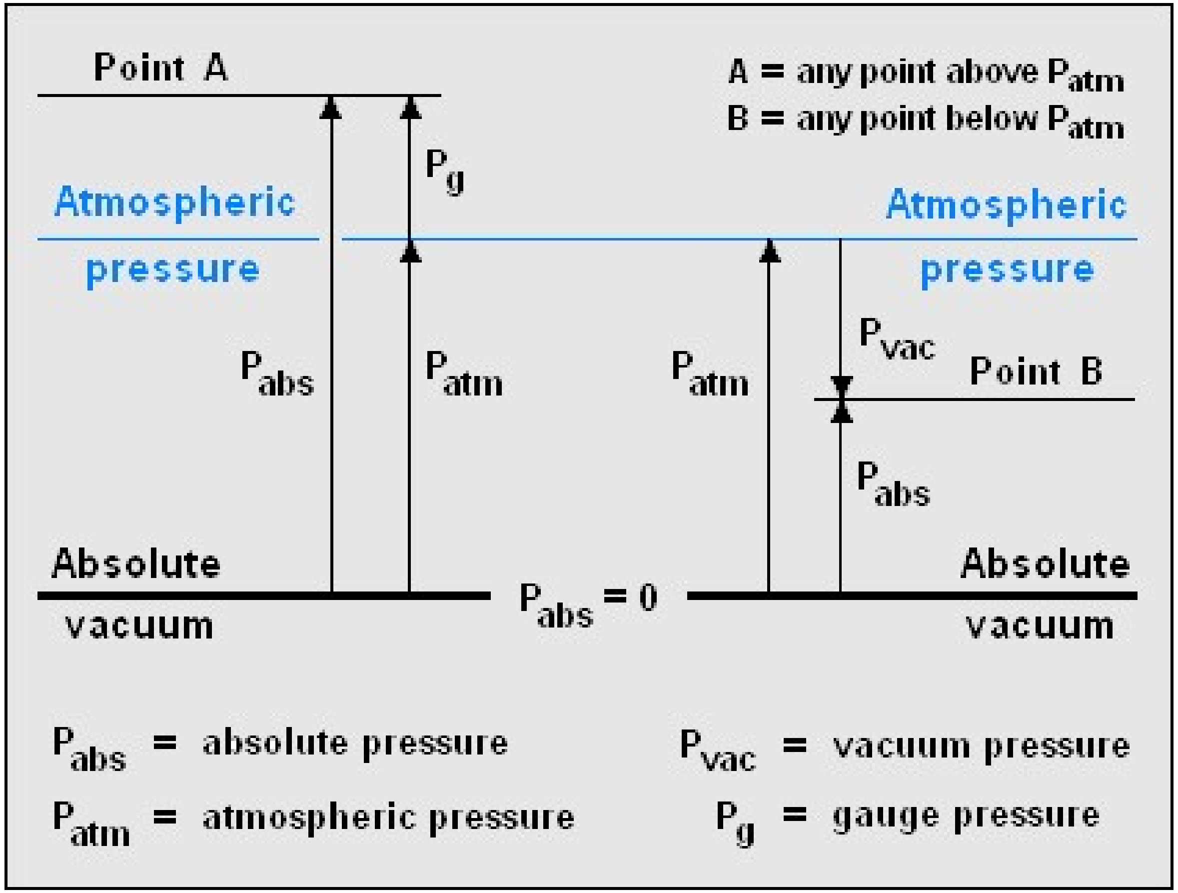
	pascal (Pa)	bar (bar)	atmosphere (atm)	torr (torr)	pound-force per square inch (psi)	kilogram-force per square centimeter (kgf/cm^2)
1 Pa	≡ 1 N/m^2	10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}	1.01972×10^{-5}
1 bar	100,000	≡ 10^6 dyn/cm^2	0.98692	750.06	14.504	1.01972
1 atm	101,325	1.01325	≡ 1 atm	760	14.696	1.03323
1 torr	133.322	1.3332×10^{-3}	1.3158×10^{-3}	≡ 1 torr ≈ 1 mmHg	19.337×10^{-3}	1.35951×10^{-3}
1 psi	6,894.76	68.948×10^{-3}	68.046×10^{-3}	51.715	≡ 1 lbf/in^2	7.03059×10^{-2}
1 kgf/cm^2	98,066.5	0.980665	0.967838	735.5576	14.22357	≡ 1 kgf/cm^2

Example reading: 1 Pa = 1 N/m^2 = 10^{-5} bar = 9.8692×10^{-6} atm = 7.5006×10^{-3} torr, etc.
Note: mmHg is an abbreviation for millimetre of mercury



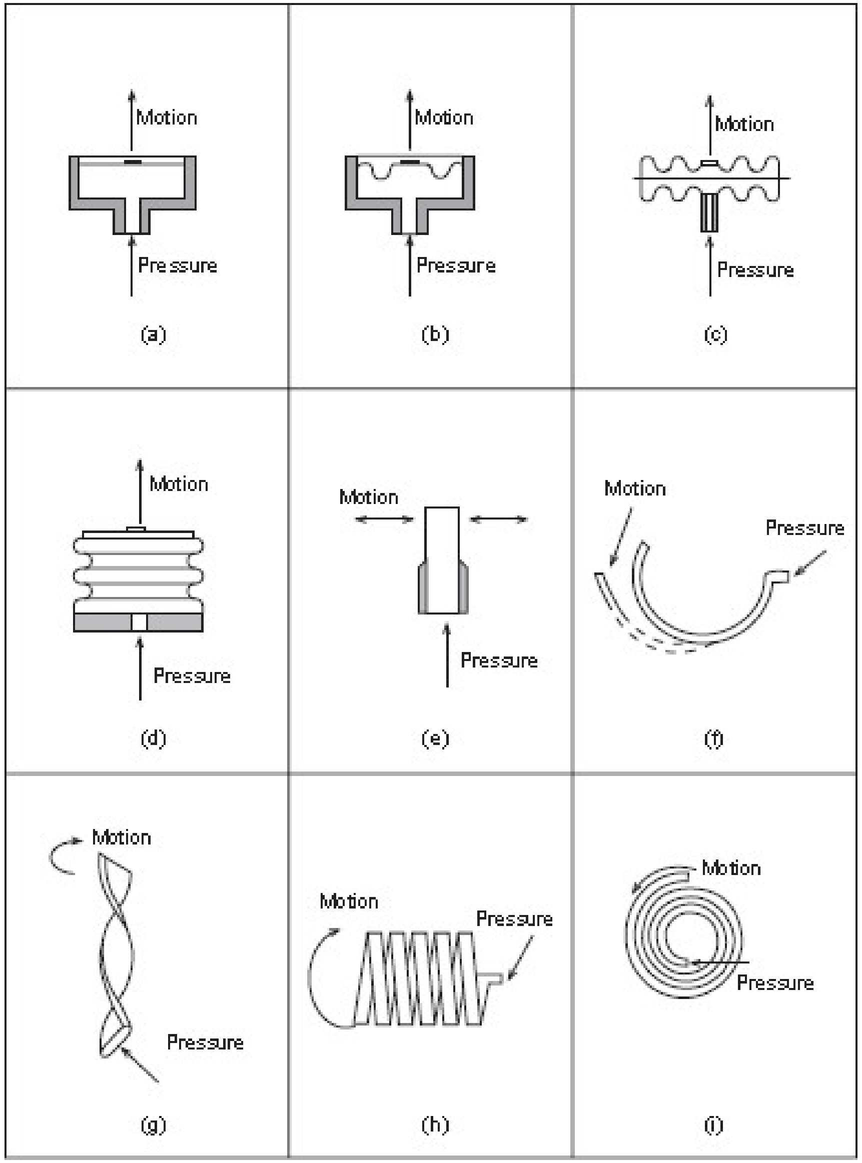
Pressão

As medições de pressão podem ter duas referências: 1) a pressão atmosférica e nesse caso os sensors e os resultados obtidos são chamadas de “pressão parcial”; 2) o zero absoluto, nesse caso a referência é o vácuo absoluto e as medições são chamdas de “pressão absoluta”.



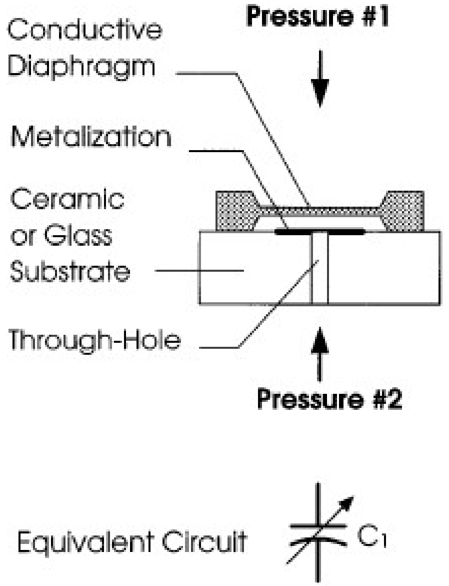
Medição de Pressão

Dispositivos para medição de pressão:

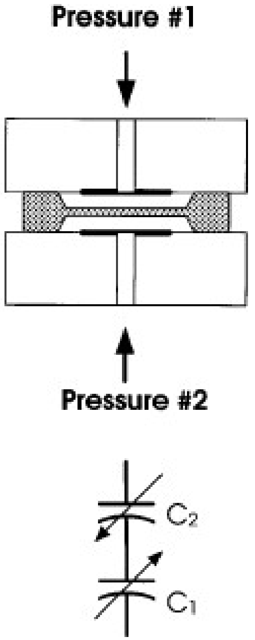


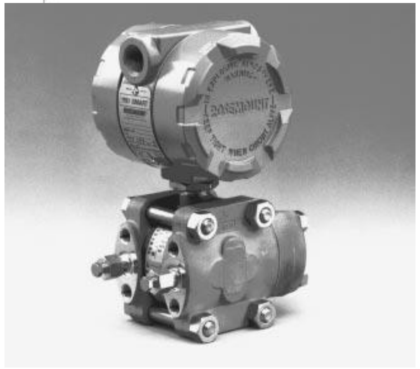
Dispositivos capacitivos para medição de pressão:

Sensor unitário

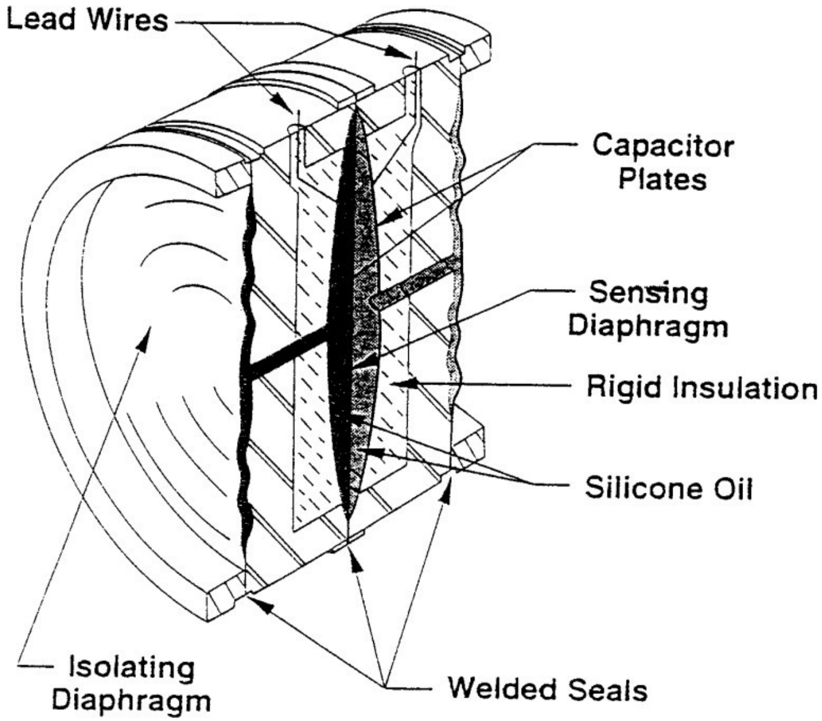


Sensor diferencial



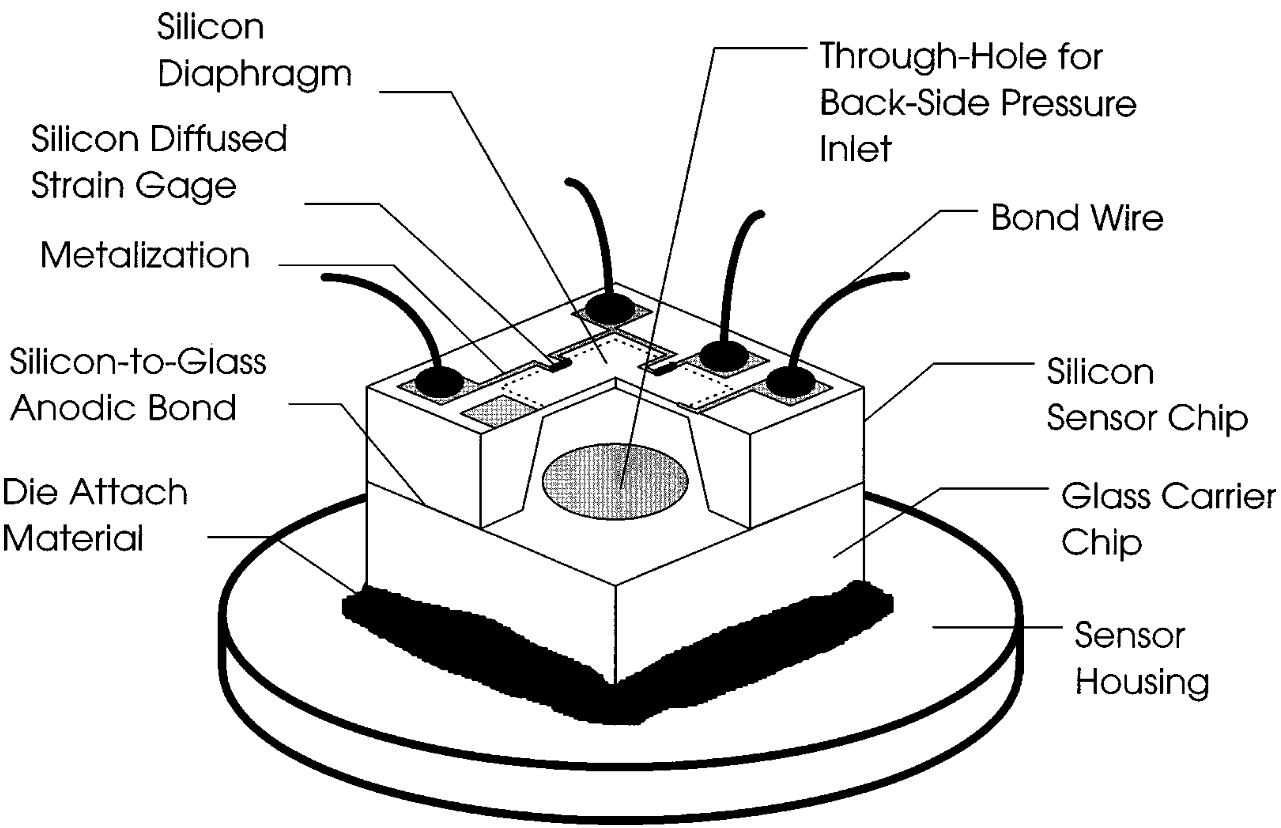


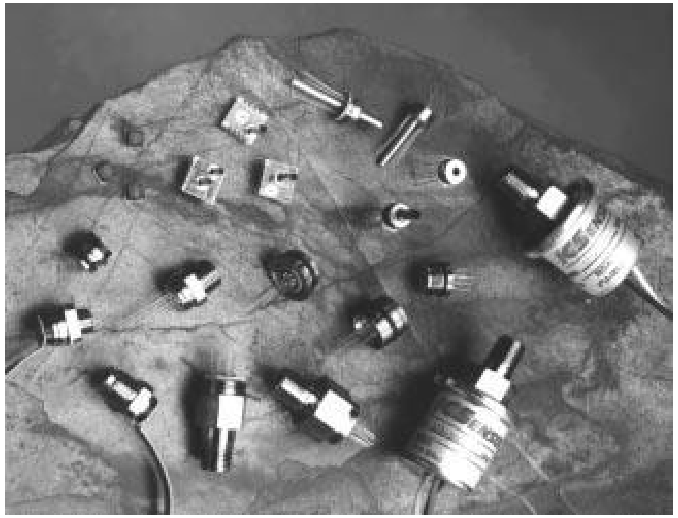
Sensor com isolamento para ambiente corrosivo:



Medição de Pressão

Dispositivos piezoresistivo para medição de pressão:





Exemplos de sensores com encapsulamento padrão industrial baseados em pastilhas semicondutoras

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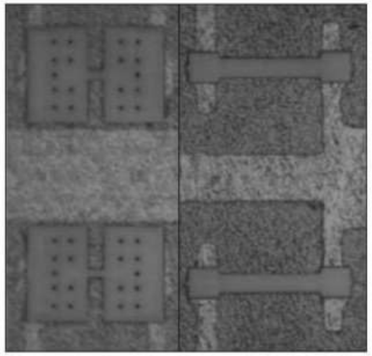
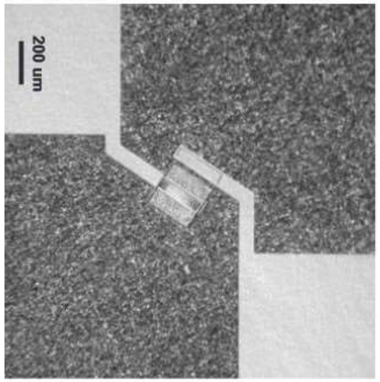
Medição de Pressão

Dispositivos piezoresistivo para medição de pressão:





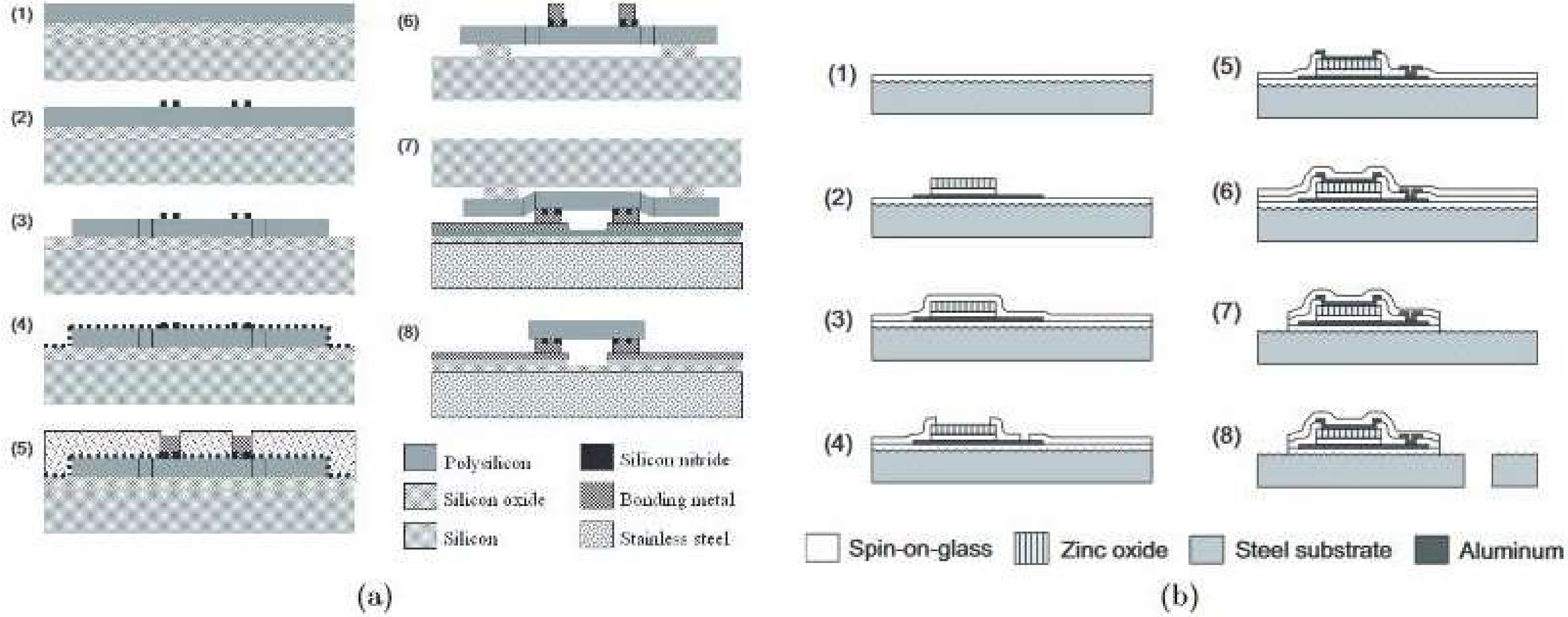
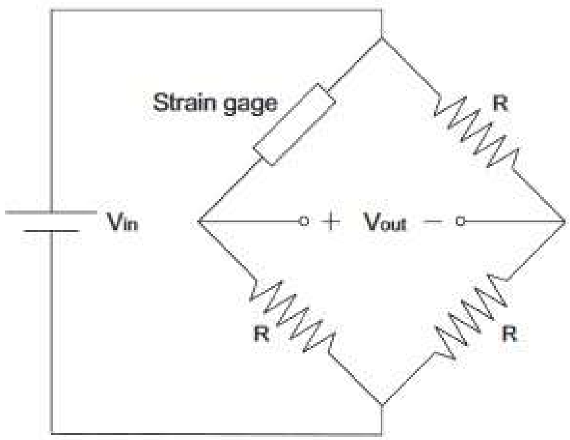
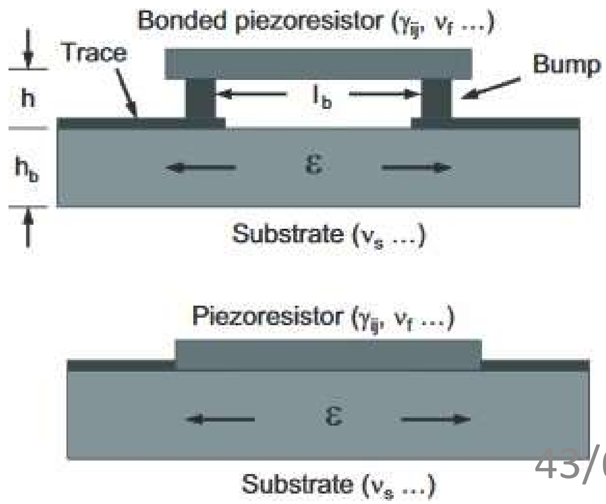


Figure 4. Fabrication processes for (a) polysilicon strain sensors (b) ZnO strain sensors on steel substrate.





Dispositivos piezoresistivo para medição de pressão:

https://www.youtube.com/watch?v=bQJHxF4-qzE

Medição de Pressão

Dispositivos para medição de vácuo:

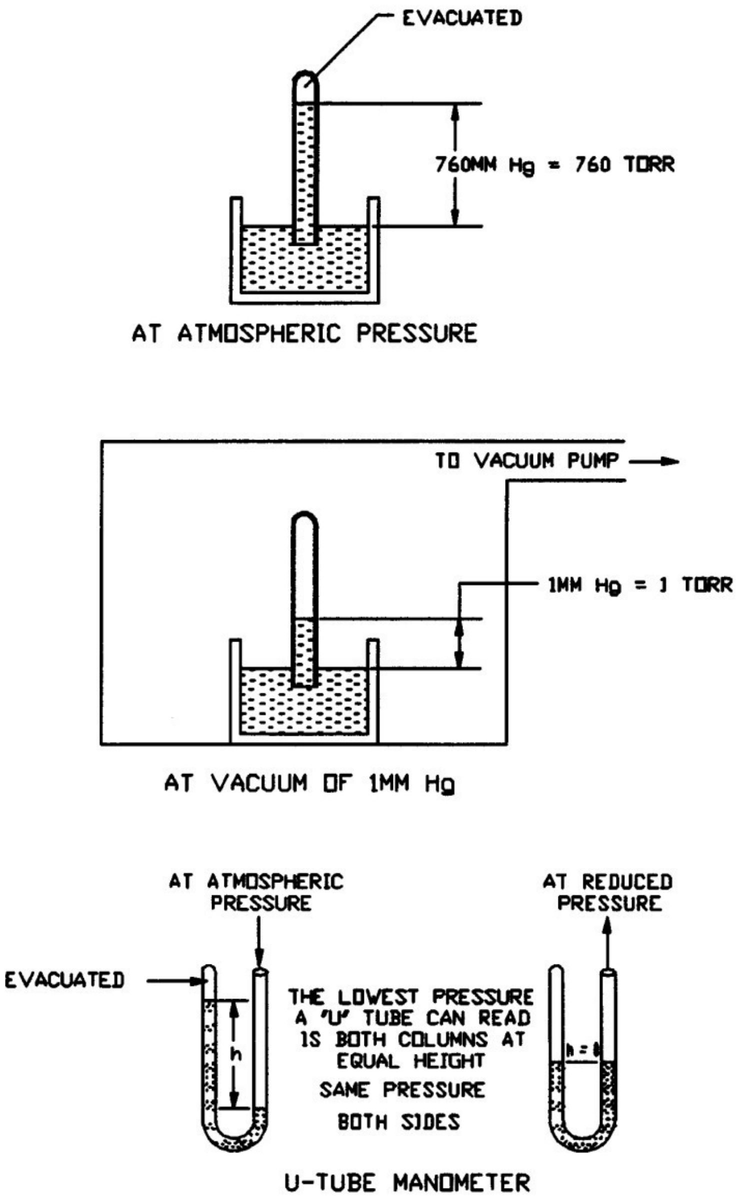
- A medição de vácuo é mais complexa que do que a de pressão parcial positiva.
  A faixa de operação dos dispositivos sensores deve normalmente ser muito grande, variando a partir da pressão atmosférica até superior a 11 ordem de magnitude, por exemplo na fabricação/processamento de semicondutores vácuos de até 7x10-9 Torr são necessários, ou seja:

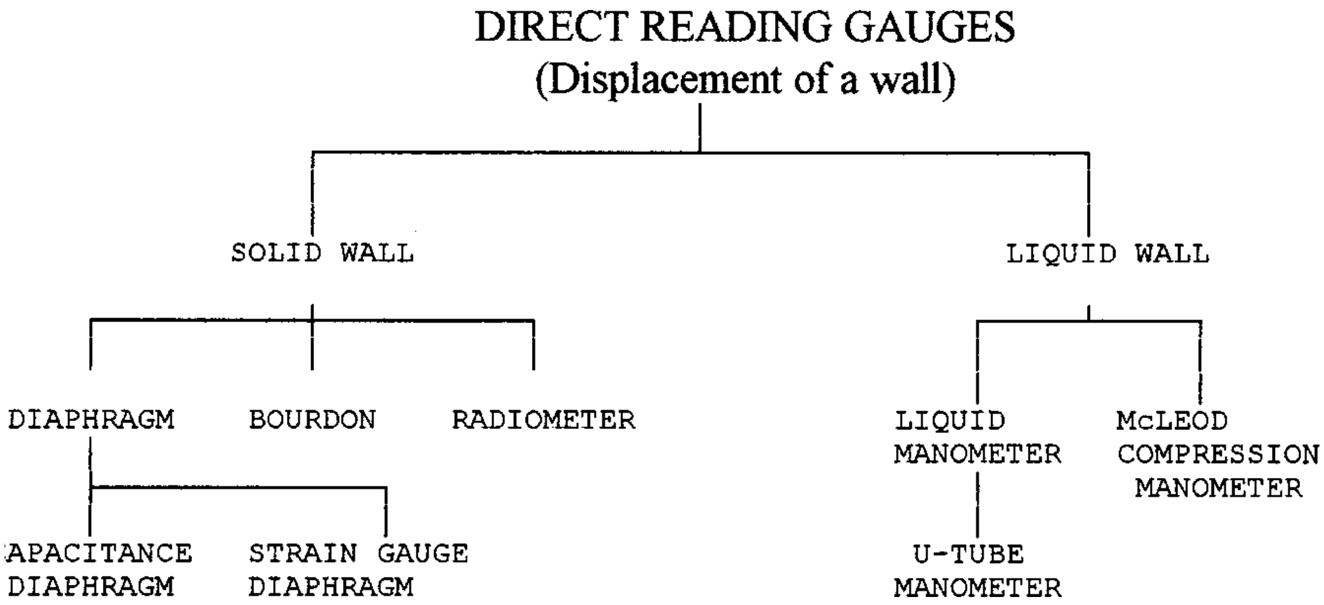
760 Torr (Patm) – 7x10-9 Torr

Na maioria dos casos são necessários mais de um elemento sensor para atender a toda a faixa de operação requerida.

Medição de Pressão

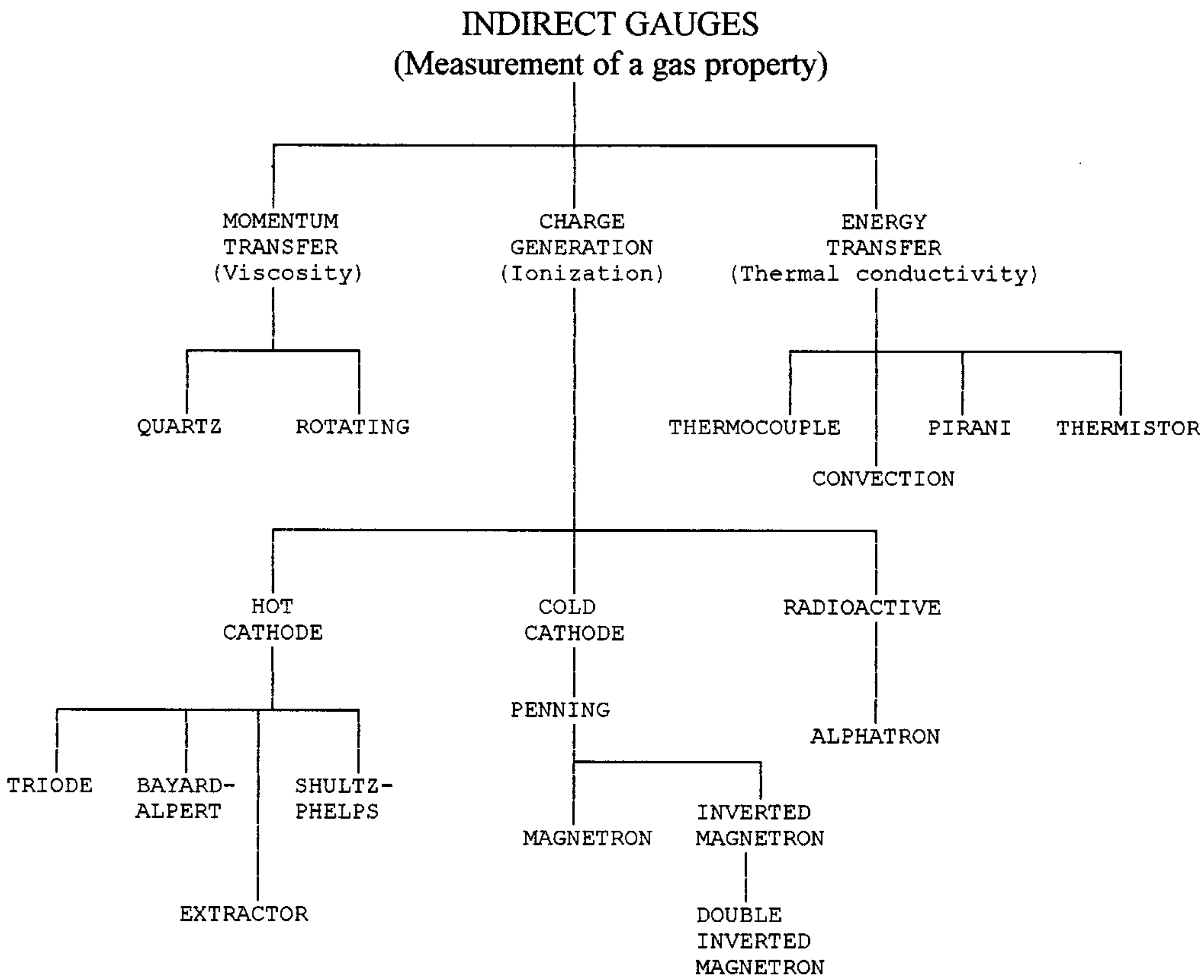
Dispositivos para medição de vácuo:





Medição de Pressão

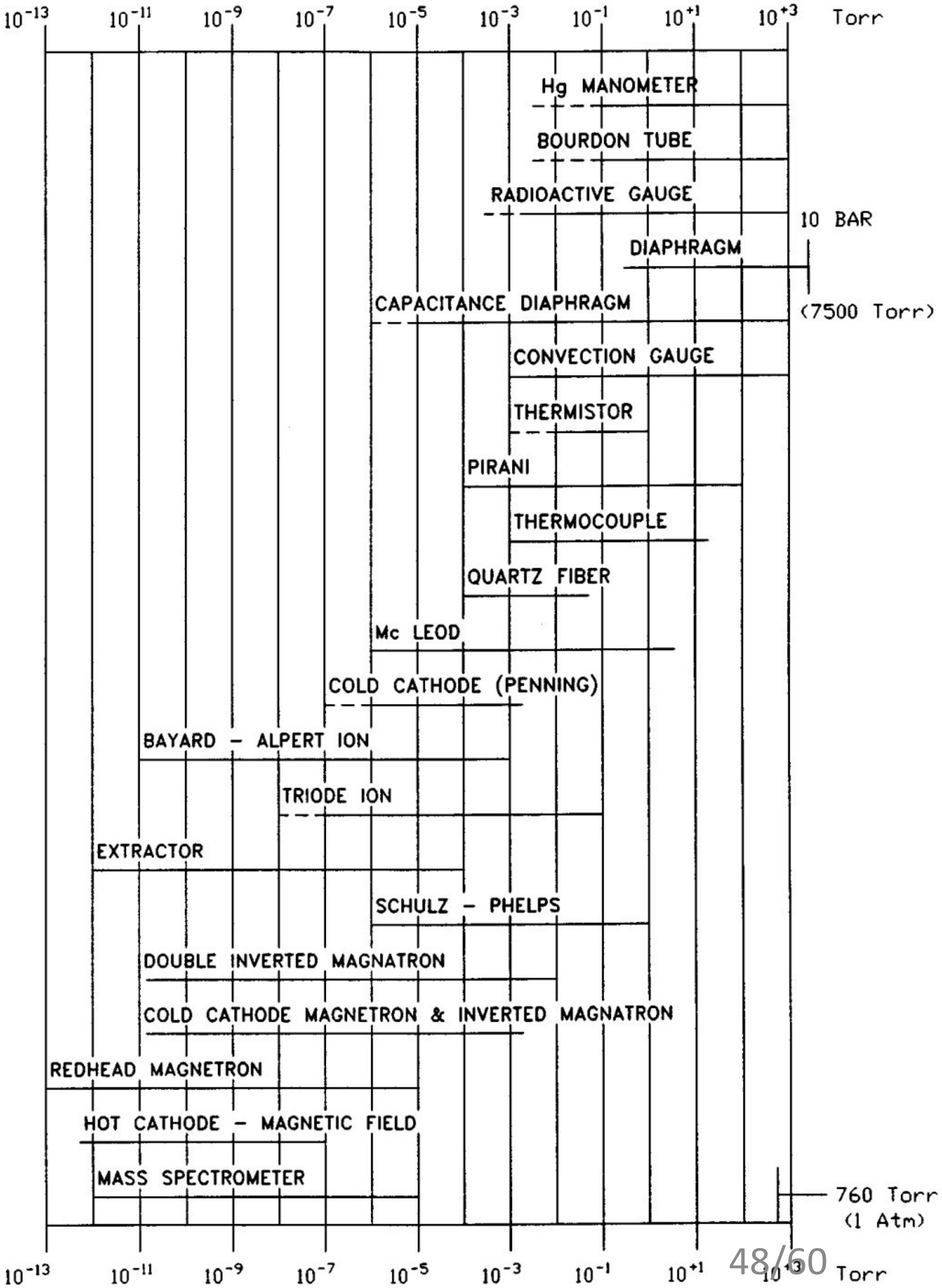
Dispositivos para medição de vácuo:



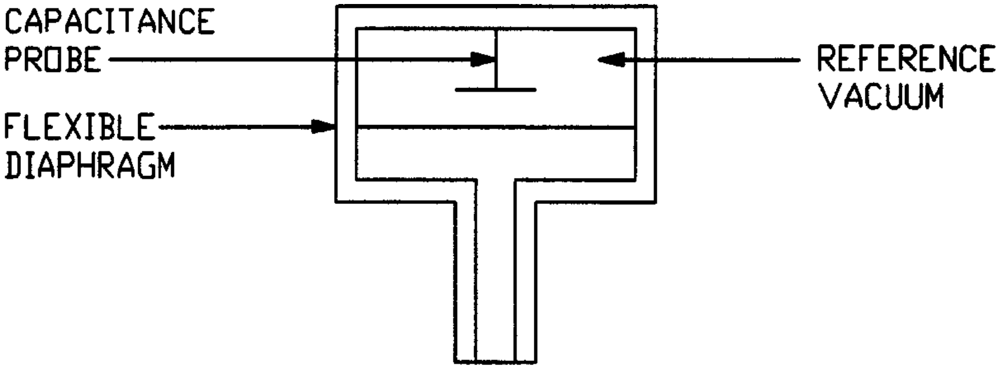
Medição de Pressão

Dispositivos para medição de vácuo:

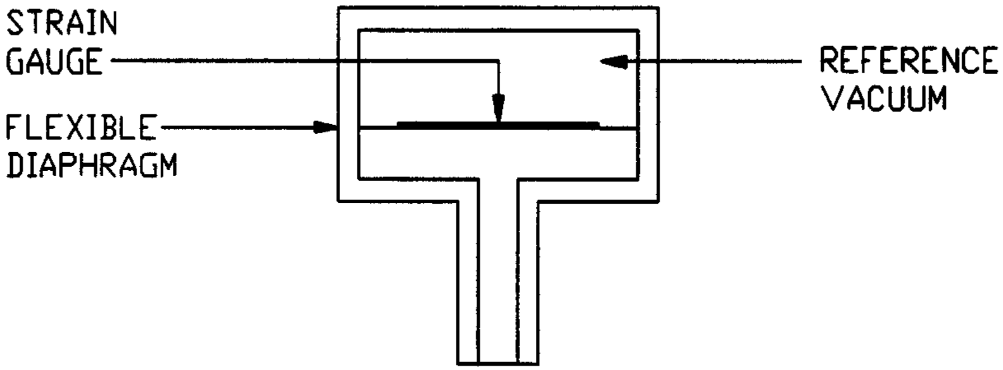
Faixa de operação das distintas tecnologias de medição



Dispositivos para medição de vácuo:



CAPACITANCE DIAPHRAGM GAUGE



STRAIN GAUGE DIAPHRAGM GAUGE

Dispositivos para medição de vácuo:

Gauge Pirani:

Sensor de vácuo baseado na condutividade térmica dos gases. A partir da medição da corrente passando por um condutor e da dissipação do calor gerado, que implica na resistividade do condutor, é possível definir a pressão de vácuo de um gás.

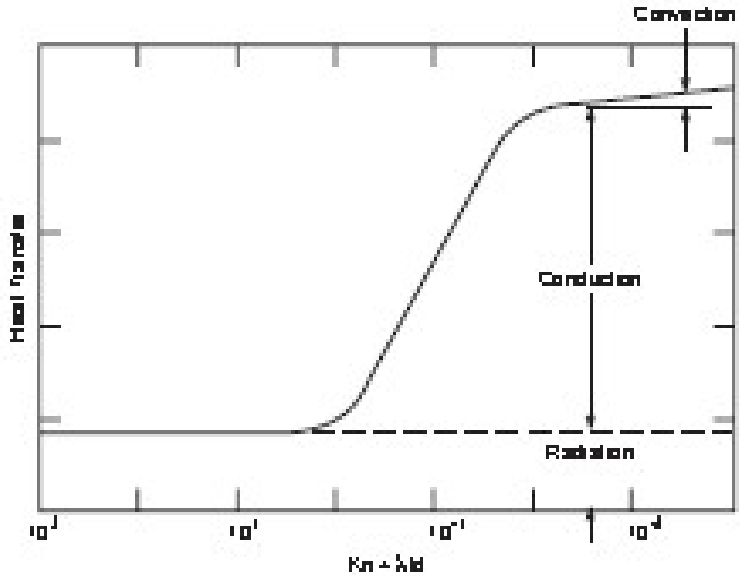
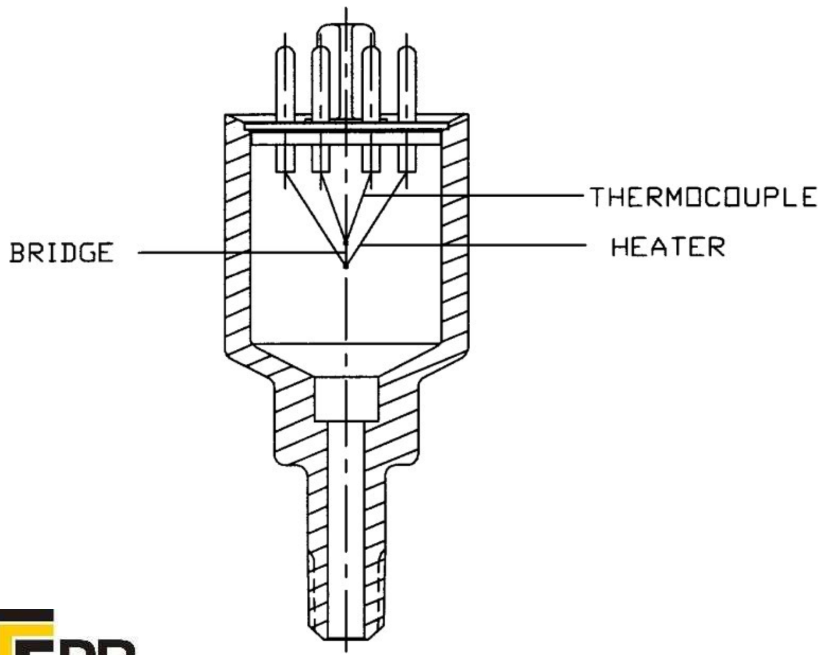


FIGURE 26.14 Heat transfer regimes in a thermal conductivity gage.



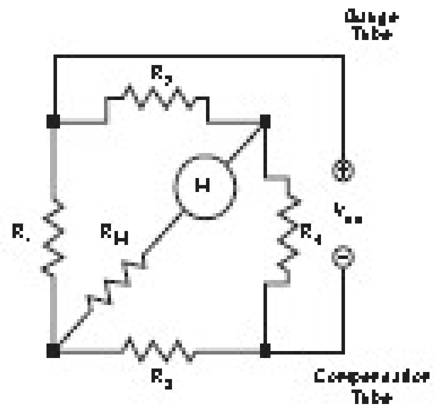
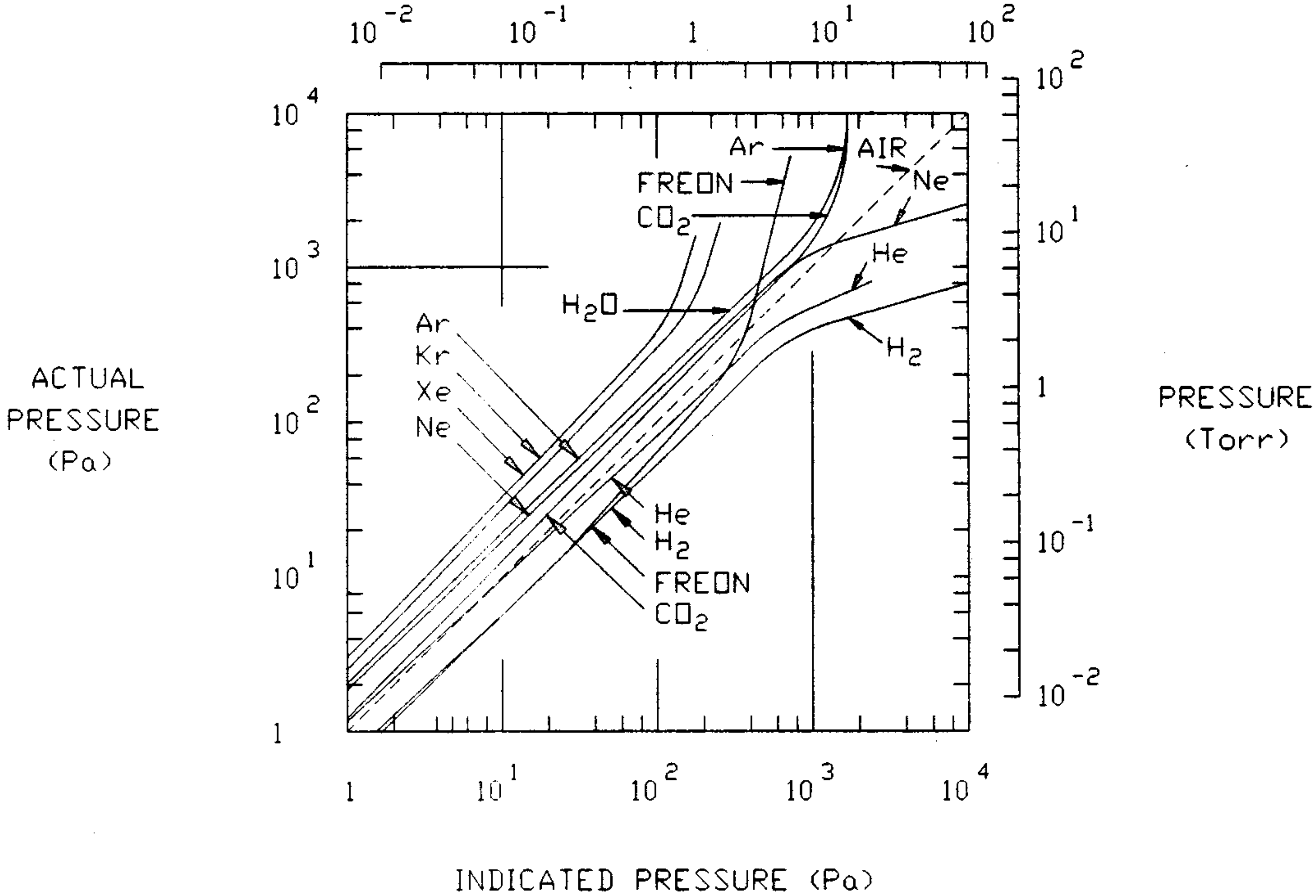


FIGURE 26.15 Pirani gage.

Medição de Pressão

Dispositivos para medição de vácuo:

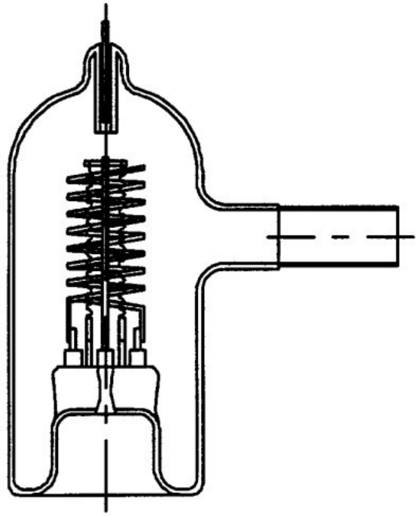


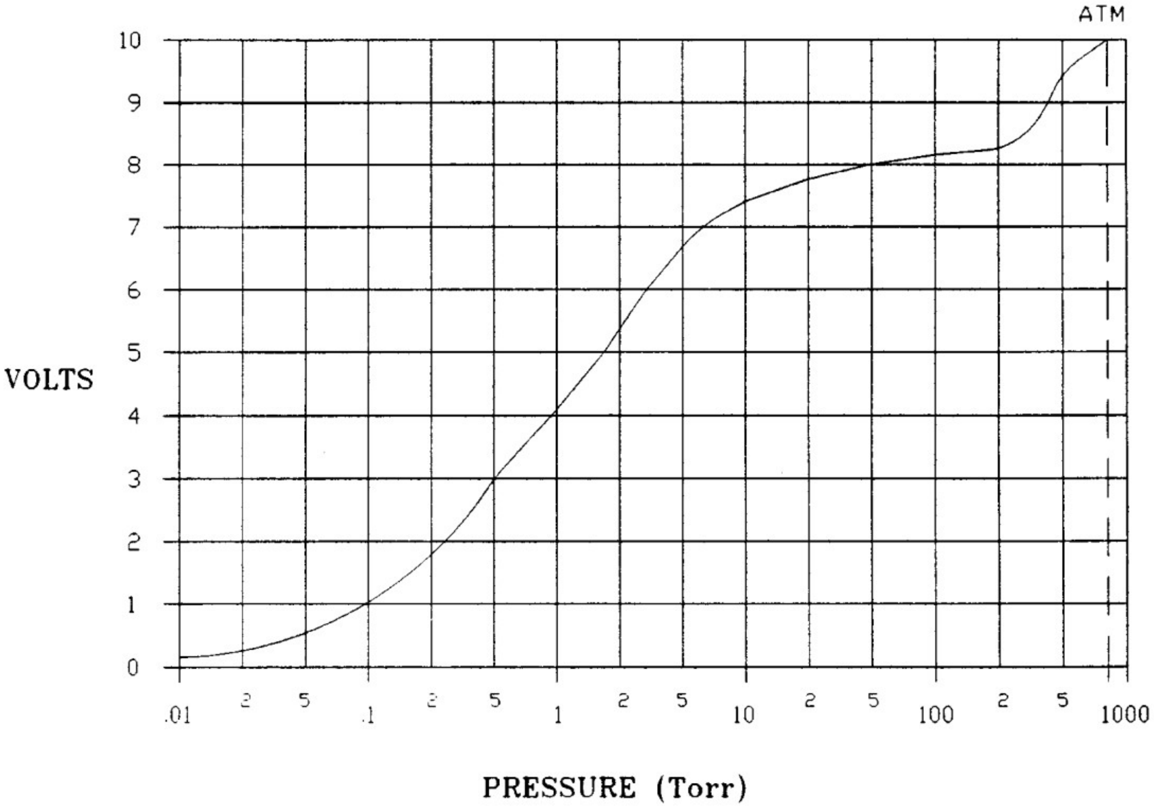
Medição de Pressão

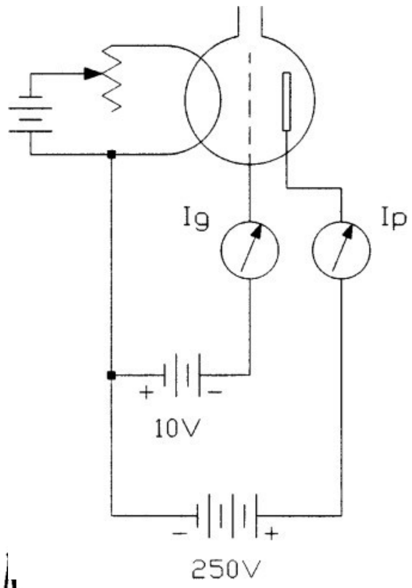
Dispositivos para medição de vácuo:

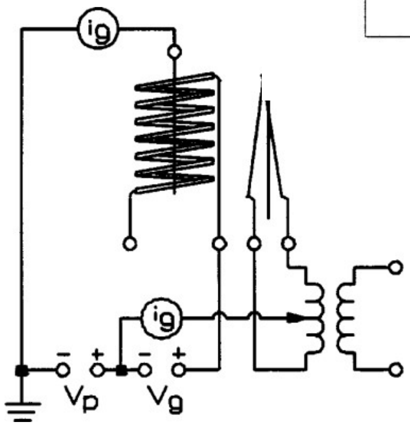
Gauge de Ionização de Catodos Quentes

* Medição UHV (ultra high vacum)





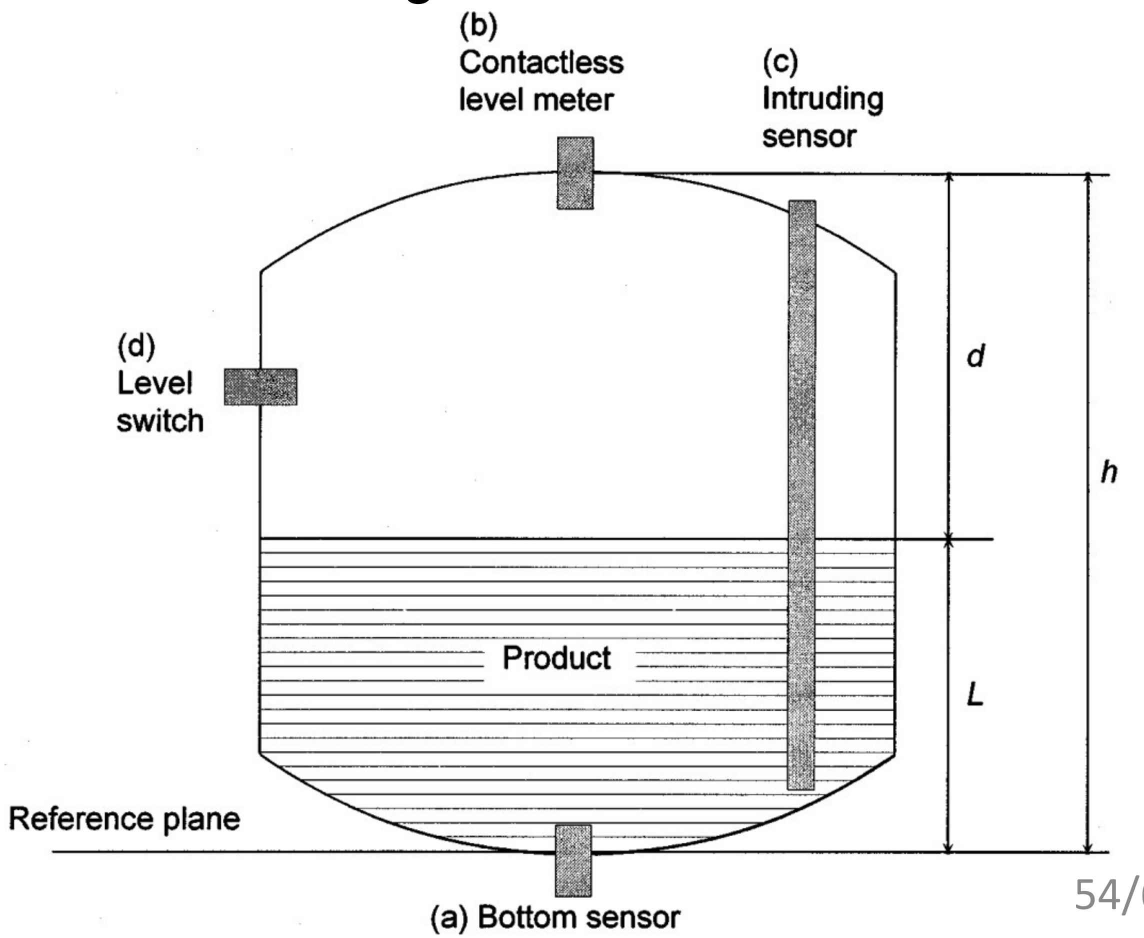




Sensores de Nível

Dispositivos para medição de nível:

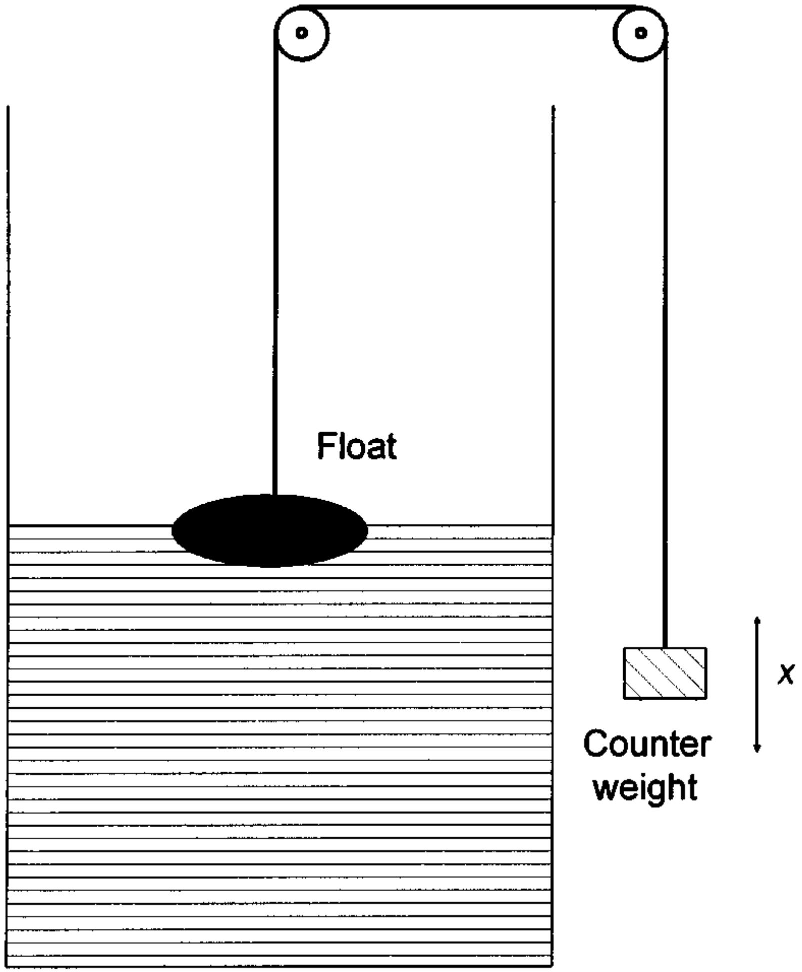
- Normalmente se refere à medição de nível de líquido em um tanque. Existem basicamente dois tipos distintos de medição, um é a medição contínua do nível e a outra é medição discreta com o indicativo do líquido, por exemplo, ter ou não atingido determinado nível, são as chaves de nível.



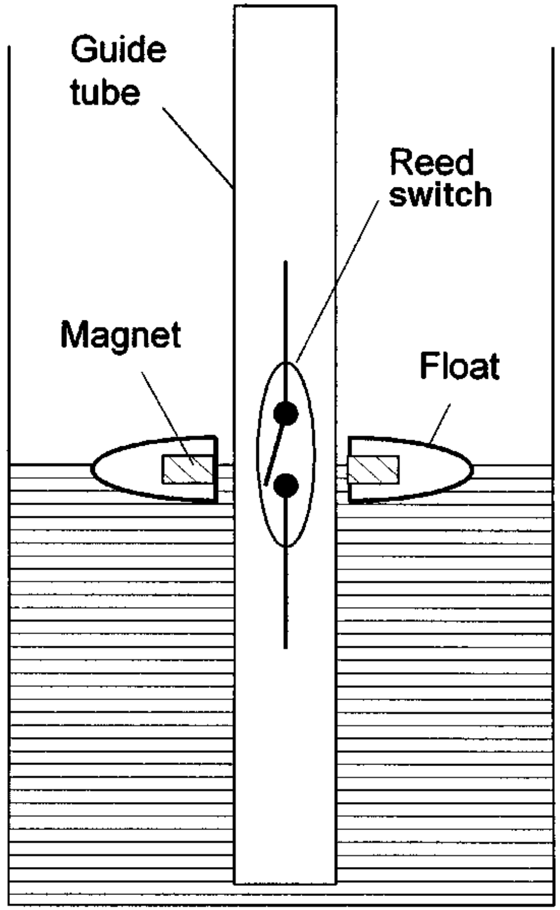
Medição de Nível

Dispositivos para medição de nível:

- Sensores baseados na flutuação sobre a superfície do fluido



(a)

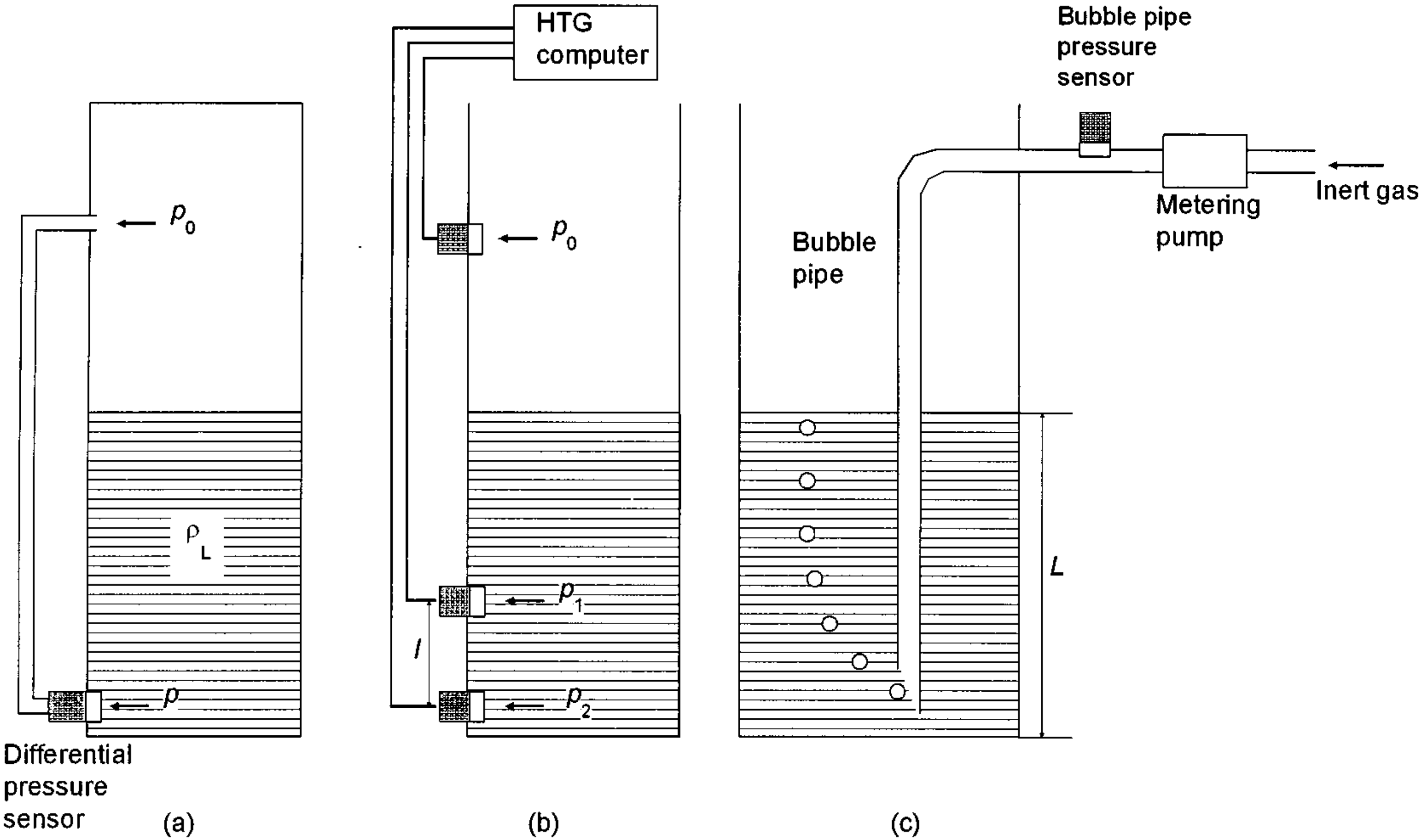


(b)

Medição de Nível

Dispositivos para medição de nível:

- Sensores baseados na pressão exercida pelo fluido

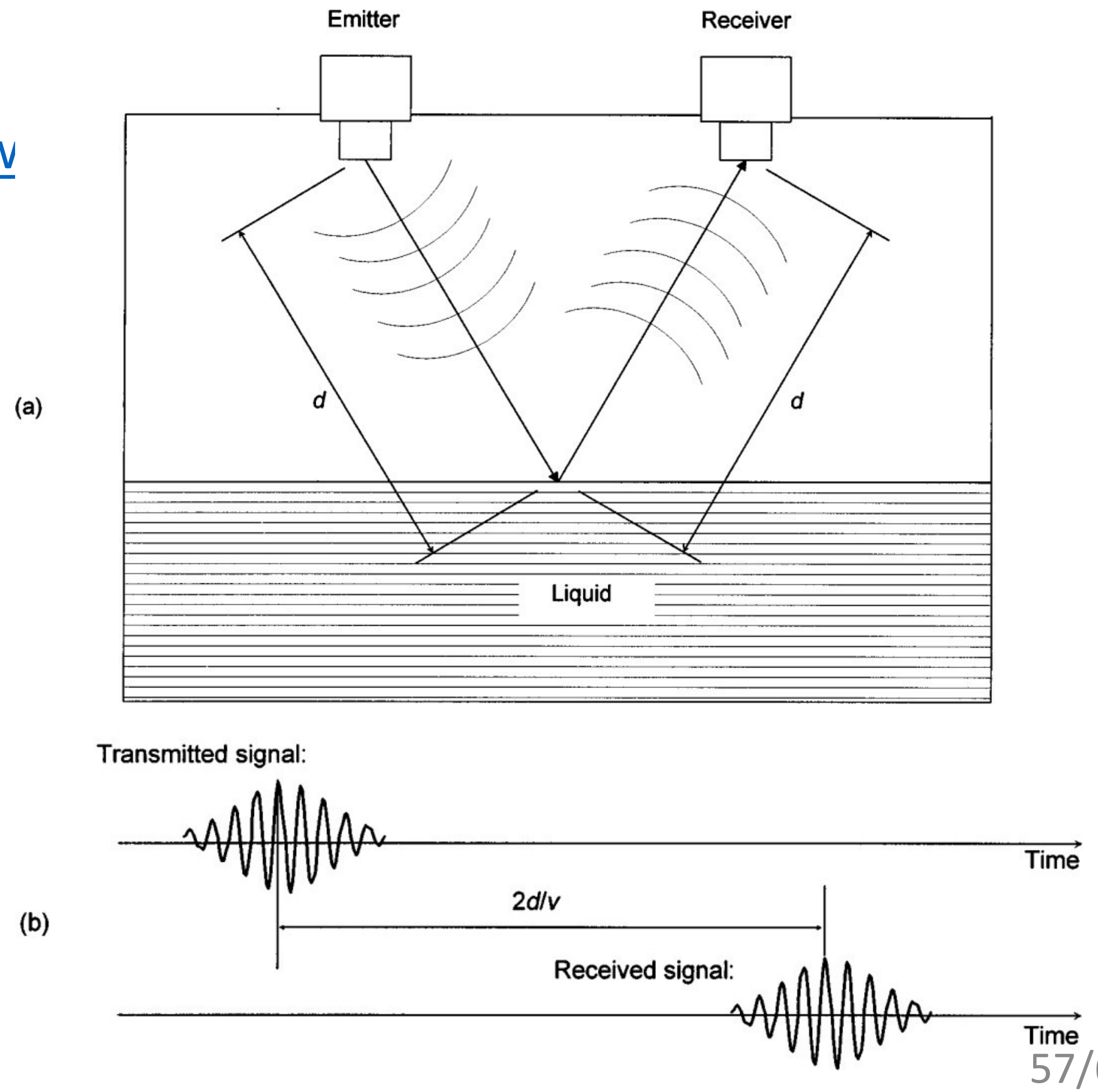


Medição de Nível

Dispositivos para medição de nível:

- Sensores baseados em medições por tempo de voo (ultrassônicos e ópticos)

https://www.youtube.com/watch?v=tvPRriWINIE



Medição de Nível

Dispositivos para medição de nível:

- Sensores baseados em medições por tempo de vôo (ultrassônicos e ópticos)

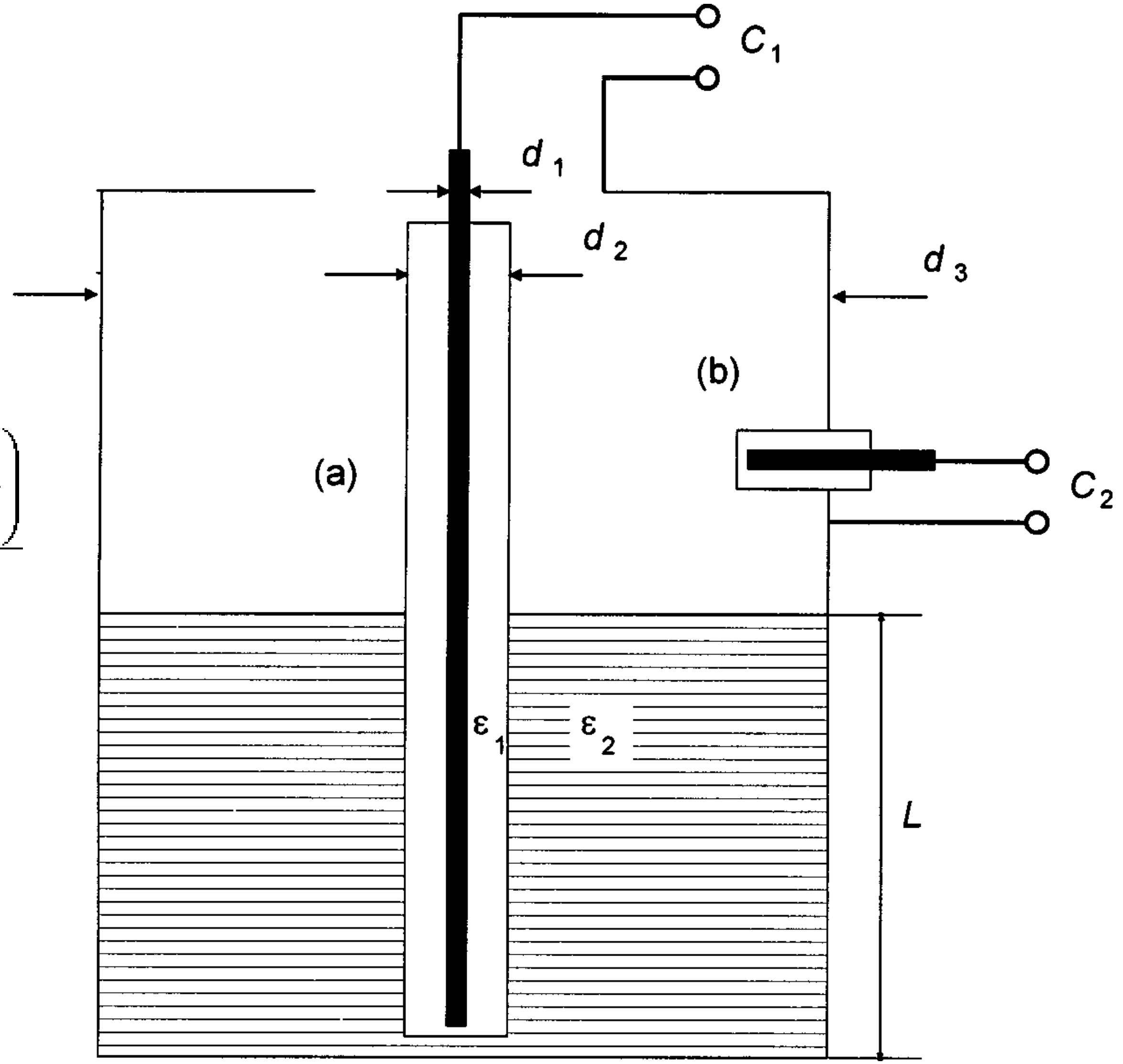
TABLE 11.1 Properties of the wave types for time-of-flight measuring.

Principle	Wave Velocity	Avg. Carrier Frequency	Wavelength	Avg. Burst Time
Ultrasonic	340 m s^{-1}	50 kHz	7 mm	1 ms
Radar	300,000 km s^{-1}	10 GHz	3 cm	1 ns
Laser	300,000 km s^{-1}	300 THz	1 µm	1 ns

Dispositivos para medição de nível:

- Sensores capacitivos

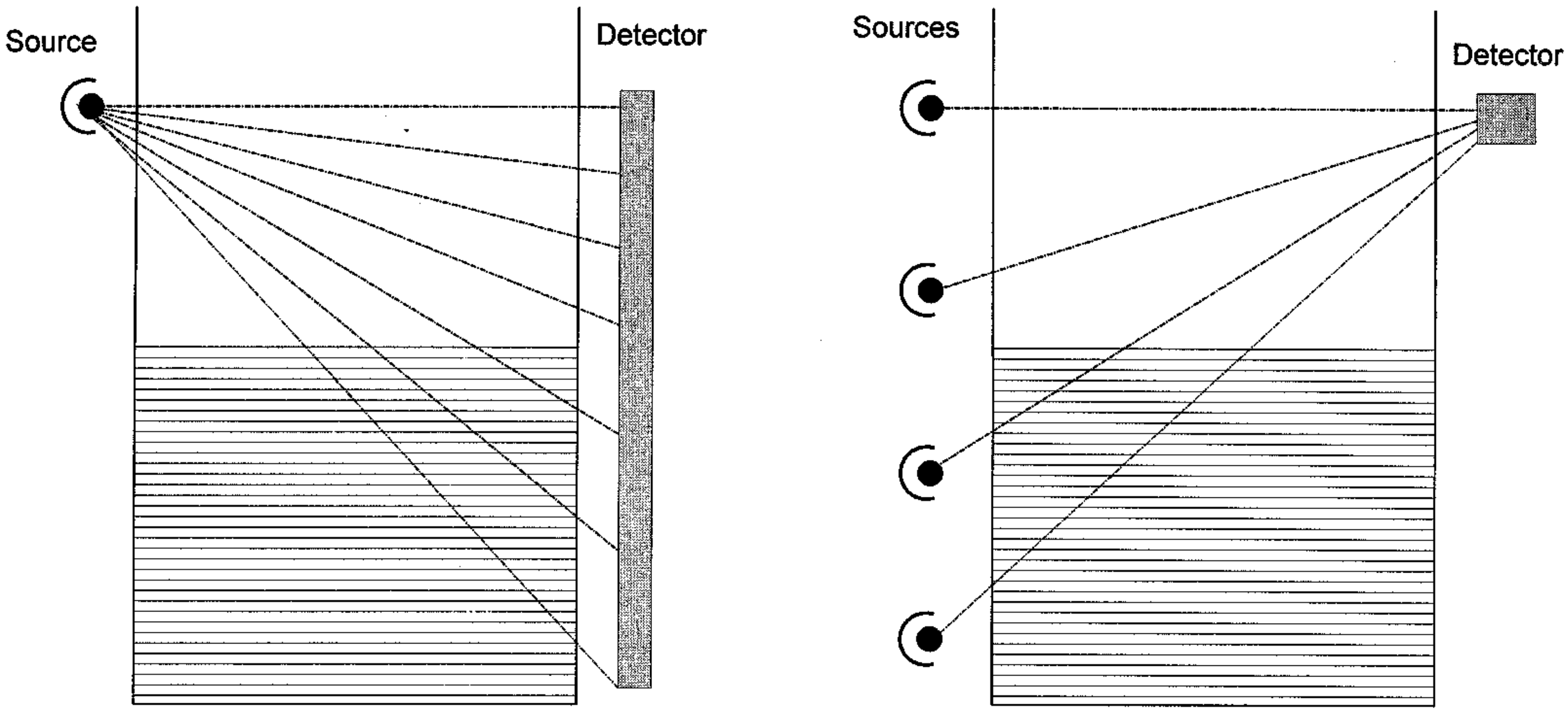
$$C = \frac{2\pi \varepsilon_0 L}{\frac{1}{\varepsilon_1}\ln\frac{d_2}{d_1} + \frac{1}{\varepsilon_2}\ln\frac{d_3}{d_2}} \Leftrightarrow L = \frac{C\left(\frac{1}{\varepsilon_1}\ln\frac{d_2}{d_1} + \frac{1}{\varepsilon_2}\ln\frac{d_3}{d_2}\right)}{2\pi\varepsilon_0}$$



Medição de Nível

Dispositivos para medição de nível:

- Sensores baseados em radiação eletromagnética



(a) (b)

Medição de Nível

Dispositivos para medição de nível:

TABLE 11.2 Priority Level Measurement Techniques and Prices for Industrial Applications

Technique	Application Range	Attainable Accuracy	Avg. Price
Displacer/float	Continuous, liquids	1 mm	$2,000
Float	Switch, liquids	10 mm	$500
Pressure	Continuous, liquids	10 mm	$2,000
Ultrasonic	Continuous, liquids, solids	5 mm	$2,500
Radar	Continuous, liquids, solids	1 mm	$3,000
TDR	Continuous, liquids, solids	3 mm	$2,500
Laser	Continuous, liquids, solids	0.1 mm	$10,000
Radiometric	Continuous, liquids, solids	10 mm	$5,000
Capacitive	Switch, liquids	10 mm	$500
Viscosity	Switch, liquids	10 mm	$500