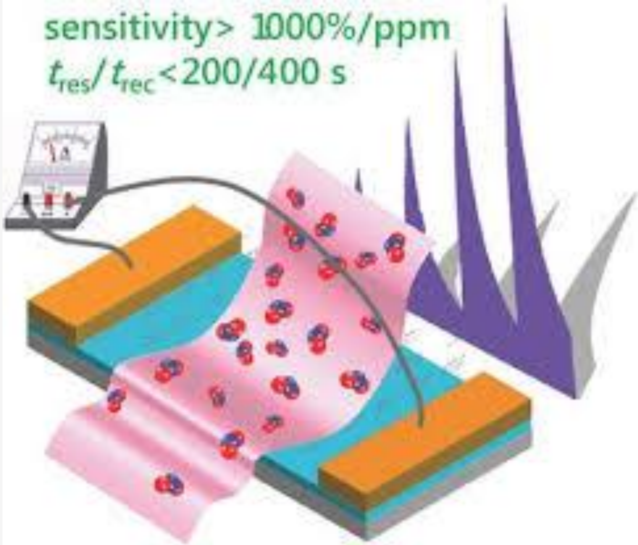
حسگرهای نیمه هادی



نوید علایی شینی
دانشگاه شهید چمران اهواز

معرفی مدرس

- دبیرستان : ریاضی و فیزیک- نمونه دکتر حسابی اهواز ۱۳۷۳
- کارشناسی: برق الکترونیک- صنعتی خواجه نصیر طوسی ۱۳۷۸
- کارشناسی ارشد: برق الکترونیک- صنعتی امیر کبیر ۱۳۸۱
- دکتری: برق الکترونیک- صنعتی خواجه نصیر طوسی ۱۳۹۵

- سابقه تدریس از ۱۳۸۲: مدار ۱و۲- الکترونیک ۱و۲- مدار منطقی- معماری کامپیوتر، الکترونیک صنعتی، طراحی سیستم های الکترونیکی، تکنیک پالس میکروپروسسور.

- علاقه مندی ها: ساخت ادوات نیمه رسانا، ابزار دقیق، پردازش.

- مقالات (گوگل اسکولار):
- https://scholar.google.com/citations?user=pjHVFjUAAAAJ&hl=en

- سوابق دانشگاه شهید چمران:

در سایت دانشکده مهندسی

- http://engg.scu.ac.ir/alaei

ارزیابی درس

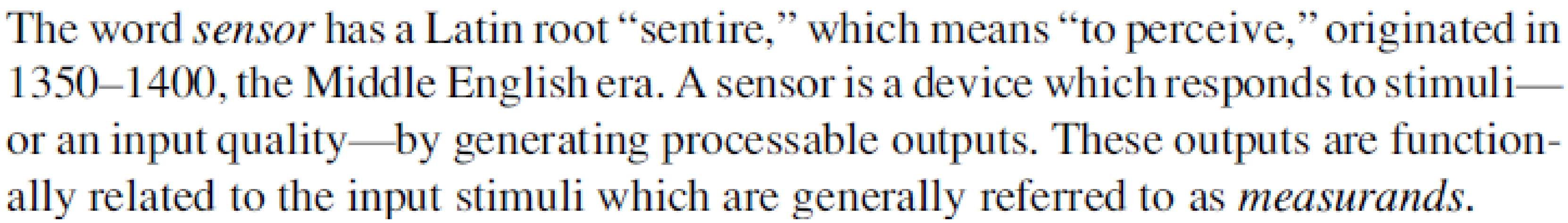
- نیم ترم: ۶تا ۸ نمره
- پایان ترم: ۸ تا ۱۰ نمره
- پروژه: ۴ نمره

- حضور الزامی
- نماینده کلاس مسوول اطلاع رسانی

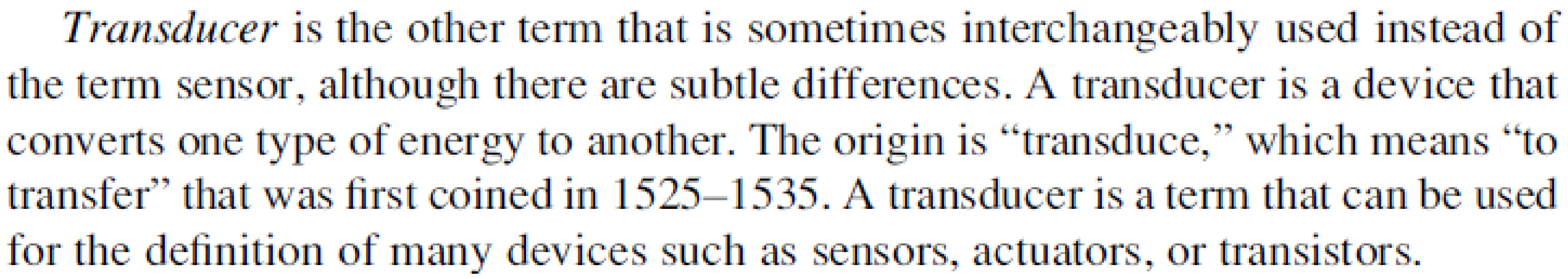
حسگر و مبدل

حسگر وسیله ای که تحریک ورودی را به یک خروجی قابل پردازش تبدیل می کند. در حسگرهای الکتریکی خروجی الکتریکی است.

مبدل: ابزاری که نوعی از انرژی را به نوع دیگر تبدیل می کند.



The word *sensor* has a Latin root “sentire,” which means “to perceive,” originated in 1350–1400, the Middle English era. A sensor is a device which responds to stimuli—or an input quality—by generating processable outputs. These outputs are functionally related to the input stimuli which are generally referred to as *measurands*.



Transducer is the other term that is sometimes interchangeably used instead of the term sensor, although there are subtle differences. A transducer is a device that converts one type of energy to another. The origin is “transduce,” which means “to transfer” that was first coined in 1525–1535. A transducer is a term that can be used for the definition of many devices such as sensors, actuators, or transistors.

حسگرها چه اندازه گیری می کنند؟

- تابش الکترومغناطیسی
- تشعشع رادیو الکتیو
- کمیتهای الکتریکی
- کمیتهای مغناطیسی
- کمیتهای زیستی
- اثر انگشت
- دما (با اتصال/ بی اتصال)
- رطوبت محیطی
- گاز های سمی
- کیفیت هوا
- کیفیت مواد غذایی

- نیرو و گشتاور
- فشار هوا
- مسافت
- سرعت
- شتاب
- زاویه
- جهت حرکت
- جریان سیال

فن آوری حسگرها:

- مکانیکی
- الکترومکانیکی
- الکترونیکی (نیمه هادی)
- الکترومکانیکی کوچک مقیاس یا MEMS(نیمه هادی)
- حسگرهای هوشمند: حسگر+ مدارات تقویت و فیلتر + پردازش و ارتباط (نیمه هادی و میکروالکترونیک)

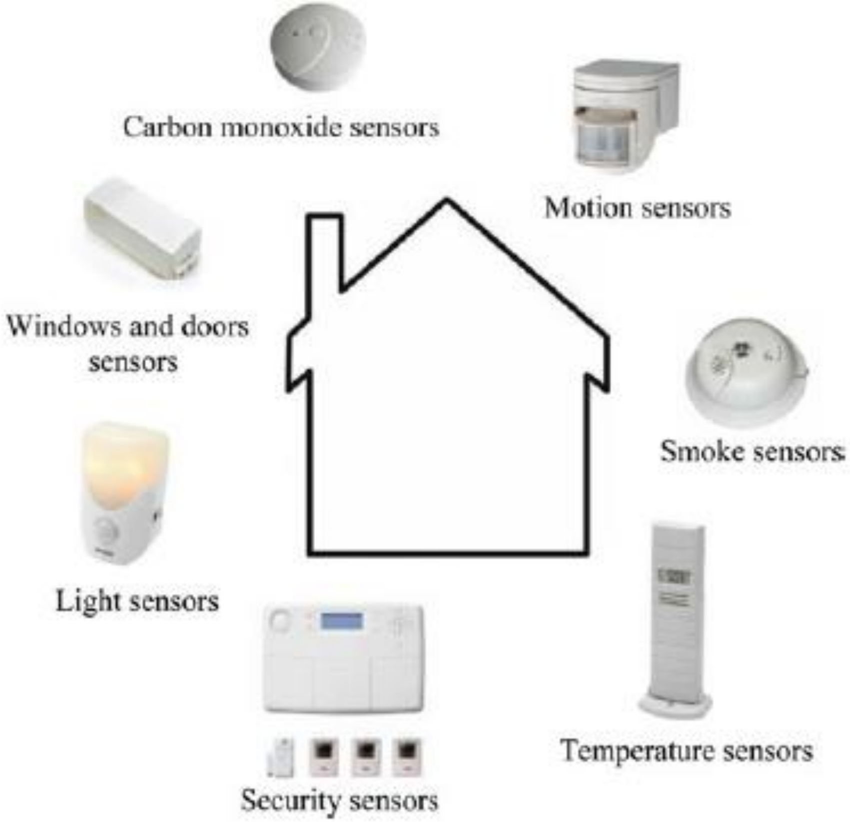
حسگرهای الکترونیکی:

- مقاومت نیمه های یا فلزی
- منبع (ولتاژ یا جریان)
- خازن
- سلف
- تیوپ خلا
- دیود (P-N، شاتکی، P-I-N)
- اتصالات فلز-فلز (ترموکوپل)
- ساختارهای کریستالی با ویژگی های خاص (پیزو، پایرو و ..)
- ترانزیستور (انواع FET و BJT)

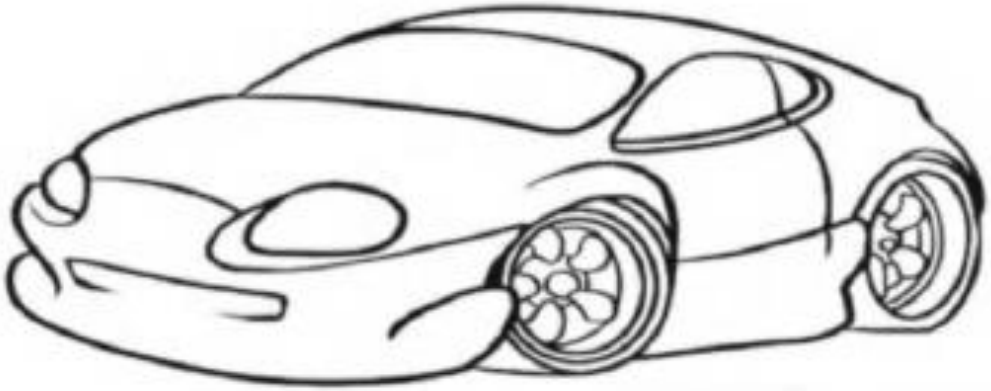
کاربرد حسگرها :

- صنایع: تولید انرژی، کشاورزی، حفاری و اکتشاف، اتوماسیون، حمل و نقل، نساجی، غذایی
- هواشناسی
- سلامت و مهندسی پزشکی
- محصولات الکترونیکی خانگی
- ایمنی مکان ها
- دفاعی و نظامی

کاربردهای خانگی



کاربردهای در خودرو

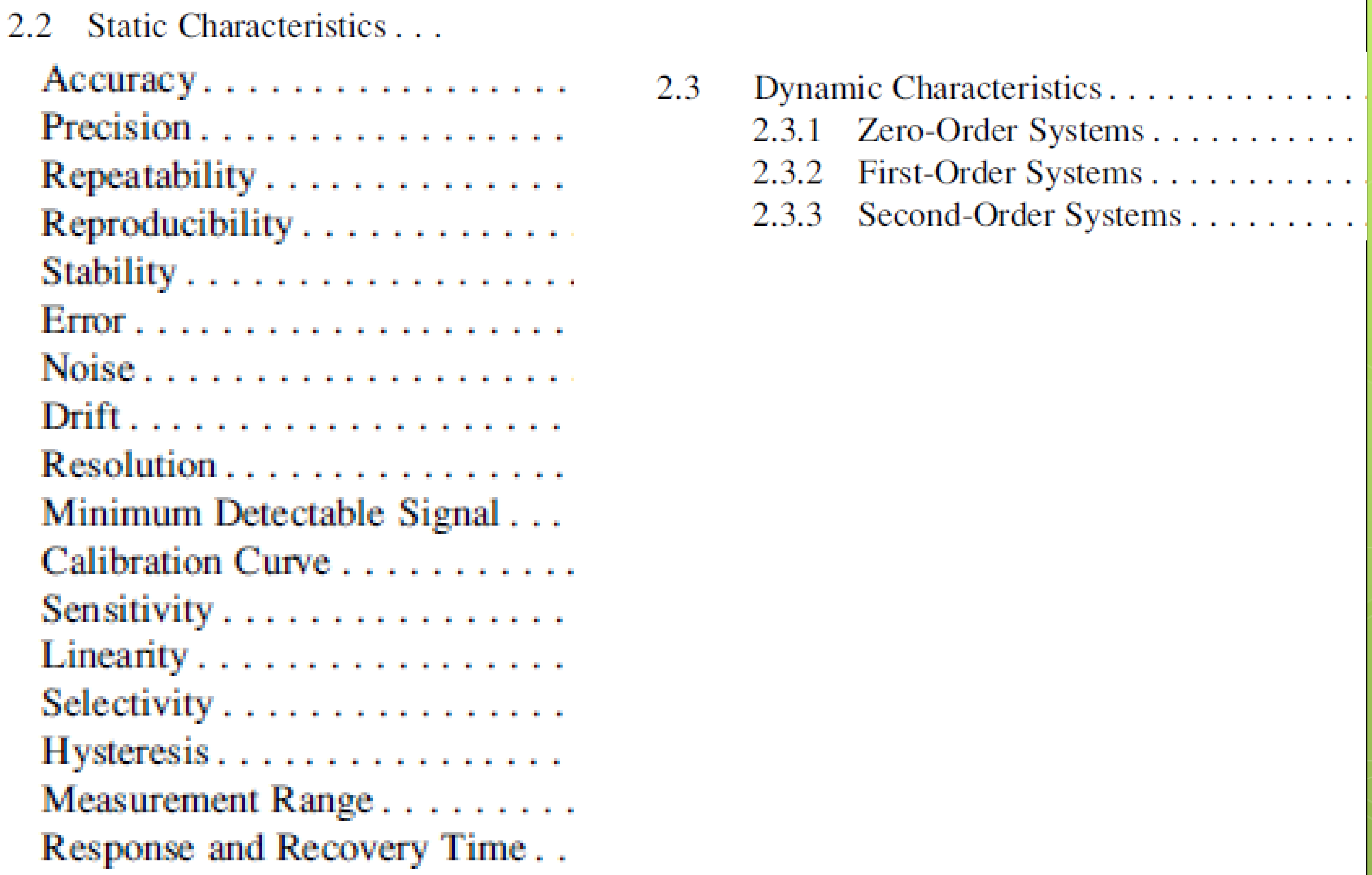


Essential drive sensors
Pressure
Mass air flow
Atmospheric pressure
Oxygen
CO_2
Rotational speed
Petrol level
Pedal position
Angular position
Engine temperature
Oil level
Crankshaft position

Safety sensors
Safety distance
Tilt
Torque
Steering wheel angle
Acceleration
Belt

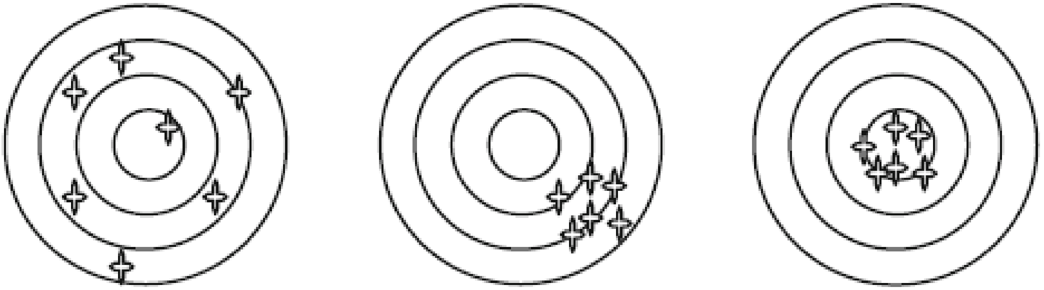
Convenience sensors
Air quality
Humidity
Temperature
Rain
Seat positon

ویژگی های حسگرها



Book: Sensors- Springer 2013- (Kourosh Kalantar-Zadeh)

دقت و درستی(صحت)



Low precision - low accuracy

High precision - low accuracy

High precision - high accuracy

2.2.1 Accuracy

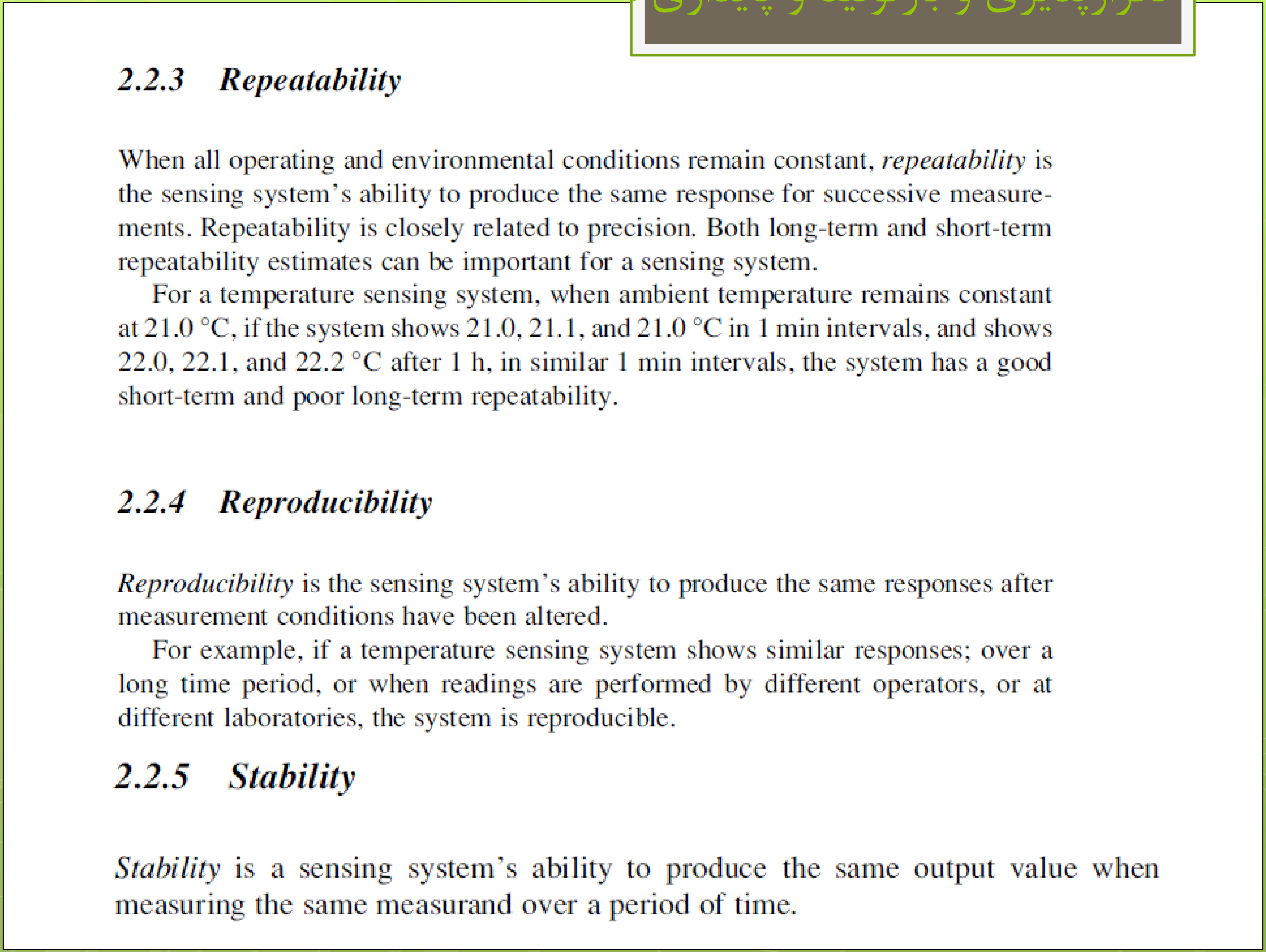
Accuracy of a sensing system represents the correctness of its output in comparison to the actual value of a measurand. To assess the accuracy, either the system is benchmarked against a standard measurand or the output is compared with a measurement system with a superior accuracy.

For instance considering a temperature sensing system, when the real temperature is 20.0 °C, the system is more accurate, if it shows 20.1 °C rather than 21.0 °C.

2.2.2 Precision

Precision represents capacity of a sensing system to give the same reading when repetitively measuring the same measurand under the same conditions. The precision is a statistical parameter and can be assessed by the standard deviation (or variance) of a set of readings of the system for similar inputs.

تکرارپذیری و بازتولید و پایداری :



2.2.3 Repeatability

When all operating and environmental conditions remain constant, *repeatability* is the sensing system's ability to produce the same response for successive measurements. Repeatability is closely related to precision. Both long-term and short-term repeatability estimates can be important for a sensing system.

For a temperature sensing system, when ambient temperature remains constant at 21.0 °C, if the system shows 21.0, 21.1, and 21.0 °C in 1 min intervals, and shows 22.0, 22.1, and 22.2 °C after 1 h, in similar 1 min intervals, the system has a good short-term and poor long-term repeatability.

2.2.4 Reproducibility

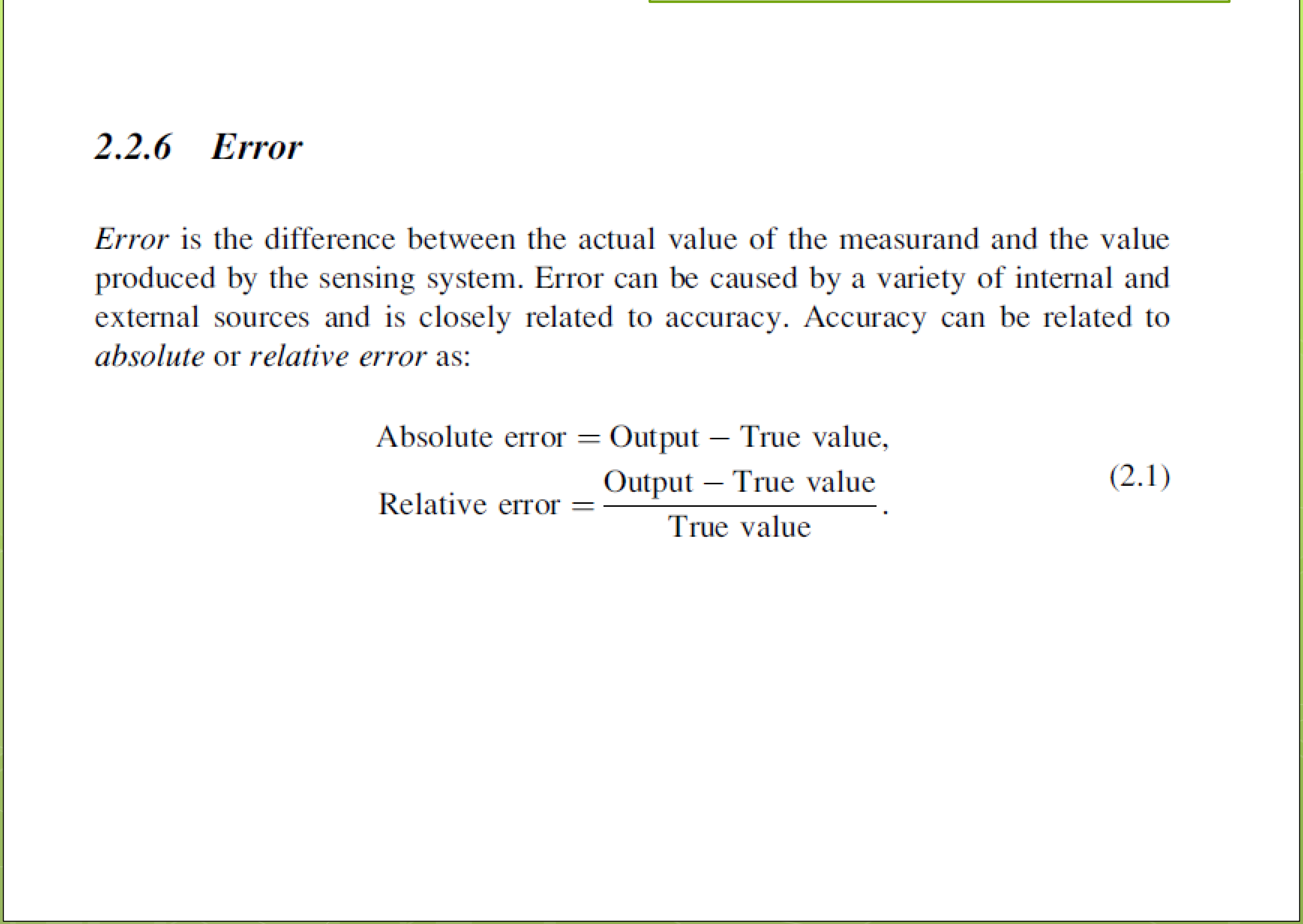
Reproducibility is the sensing system's ability to produce the same responses after measurement conditions have been altered.

For example, if a temperature sensing system shows similar responses; over a long time period, or when readings are performed by different operators, or at different laboratories, the system is reproducible.

2.2.5 Stability

Stability is a sensing system's ability to produce the same output value when measuring the same measurand over a period of time.

خطای مطلق و نسبی:

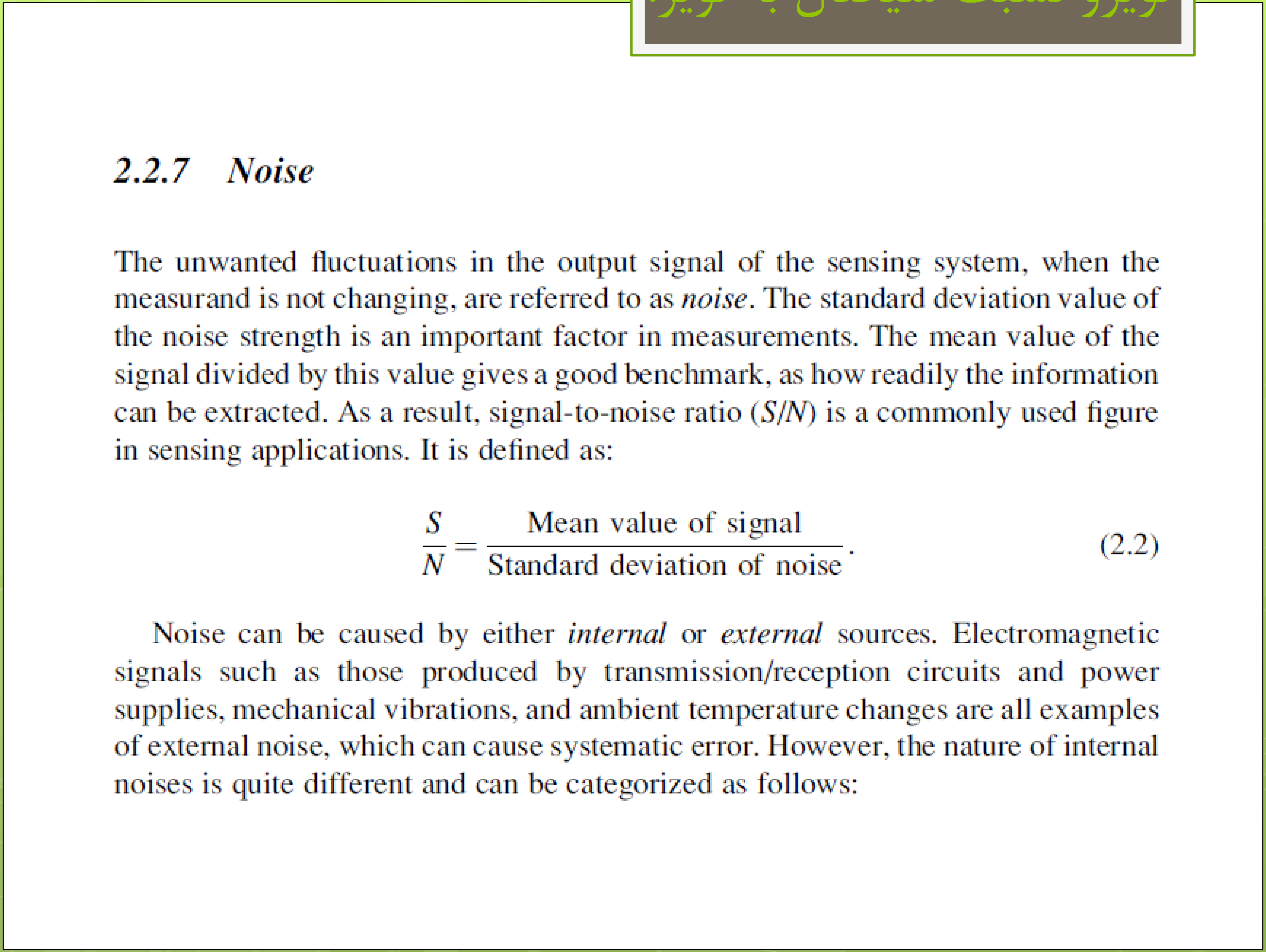


2.2.6 *Error*

Error is the difference between the actual value of the measurand and the value produced by the sensing system. Error can be caused by a variety of internal and external sources and is closely related to accuracy. Accuracy can be related to *absolute* or *relative error* as:

$$\begin{aligned}\text{Absolute error} &= \text{Output} - \text{True value},\\ \text{Relative error} &= \frac{\text{Output} - \text{True value}}{\text{True value}}.\end{aligned} \tag{2.1}$$

نویزو نسبت سیگنال به نویز:



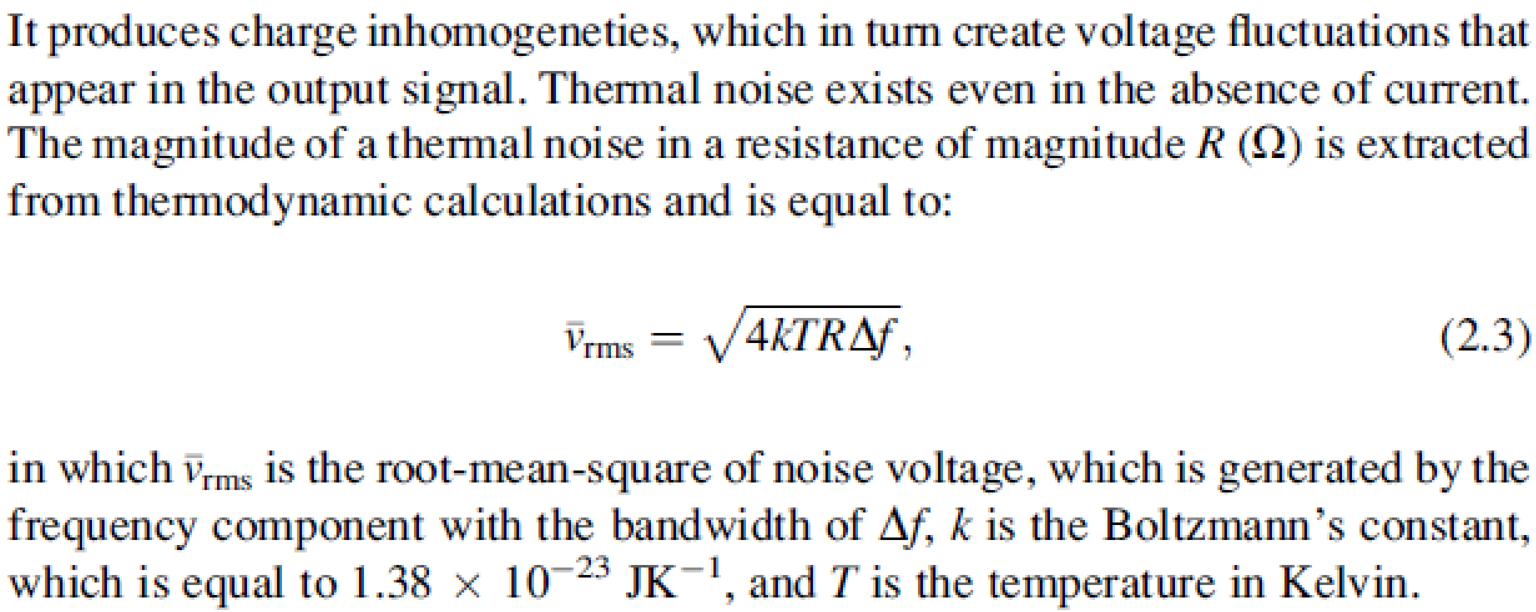
2.2.7 *Noise*

The unwanted fluctuations in the output signal of the sensing system, when the measurand is not changing, are referred to as *noise*. The standard deviation value of the noise strength is an important factor in measurements. The mean value of the signal divided by this value gives a good benchmark, as how readily the information can be extracted. As a result, signal-to-noise ratio (S/N) is a commonly used figure in sensing applications. It is defined as:

$$\frac{S}{N} = \frac{\text{Mean value of signal}}{\text{Standard deviation of noise}}. \tag{2.2}$$

Noise can be caused by either *internal* or *external* sources. Electromagnetic signals such as those produced by transmission/reception circuits and power supplies, mechanical vibrations, and ambient temperature changes are all examples of external noise, which can cause systematic error. However, the nature of internal noises is quite different and can be categorized as follows:

نویز حرارتی:



It produces charge inhomogeneties, which in turn create voltage fluctuations that appear in the output signal. Thermal noise exists even in the absence of current. The magnitude of a thermal noise in a resistance of magnitude *R* (Ω) is extracted from thermodynamic calculations and is equal to:

$$\bar{v}_{\mathrm{rms}} = \sqrt{4kTR\Delta f}\,, \tag{2.3}$$

in which $\bar{v}_{\mathrm{rms}}$ is the root-mean-square of noise voltage, which is generated by the frequency component with the bandwidth of Δf, k is the Boltzmann's constant, which is equal to $1.38 \times 10^{-23}\ \mathrm{JK}^{-1}$, and T is the temperature in Kelvin.

نویز حرارتی:

Example 1. The rise and fall time of a sensor signal are generally inversely proportional to its bandwidth. Assume that the rise time of a thermistor response is 0.05 s and the relation between the rise time and the bandwidth is $\tau_{\text{rise}} = 1/2\Delta f$. (A) Calculate the magnitude of the thermal noise. The ambient temperature is 27 °C and the thermistor resistance is 5 kΩ at this temperature. (B) What is the signal-to-noise ratio, if the average of current passing through the resistor is 0.2 mA?

Answer:

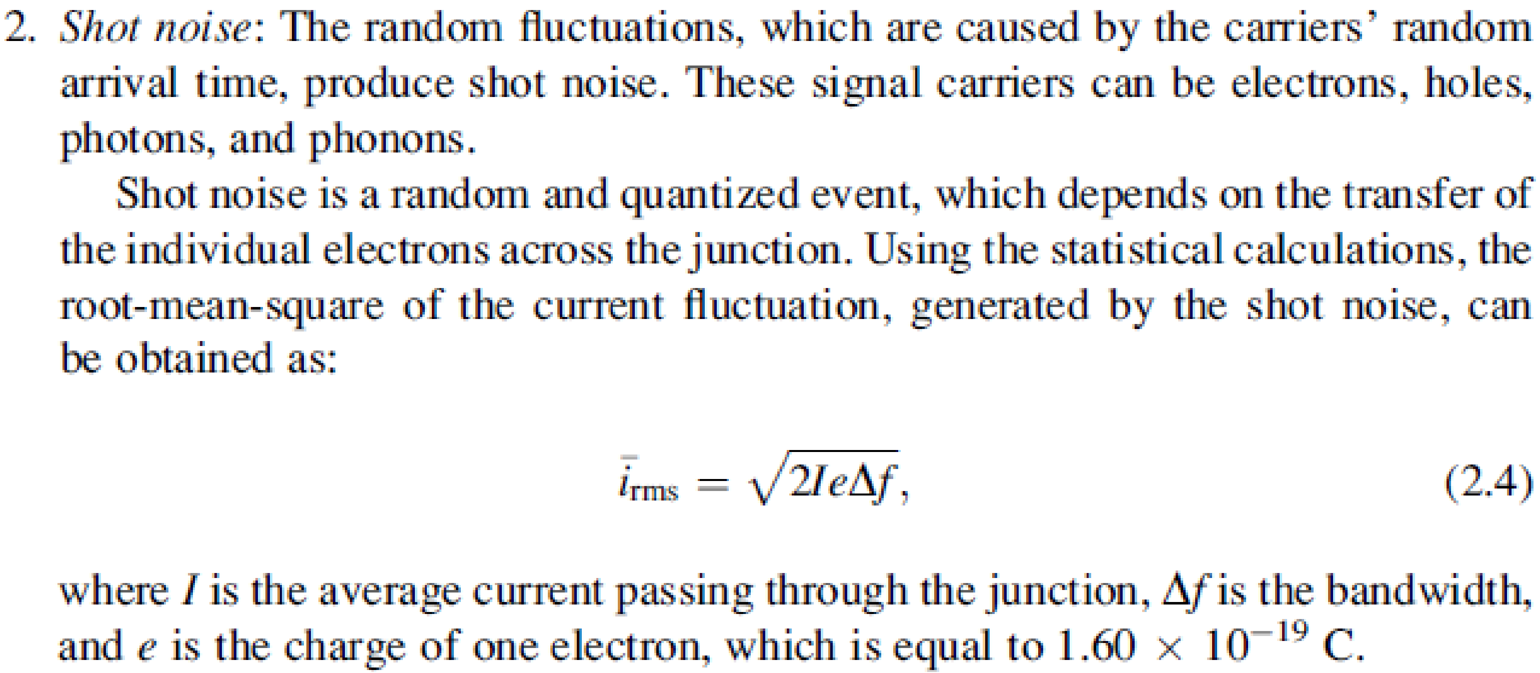
(a) The bandwidth is equal to $\Delta f = 1/2\tau_{\text{rise}} = 1/2 \times 0.05\ (\text{s}) = 10\ \text{Hz}$ and according to (2.3), the rms value of the thermal noise voltage is equal to:

$$\bar{v}_{\text{rms}} = \sqrt{4 \times 1.38 \times 10^{-23} \times 300\ (\text{K}) \times 5,000\ (\Omega) \times 10\ (\text{Hz})}$$
$$= 2.88 \times 10^{-8}\ (\text{V}) = 0.0288\ \text{mV or } 20\log(\bar{v}_{\text{rms}}) = -150.8\ \text{dB}.$$

(b) Current of 0.2 mA generates a voltage of 5,000 (kΩ) × 0.0002 (A) = 1 V in the thermistor. As a result, the signal-to-noise ratio is:

$$\frac{S}{N} = 1(\text{V})/2.88 \times 10^{-8}(\text{V}) = 3.47 \times 10^{9}.$$

شات نویز:



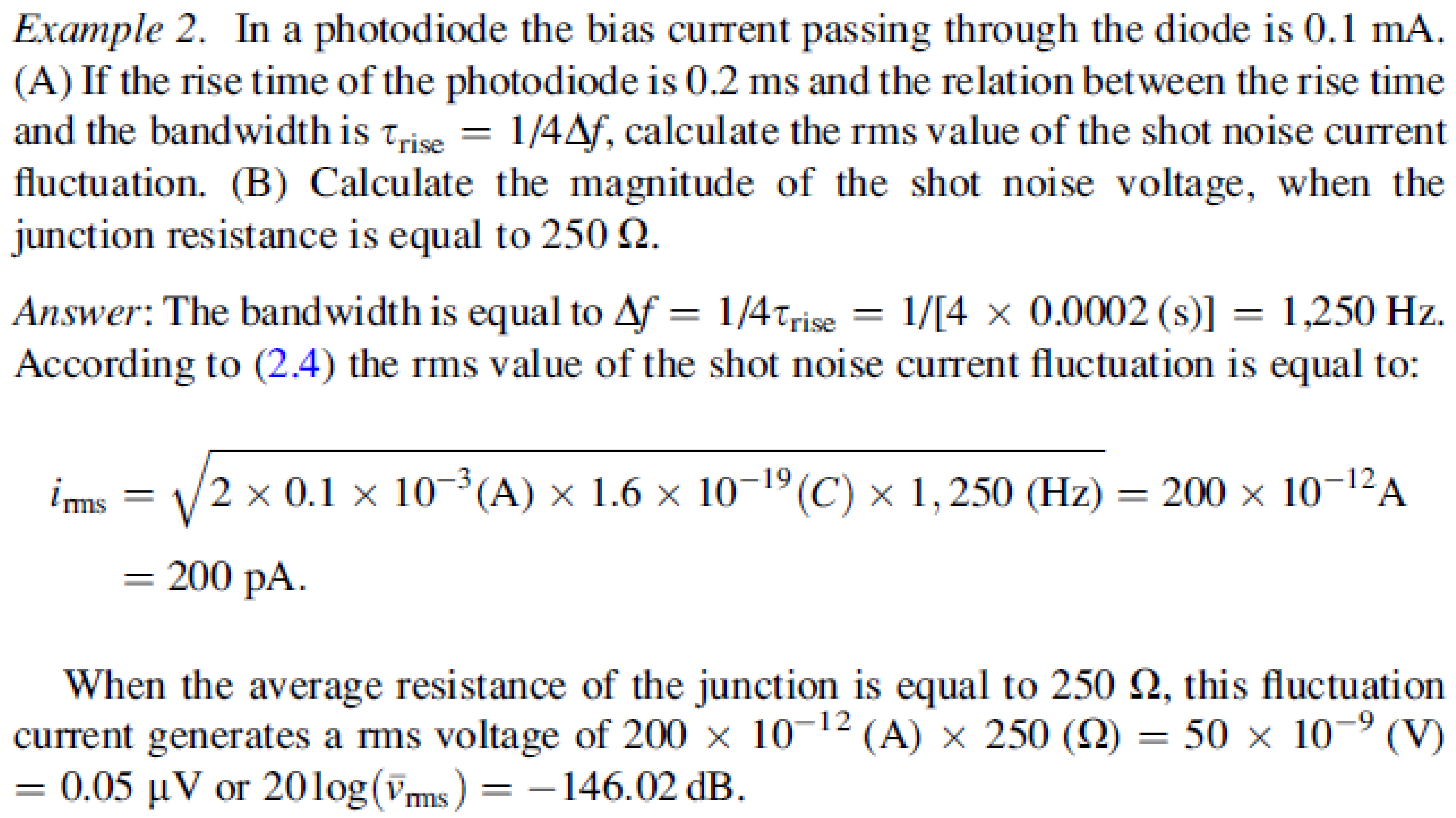
2. *Shot noise*: The random fluctuations, which are caused by the carriers' random arrival time, produce shot noise. These signal carriers can be electrons, holes, photons, and phonons.

   Shot noise is a random and quantized event, which depends on the transfer of the individual electrons across the junction. Using the statistical calculations, the root-mean-square of the current fluctuation, generated by the shot noise, can be obtained as:

$$\bar{i}_{\mathrm{rms}} = \sqrt{2Ie\Delta f}, \tag{2.4}$$

   where I is the average current passing through the junction, Δf is the bandwidth, and e is the charge of one electron, which is equal to 1.60×10^{-19} C.

شات نویز:



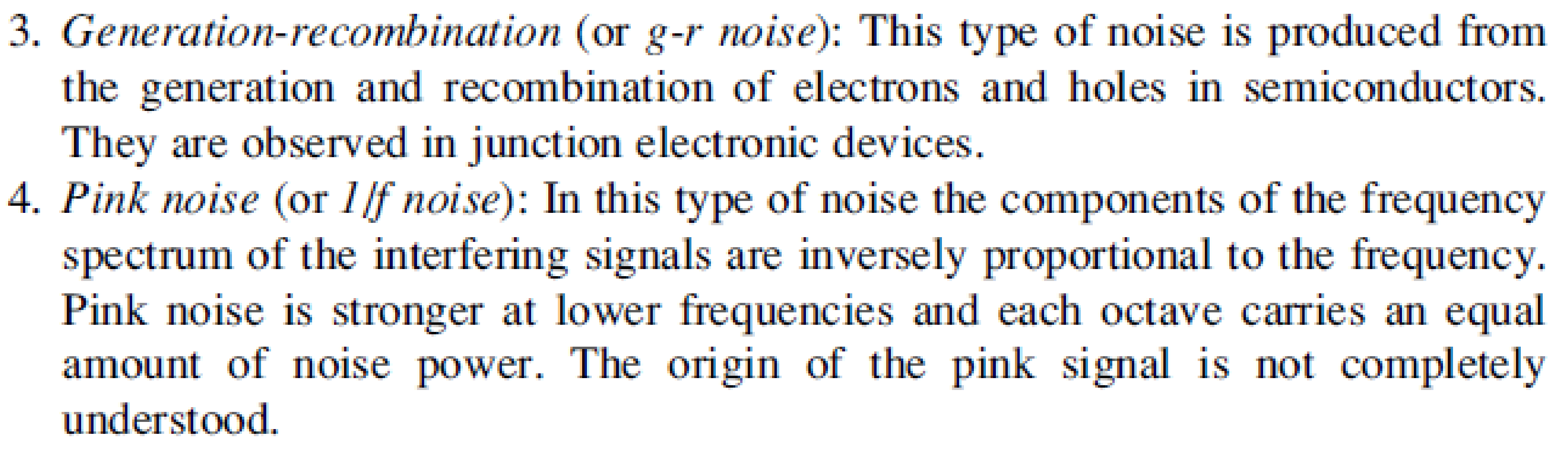
Example 2. In a photodiode the bias current passing through the diode is 0.1 mA. (A) If the rise time of the photodiode is 0.2 ms and the relation between the rise time and the bandwidth is $\tau_{\text{rise}} = 1/4\Delta f$, calculate the rms value of the shot noise current fluctuation. (B) Calculate the magnitude of the shot noise voltage, when the junction resistance is equal to 250 Ω.

Answer: The bandwidth is equal to $\Delta f = 1/4\tau_{\text{rise}} = 1/[4 \times 0.0002\,(\text{s})] = 1{,}250$ Hz. According to (2.4) the rms value of the shot noise current fluctuation is equal to:

$$i_{\text{rms}} = \sqrt{2 \times 0.1 \times 10^{-3}(\text{A}) \times 1.6 \times 10^{-19}(C) \times 1,250\ (\text{Hz})} = 200 \times 10^{-12}\text{A}$$
$$= 200\ \text{pA}.$$

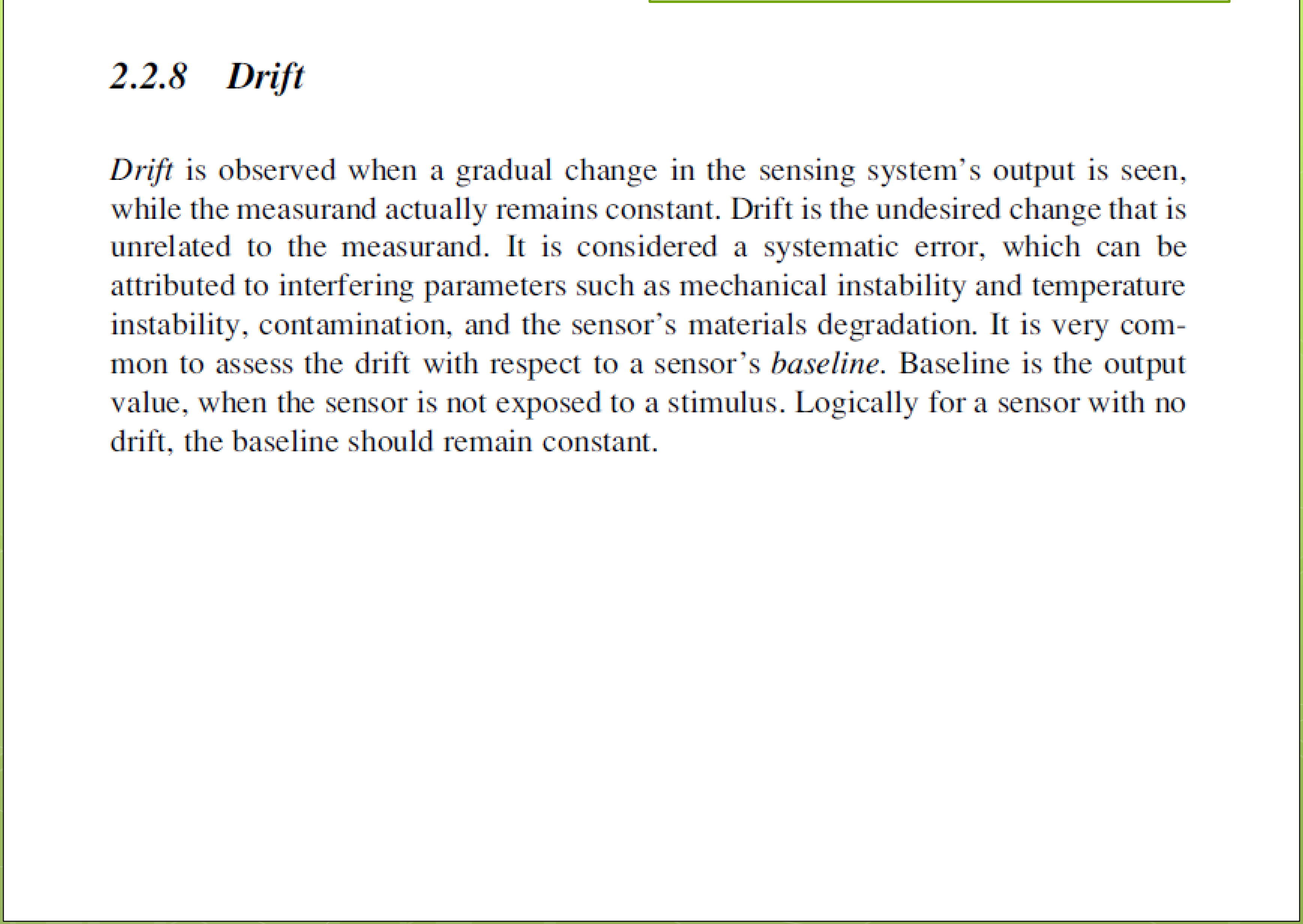
When the average resistance of the junction is equal to 250 Ω, this fluctuation current generates a rms voltage of 200×10^{-12} (A) × 250 (Ω) = 50×10^{-9} (V) = 0.05 µV or $20\log(\bar{v}_{\text{rms}}) = -146.02$ dB.

دیگر نویزهای الکتریکی:



3. *Generation-recombination* (or *g-r noise*): This type of noise is produced from the generation and recombination of electrons and holes in semiconductors. They are observed in junction electronic devices.
4. *Pink noise* (or *1/f noise*): In this type of noise the components of the frequency spectrum of the interfering signals are inversely proportional to the frequency. Pink noise is stronger at lower frequencies and each octave carries an equal amount of noise power. The origin of the pink signal is not completely understood.

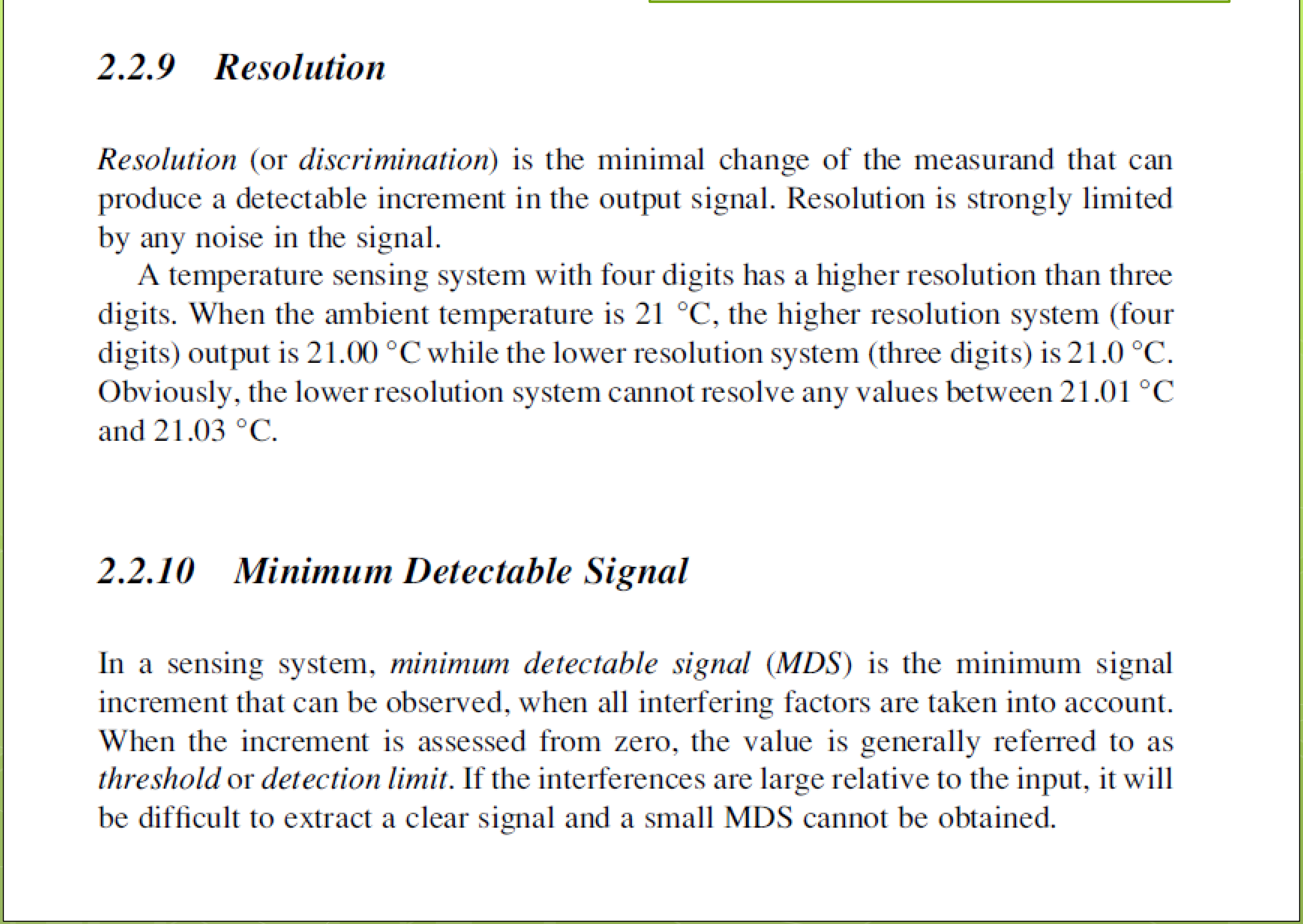
رانش:



2.2.8 *Drift*

Drift is observed when a gradual change in the sensing system's output is seen, while the measurand actually remains constant. Drift is the undesired change that is unrelated to the measurand. It is considered a systematic error, which can be attributed to interfering parameters such as mechanical instability and temperature instability, contamination, and the sensor's materials degradation. It is very common to assess the drift with respect to a sensor's *baseline*. Baseline is the output value, when the sensor is not exposed to a stimulus. Logically for a sensor with no drift, the baseline should remain constant.

وضوح (تفکیک پذیری) و MDS:



2.2.9 *Resolution*

Resolution (or *discrimination*) is the minimal change of the measurand that can produce a detectable increment in the output signal. Resolution is strongly limited by any noise in the signal.

A temperature sensing system with four digits has a higher resolution than three digits. When the ambient temperature is 21 °C, the higher resolution system (four digits) output is 21.00 °C while the lower resolution system (three digits) is 21.0 °C. Obviously, the lower resolution system cannot resolve any values between 21.01 °C and 21.03 °C.

2.2.10 *Minimum Detectable Signal*

In a sensing system, *minimum detectable signal* (*MDS*) is the minimum signal increment that can be observed, when all interfering factors are taken into account. When the increment is assessed from zero, the value is generally referred to as *threshold* or *detection limit*. If the interferences are large relative to the input, it will be difficult to extract a clear signal and a small MDS cannot be obtained.

منحنی کالیبراسیون:

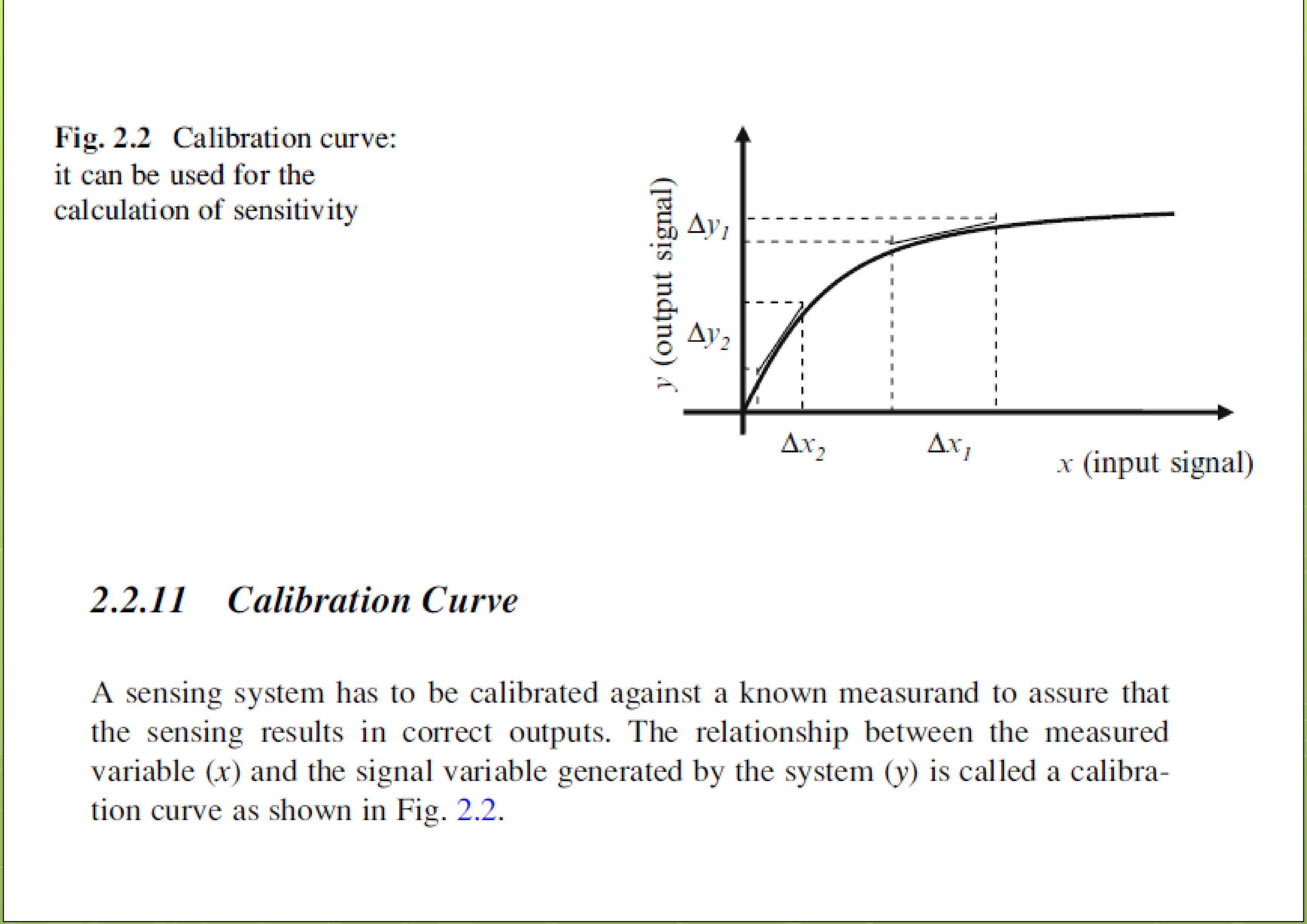


Fig. 2.2 Calibration curve: it can be used for the calculation of sensitivity

2.2.11 Calibration Curve

A sensing system has to be calibrated against a known measurand to assure that the sensing results in correct outputs. The relationship between the measured variable (x) and the signal variable generated by the system (y) is called a calibration curve as shown in Fig. 2.2.

حساسیت:

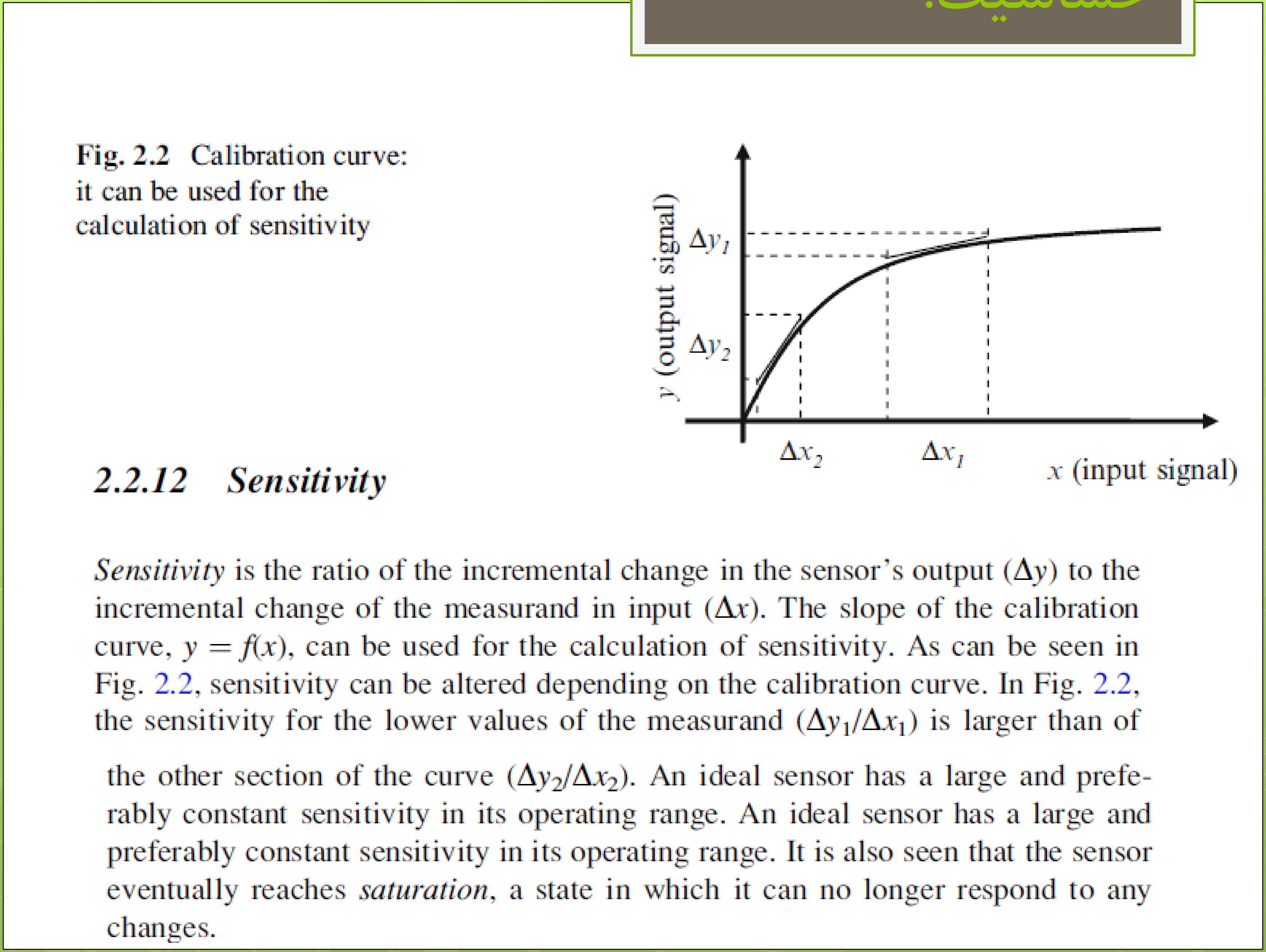
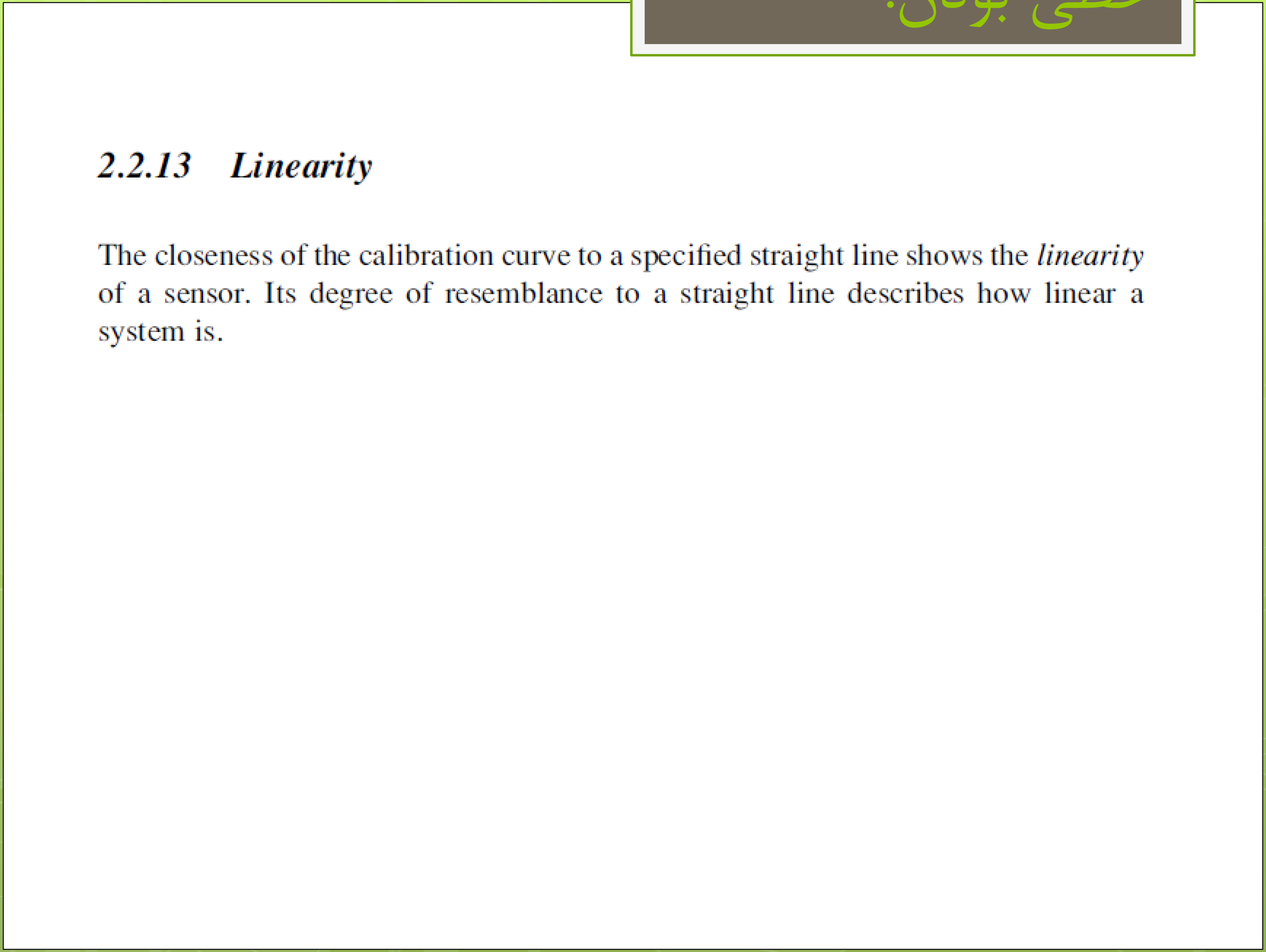


Fig. 2.2 Calibration curve: it can be used for the calculation of sensitivity

2.2.12 *Sensitivity*

Sensitivity is the ratio of the incremental change in the sensor's output (Δy) to the incremental change of the measurand in input (Δx). The slope of the calibration curve, $y = f(x)$, can be used for the calculation of sensitivity. As can be seen in Fig. 2.2, sensitivity can be altered depending on the calibration curve. In Fig. 2.2, the sensitivity for the lower values of the measurand ($\Delta y_1/\Delta x_1$) is larger than of the other section of the curve ($\Delta y_2/\Delta x_2$). An ideal sensor has a large and preferably constant sensitivity in its operating range. An ideal sensor has a large and preferably constant sensitivity in its operating range. It is also seen that the sensor eventually reaches *saturation*, a state in which it can no longer respond to any changes.

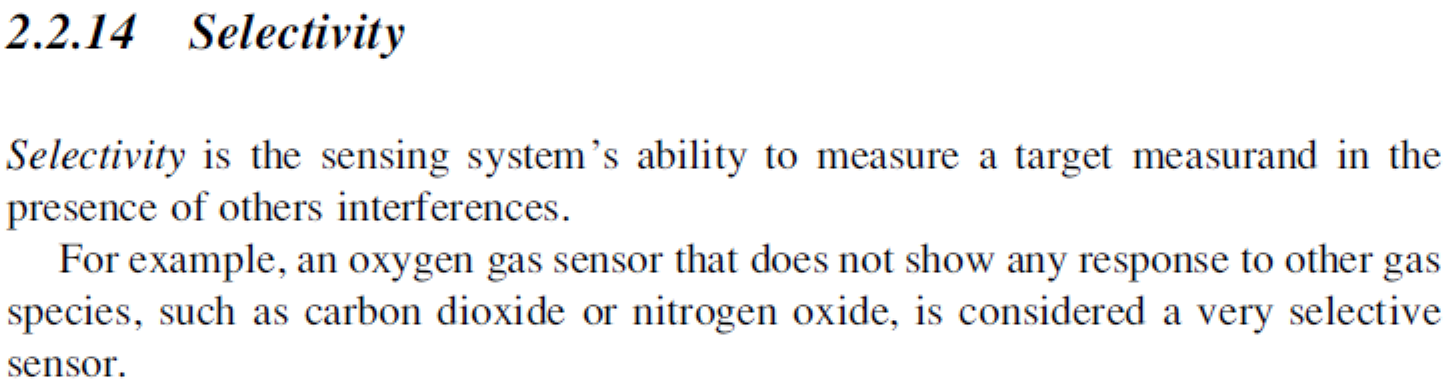
خطی بودن:



2.2.13 *Linearity*

The closeness of the calibration curve to a specified straight line shows the *linearity* of a sensor. Its degree of resemblance to a straight line describes how linear a system is.

انتخاب گری:



2.2.14 Selectivity

Selectivity is the sensing system's ability to measure a target measurand in the presence of others interferences.

For example, an oxygen gas sensor that does not show any response to other gas species, such as carbon dioxide or nitrogen oxide, is considered a very selective sensor.

هیسترزیس:

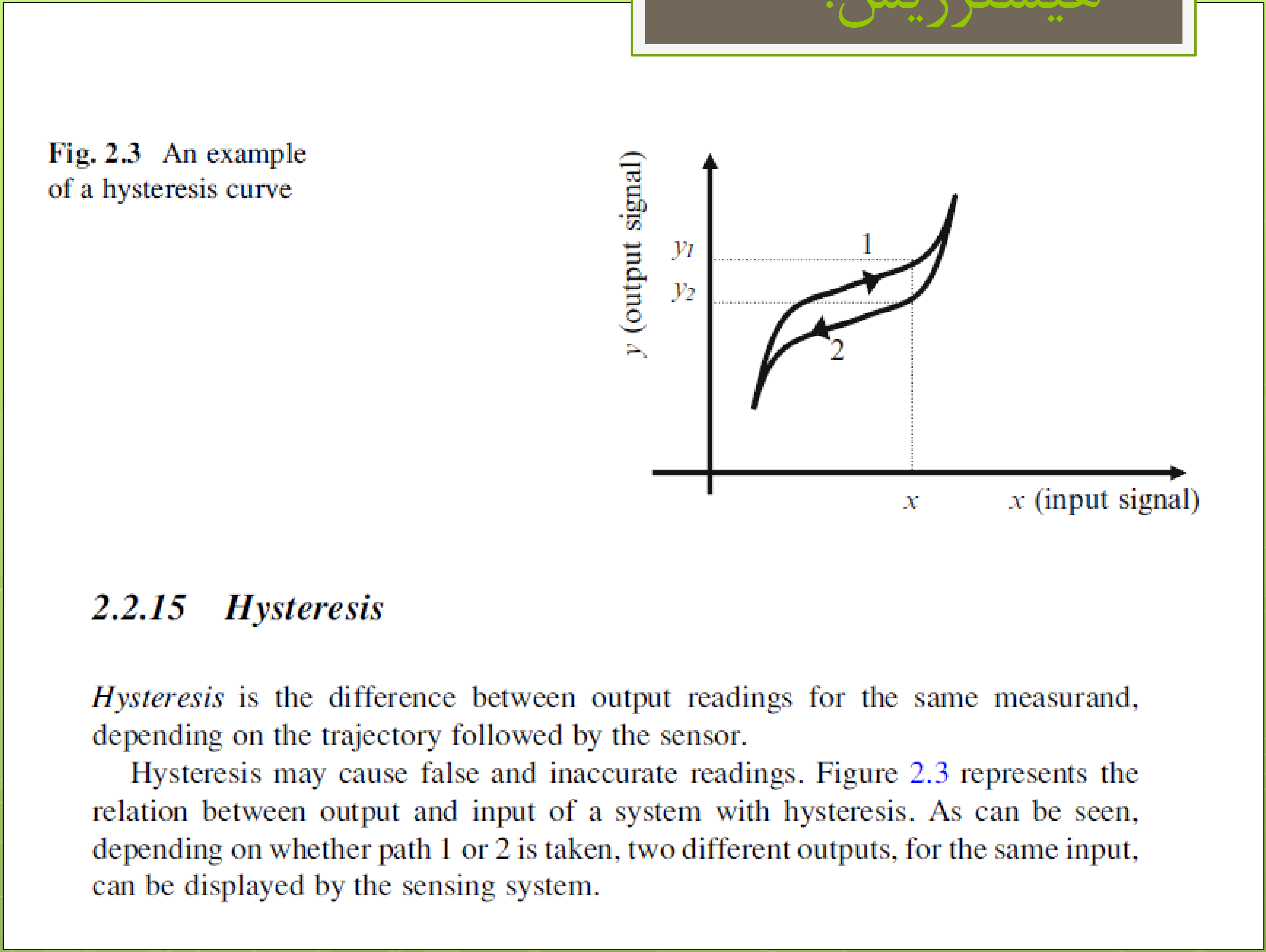


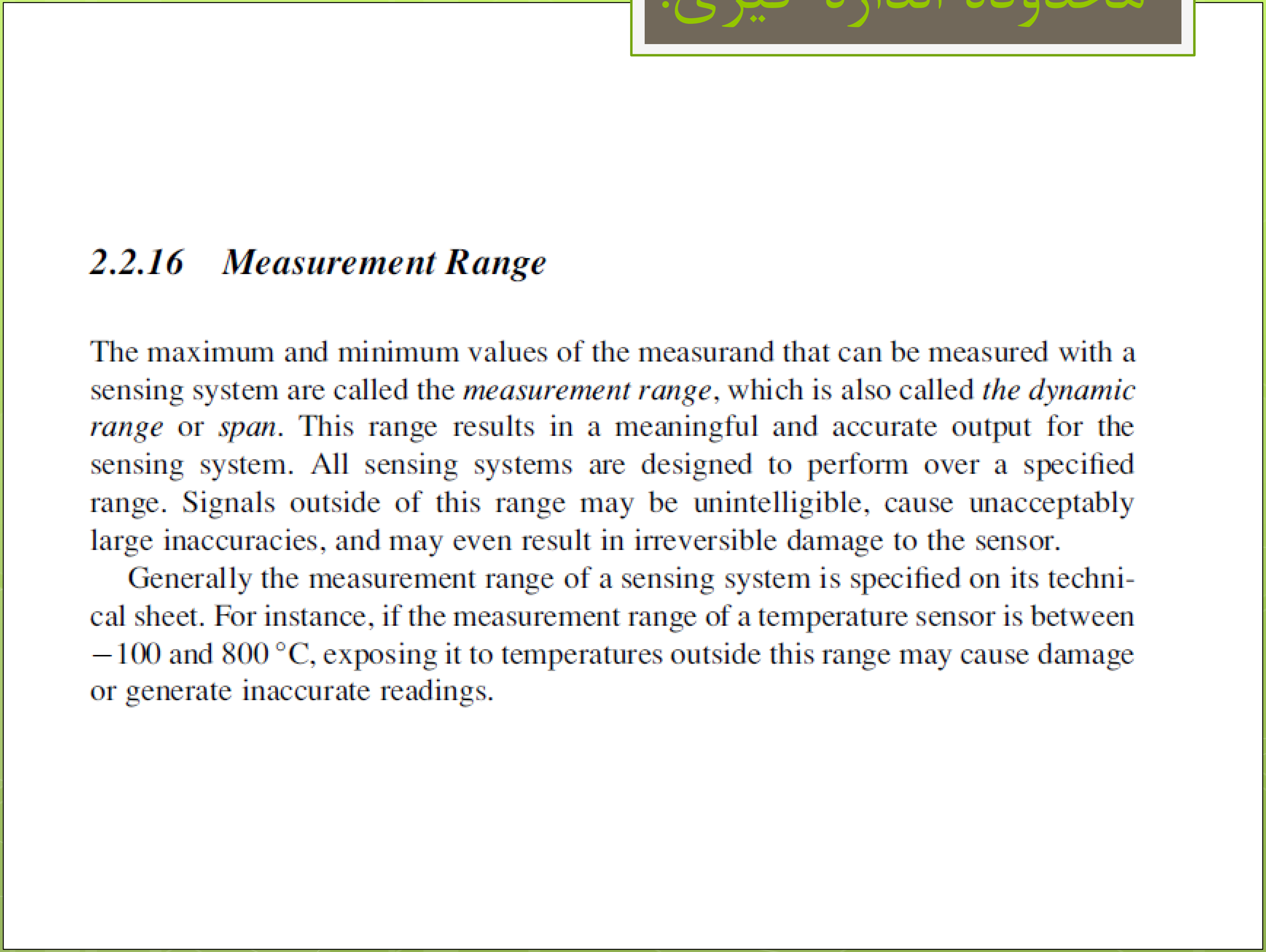
Fig. 2.3 An example of a hysteresis curve

2.2.15 *Hysteresis*

Hysteresis is the difference between output readings for the same measurand, depending on the trajectory followed by the sensor.

Hysteresis may cause false and inaccurate readings. Figure 2.3 represents the relation between output and input of a system with hysteresis. As can be seen, depending on whether path 1 or 2 is taken, two different outputs, for the same input, can be displayed by the sensing system.

محدوده اندازه گیری:

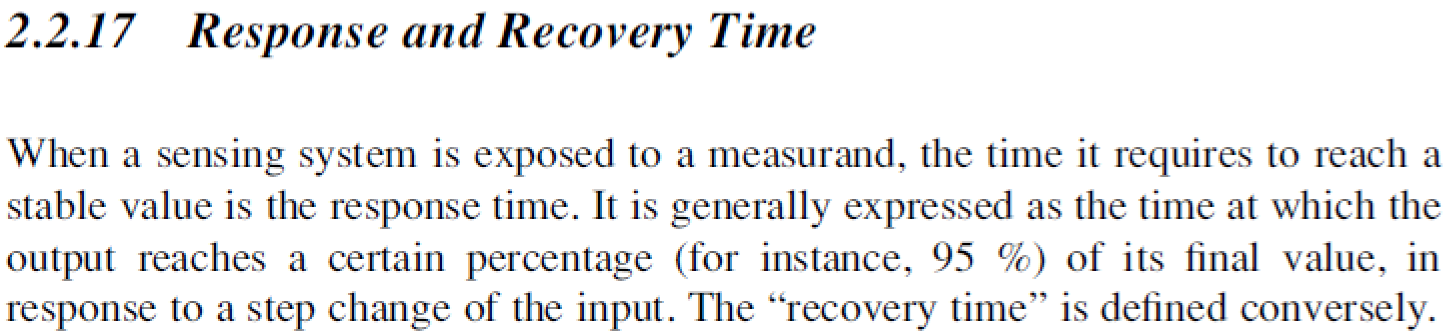


2.2.16 Measurement Range

The maximum and minimum values of the measurand that can be measured with a sensing system are called the *measurement range*, which is also called *the dynamic range* or *span*. This range results in a meaningful and accurate output for the sensing system. All sensing systems are designed to perform over a specified range. Signals outside of this range may be unintelligible, cause unacceptably large inaccuracies, and may even result in irreversible damage to the sensor.

Generally the measurement range of a sensing system is specified on its technical sheet. For instance, if the measurement range of a temperature sensor is between −100 and 800 °C, exposing it to temperatures outside this range may cause damage or generate inaccurate readings.

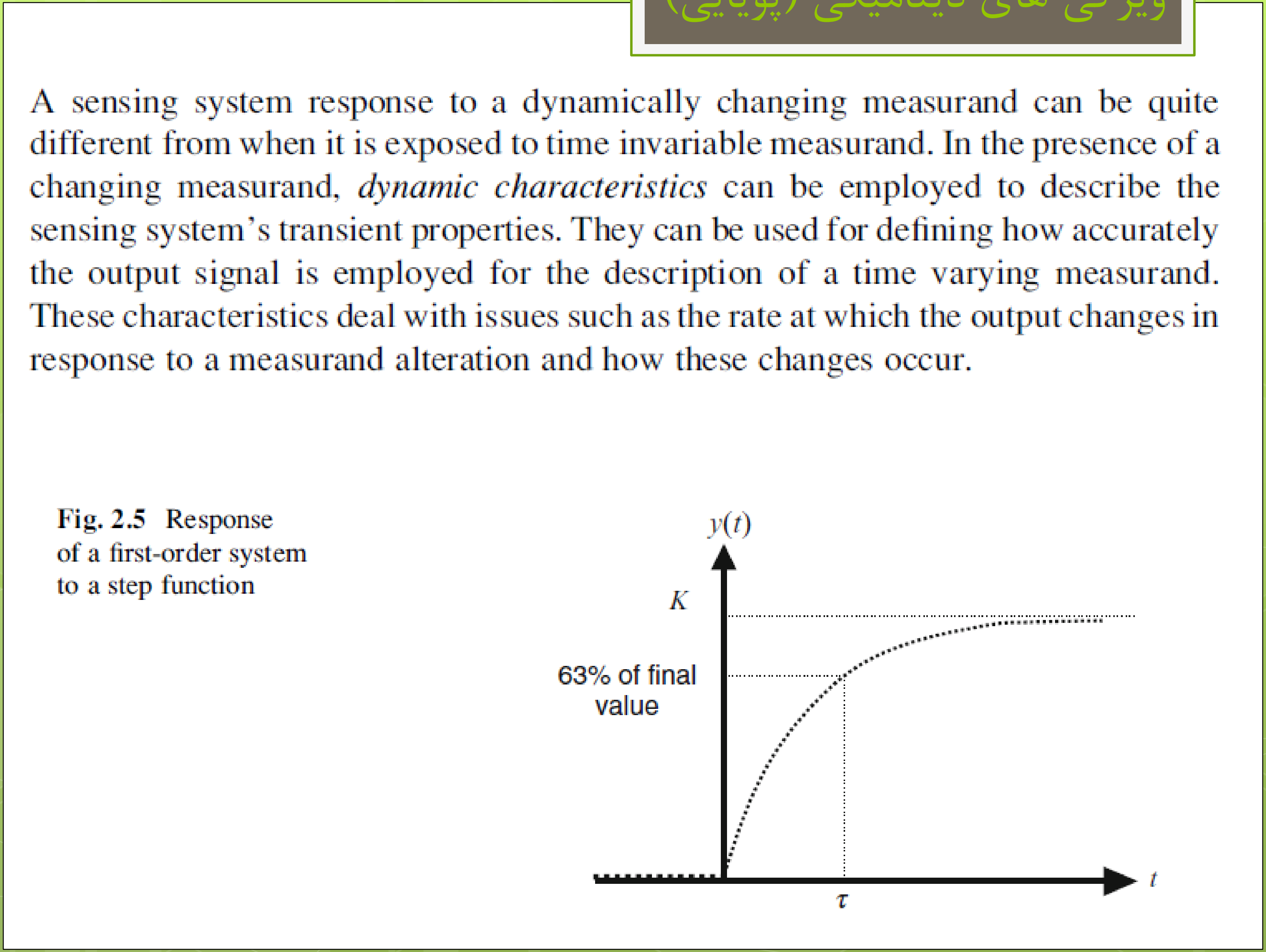
زمان پاسخ و زمان بازیابی:



2.2.17 *Response and Recovery Time*

When a sensing system is exposed to a measurand, the time it requires to reach a stable value is the response time. It is generally expressed as the time at which the output reaches a certain percentage (for instance, 95 %) of its final value, in response to a step change of the input. The "recovery time" is defined conversely.

ویژگی های دینامیکی (پویایی)



A sensing system response to a dynamically changing measurand can be quite different from when it is exposed to time invariable measurand. In the presence of a changing measurand, *dynamic characteristics* can be employed to describe the sensing system's transient properties. They can be used for defining how accurately the output signal is employed for the description of a time varying measurand. These characteristics deal with issues such as the rate at which the output changes in response to a measurand alteration and how these changes occur.

Fig. 2.5 Response of a first-order system to a step function

ویژگی های دینامیکی (پویایی)

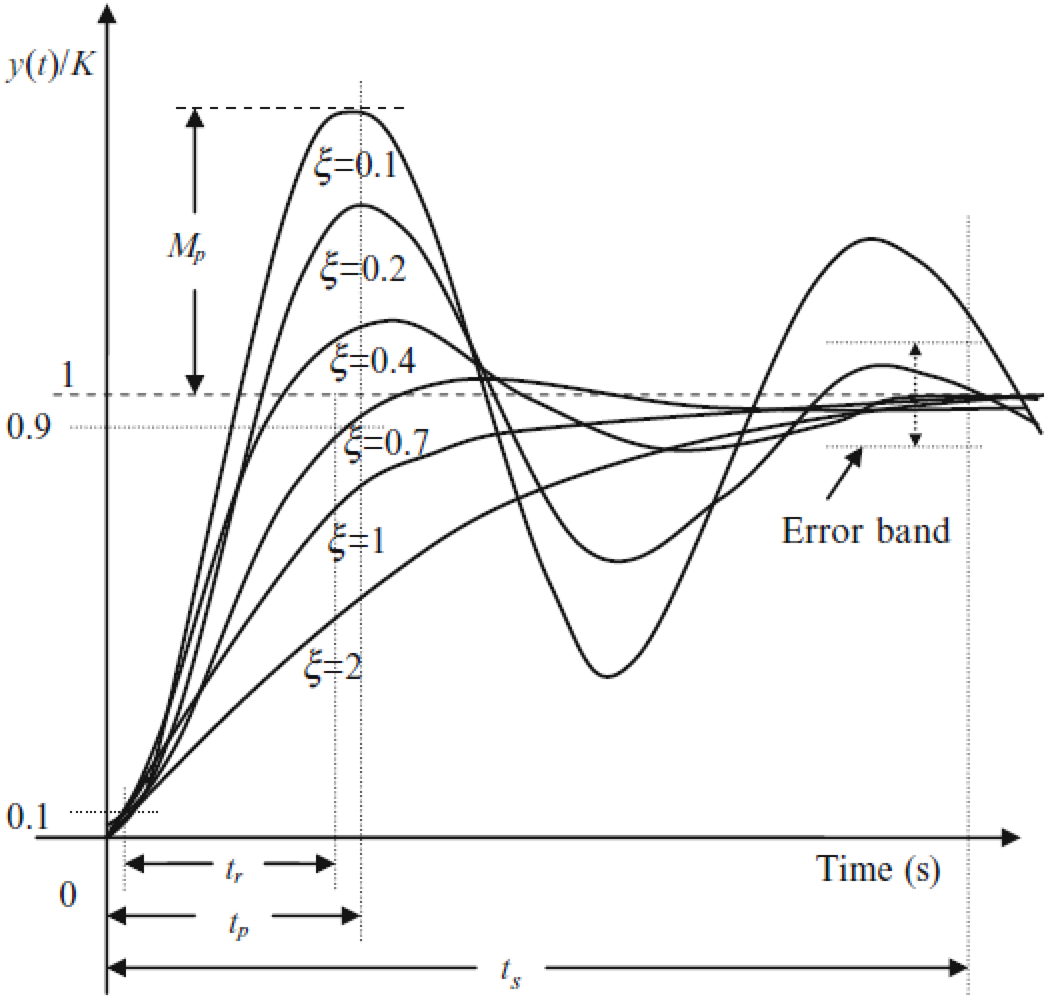
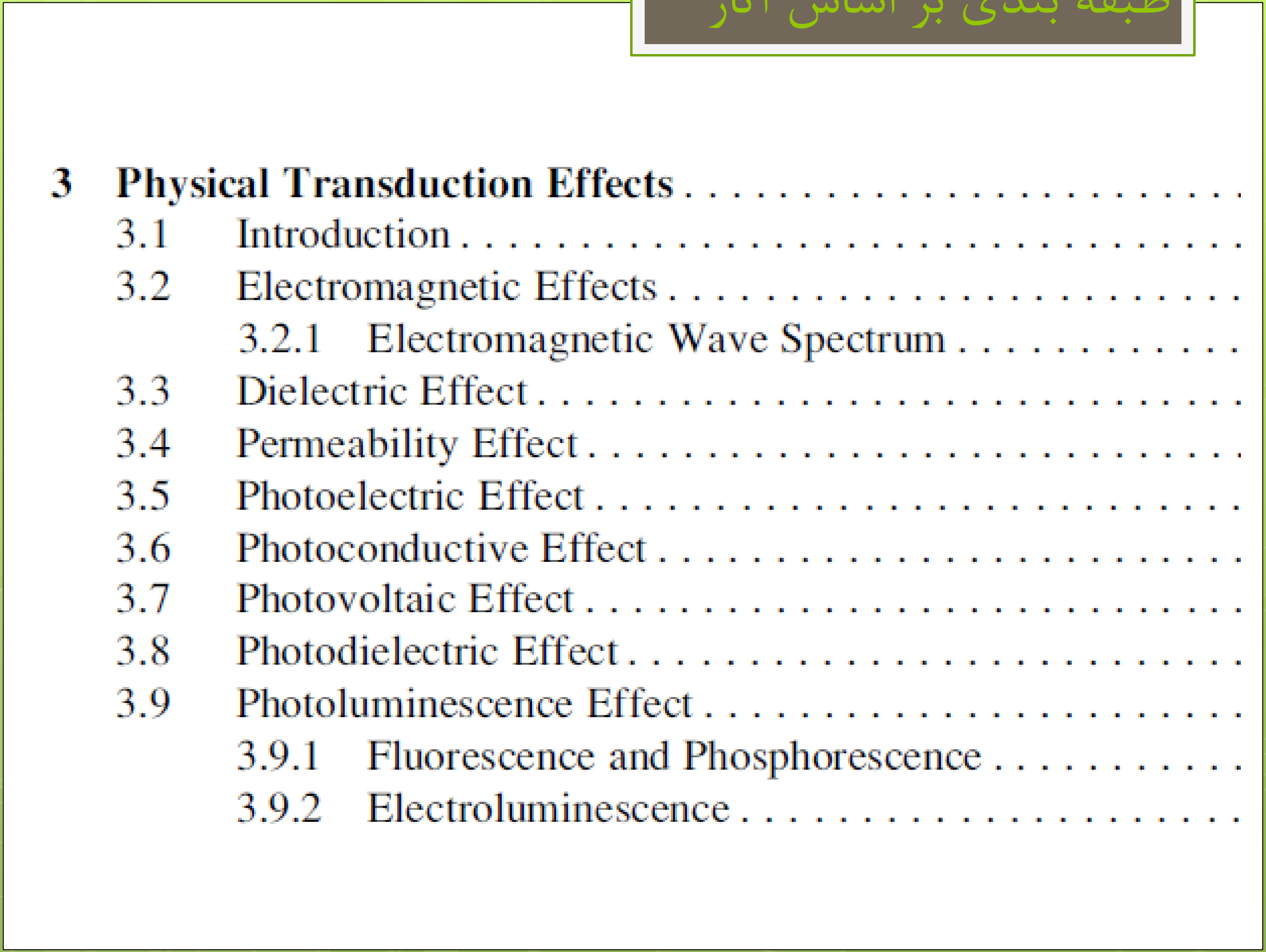
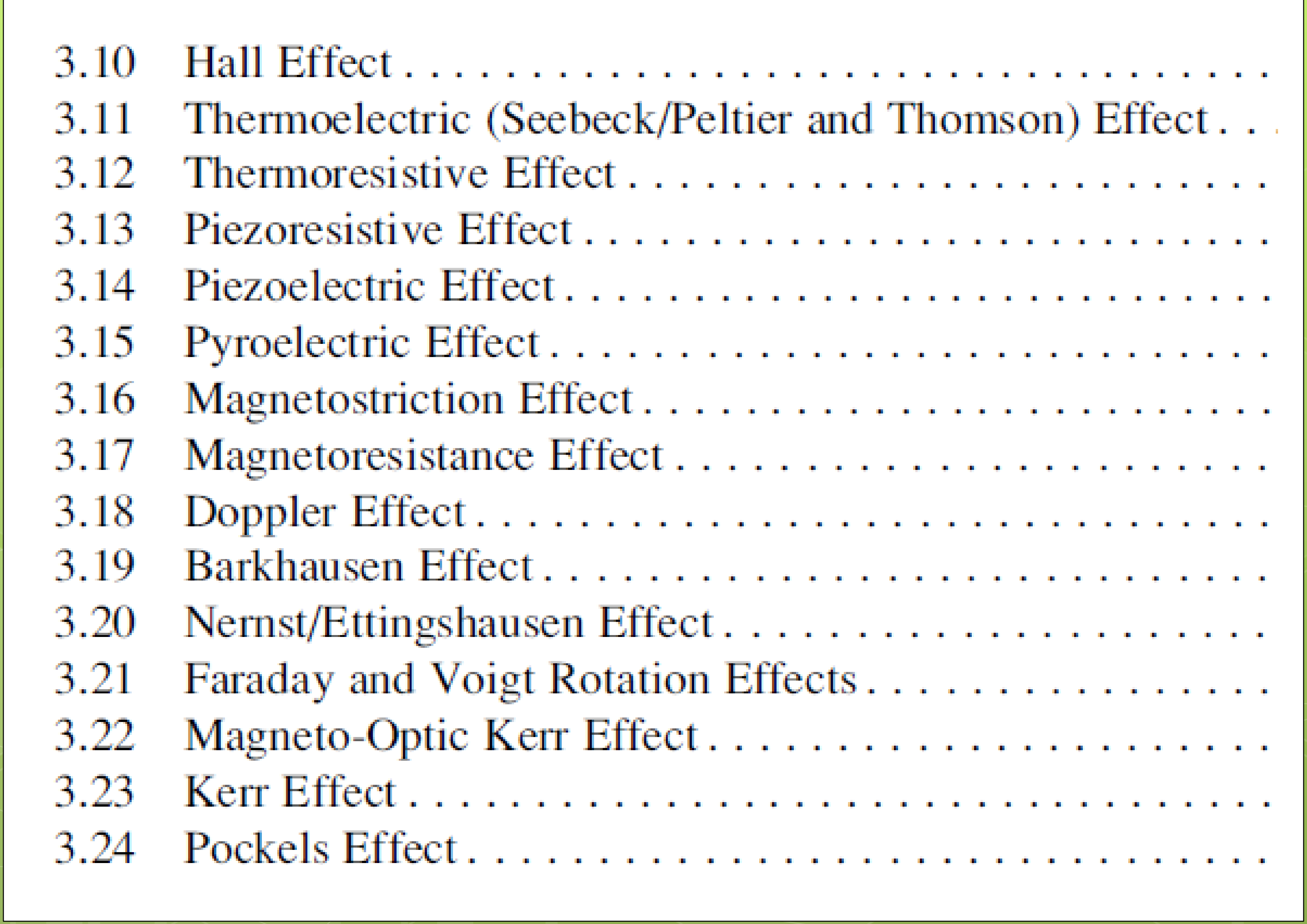


Fig. 2.8 Responses of a second-order sensing system to a step function at different damping ratios

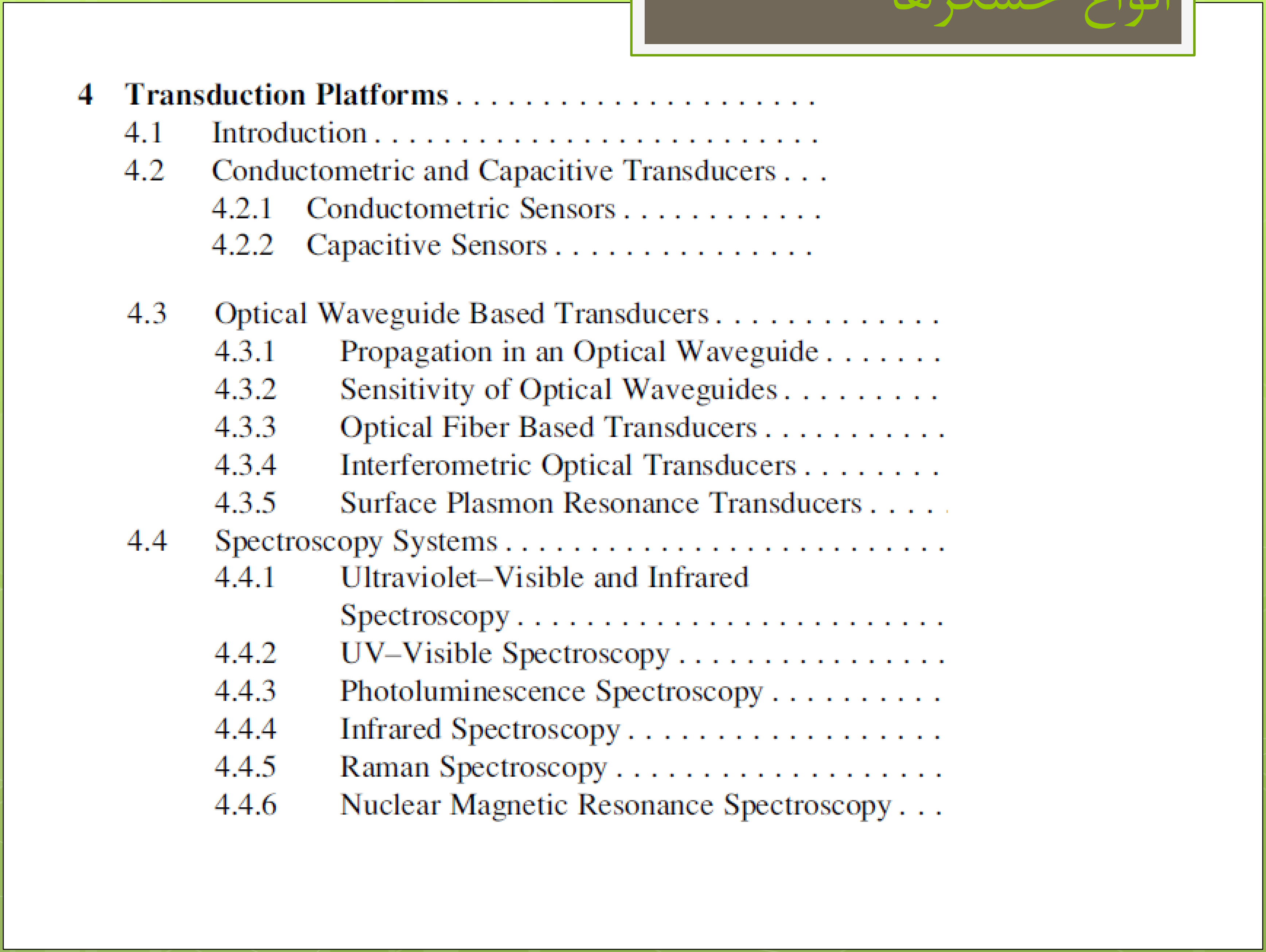
طبقه بندی بر اساس آثار



طبقه بندی بر اساس آثار



انواع حسگرها



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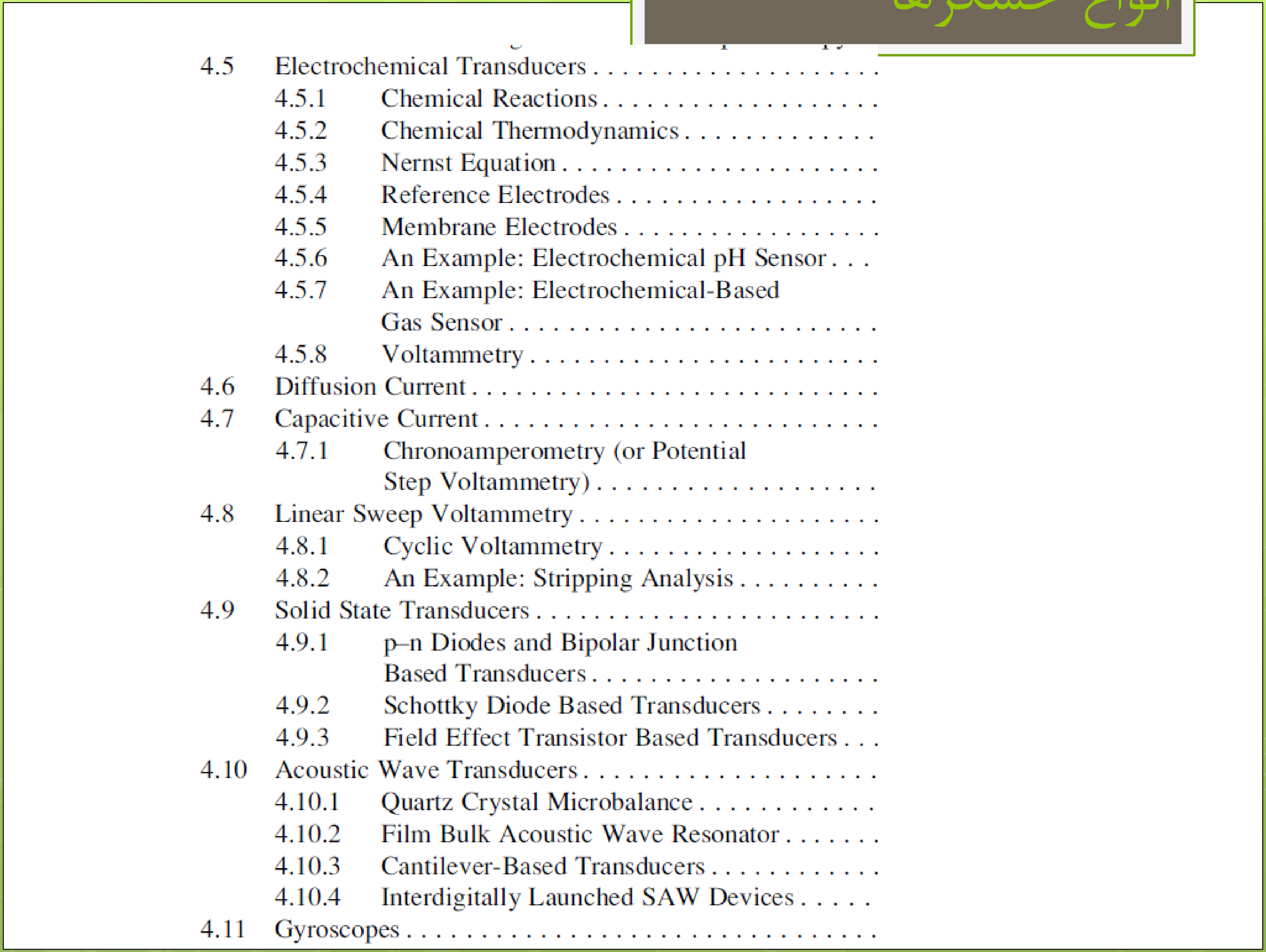

محصولات سنسوری TI

- حسگر دما
- حسگر موج میلی متری
- حسگر رطوبت
- حسگر نوری
- حسگر مغناطیسی
- حسگر دیود نوری
- حسگر خازنی
- حسگر القایی
- حسگر ماورا صوت
- حسگر گاز و شیمیایی
- مبدل LVDT
- حسگری جریان