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# Lecture 4:
# Sensor Characteristics

**(Contents from Handbook of Modern Sensors-Jacob Fraden)**

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# Learning Outcomes

- Sensor Characteristics with an Example
- Transfer Functions
- Types of Transfer Functions, Uni, Multi dimension
- Non-Linear Transfer Function
- Sensitivity
- Inverse Transfer Function
- Span
- Full Scale Output
- Accuracy

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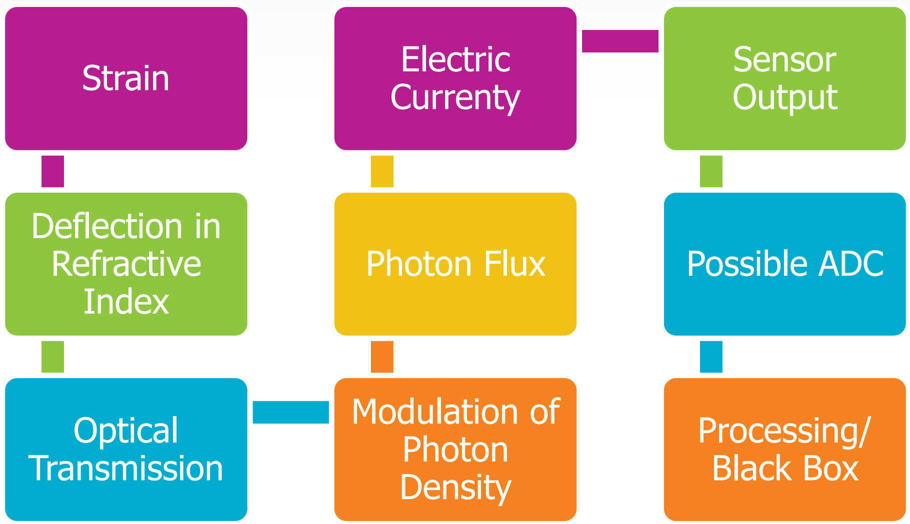
# 1. Sensor Characteristics

From the input to the output, a sensor may have several conversion steps before it produces an electrical signal.




Pressure Inflicted on the fiber-optic sensor

## 1.1 Transfer Function

- An *ideal* or *theoretical* output–stimulus relationship exists for every sensor
- An ideal (theoretical) output–stimulus relationship is characterized by the so-called *transfer function*.
- This function establishes dependence between the electrical signal $S$ produced by the sensor and the stimulus $s$ : $S = f(s)$.
- That function may be a simple linear connection or a nonlinear dependence, (e.g., logarithmic, exponential, or power function).

## Unidimensional Transfer Function

- In many cases, the relationship is unidimensional (i.e., the output versus one input stimulus). A unidimensional linear relationship is represented by the equation

$$S = a + bs,$$

- where *a* is the intercept (i.e., the output signal at zero input signal) and *b* is the slope, which is sometimes called *sensitivity*.

- *S* is one of the characteristics of the output electric signal used by the data acquisition devices as the sensor's output

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## Transfer Function

Logarithmic function: $S = a + b \ln s$

Exponential function: $S = ae^{ks}$

Power function: $S = a_0 + a_1 s^k$,

Where *k* is a constant number.

A sensor may have such a transfer function that none of the above approximations fits sufficiently well. In that case, a higher-order polynomial approximation is often employed.

## Non-Linear Transfer Function

For a nonlinear transfer function, the sensitivity *b* is not a fixed number as for the linear relationship

At any particular input value, $s_0$, it can be defined as

$$b = \frac{dS(s_0)}{ds}$$

In many cases, a nonlinear sensor may be considered linear over a limited range.

Over the extended range, a nonlinear transfer function may be modeled by several straight lines. This is called a piecewise approximation.

$$b = \frac{dS(s_0)}{ds}$$

## Multi-Dimensional Transfer Function

A transfer function may have more than one dimension when the sensor's output is influenced by more than one input stimuli.

An example is the transfer function of a thermal radiation (infrared) sensor. The function connects two temperatures ($T_b$, the absolute temperature of an object of measurement, and $T_s$, the absolute temperature of the sensor's surface) and the output voltage $V$ :

$$V = G(T_b^4 - T_s^4)$$

Where $G$ is a constant.

Clearly, the relationship between the object's temperature and the output voltage (transfer function) is not only nonlinear (the fourth-order parabola) but also depends on the sensor's surface temperature.

## Determining Sensitivity

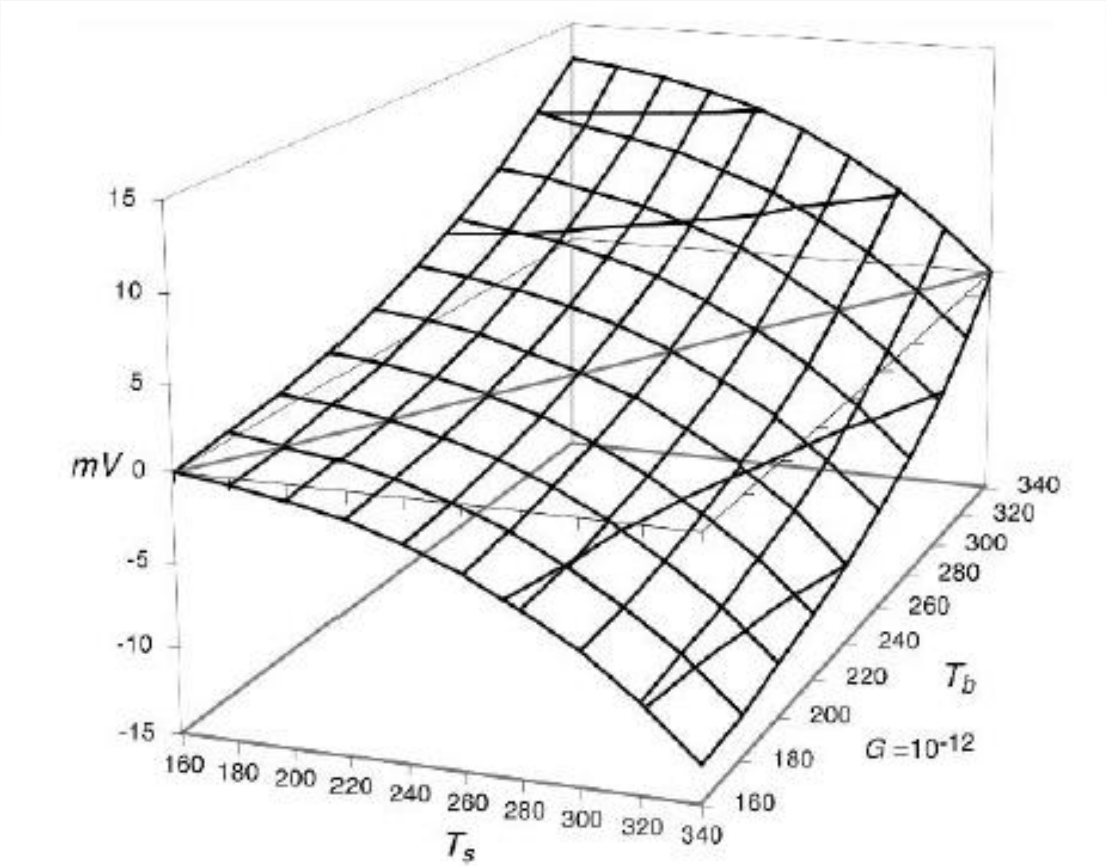
This function is generally known as the Stefan–Boltzmann law.

To determine the sensitivity of the sensor with respect to the object’s temperature, a partial derivative will be calculated as

$$b = \frac{\partial V}{\partial T_b} = 4GT_b^3$$

It can be seen that each value of the output voltage can be uniquely determined from two input temperatures.

# Two Dimensional Transfer Function of a thermal radiation sensor



## Inverse Transfer Function

- It should be noted that a transfer function represents the input-to-output relationship.
- However, when a sensor is used for measuring or detecting a stimulus, an inversed function (output-to-input) needs to be employed.
- When a transfer function is linear, the inversed function is very easy to compute.
- When it is nonlinear the task is more complex, and in many cases, the analytical solution may not lend itself to reasonably simple data processing.
- In these cases, an approximation technique often is the solution

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## 1.2 Span (Full Scale Input)

- A dynamic range of stimuli which may be converted by a sensor is called a *span* or an ***input full scale* (FS)**.
- It represents the highest possible input value that can be applied to the sensor without causing an unacceptably large inaccuracy.
- For the sensors with a very broad and nonlinear response characteristic, a dynamic range of the input stimuli is often expressed in decibels, which is a logarithmic measure of ratios of either power or force (voltage)
- It should be emphasized that decibels do not measure absolute values, but a ratio of values only.
- A decibel scale represents signal magnitudes by much smaller numbers, which, in many cases, is far more convenient.

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# Relationship Among Power, Force and Decibels

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Power ratio | 1.023 | 1.26 | 10.0 | 100 | $10^3$ | $10^4$ | $10^5$ | $10^6$ | $10^7$ | $10^8$ | $10^9$ | $10^{10}$ |
| Force ratio | 1.012 | 1.12 | 3.16 | 10.0 | 31.6 | 100 | 316 | $10^3$ | 3162 | $10^4$ | $3 \times 10^4$ | $10^5$ |
| Decibels | 0.1 | 1.0 | 10.0 | 20.0 | 30.0 | 40.0 | 50.0 | 60.0 | 70.0 | 80.0 | 90.0 | 100.0 |

Decibels are equal to 10 times the log of the ratio of powers

$$1 \text{ dB} = 10 \, log \frac{P_2}{P_1}$$

In a similar manner, decibels are equal to 20 times the log of the force, current, or voltage:

$$1 \text{ dB} = 20 \, log \frac{S_2}{S_1}$$

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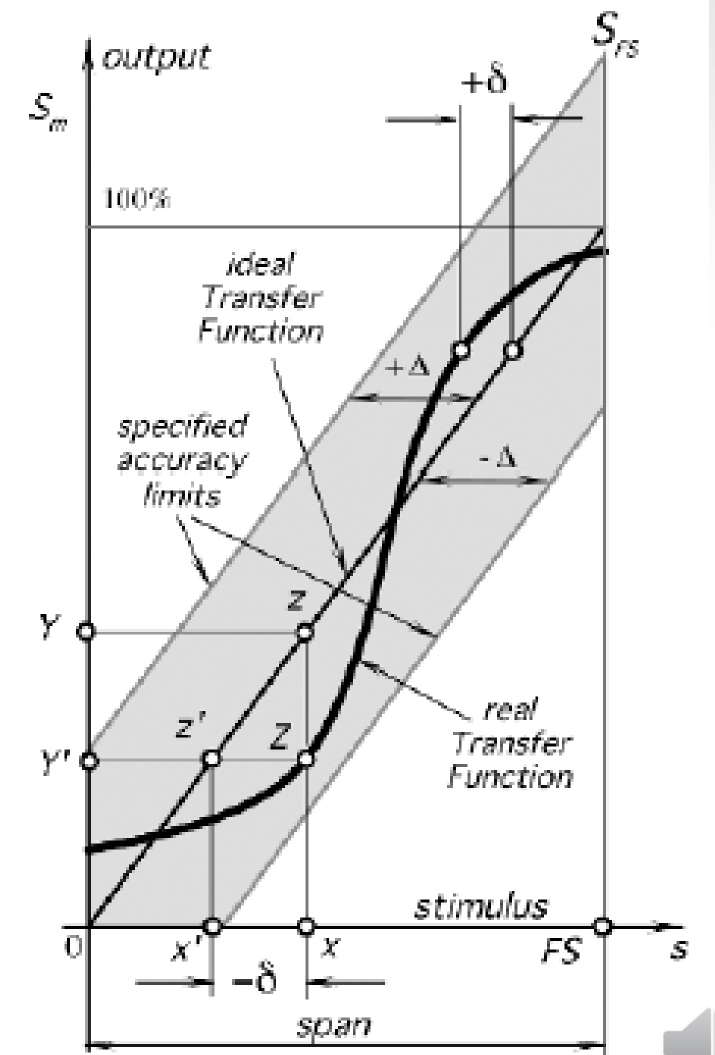
## 1.2 Full-Scale Output

***Full-scale output (FSO)*** is the algebraic difference between the electrical output signals measured with maximum input stimulus and the lowest input stimulus applied.

This must include all deviations from the ideal transfer function. For instance, the FSO output in Fig. is represented by $S_{FS}$.

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## 1.4 Accuracy

Avery important characteristic of a sensor is *accuracy* which really means *inaccuracy*. Inaccuracy is measured as a highest deviation of a value represented by the sensor from the ideal or true value at its input.

In modern sensors, specification of accuracy often is replaced by a more comprehensive value of *uncertainty because* uncertainty is comprised of all distorting effects both systematic and random and is not limited to the inaccuracy of a transfer function.