Measurements and Instrumentation [SBE206A] (Fall 2018)
Tutorial 7

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Errors during the measurement process

Introduction

- Measurement errors are impossible to avoid.
- we can minimize their magnitude by:
  - good measurement system design.
  - appropriate analysis and processing of measurement data.
- Errors are categorized to:
  - Systematic errors
  - Random errors

Systematic errors

The systematic errors affect the readings in a consistent way, such that all readings are on one side of the true value (either all positive or all negative).

Sources of systematic errors are:

- *Loading error*: system disturbances due to measurement.
- Environmental changes (results in change of sensitivity drift or zero drift).
- *Calibration error*: use of uncalibrated instruments.
- Wear in instruments components (can be compensated by calibration).
- Poor cabling practices.

Random errors

In contrast, random errors have stochastic effects on readings; the readings are distributed around a the true value.

Possible sources of random errors are:

1. Human reading errors.
2. Electrical noise.

Systematic Error	Random Error
Poor accuracy	poor precision
definite causes	indefinite causes
reproducible	not reproducible

Table 1: Comparison between systematic and random errors

Comparison between systematic and random errors

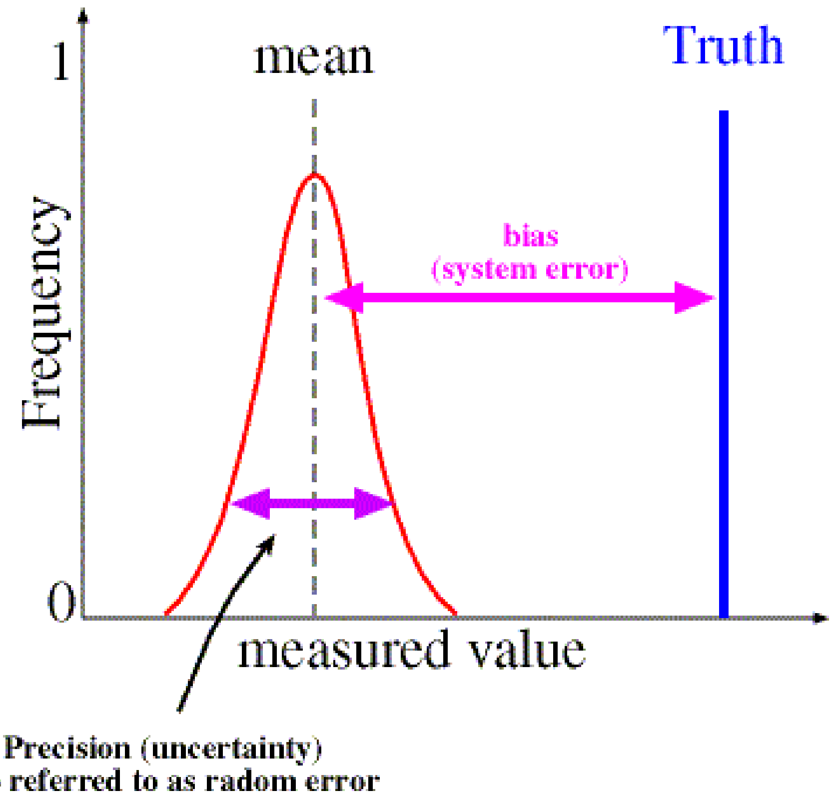

Figure 1: Difference between systematic errors effect and random errors effect.

1. Exercise

Which is more challenging? Systematic errors or random errors?

1. Solution

Aggregation of measurement system errors

The worst-case prediction of maximum error

$$\text{error} = \sum_{i}^{n} x_i \tag{1}$$

Likely maximum systematic error

$$\text{error} = \sqrt{x_1^2 + x_2^2 + \ldots + x_n^2} \tag{2}$$

Problems

Systematic Errors

Systematic erros due to disturbance

System Disturbance **2. Exercise**

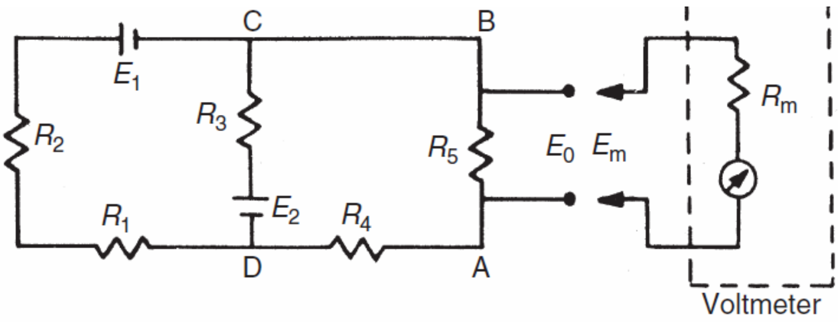

Figure 2: Effect of applying the voltmeter to the measured quantity.

1. Derive the relation of the true and output readings.
2. Suppose that the components of the circuit in Figure 2 have the following values: $R_1 = 400\Omega$, $R_2 = 600\Omega$, $R_3 = 1000\Omega$, $R_4 = 500\Omega$, $R_5 = 1000\Omega$

2. Solution

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3. Exercise

An inexpensive voltmeter is used to measure the voltage to with 1 % across the power terminals of a stereo system. Such a system typically has an output impedance of 500 Ω and a voltage of 120 V at its power terminals. Assuming that the voltmeter is 100 % accurate such that the instrument and zero-order uncertainties are negligible, determine the minimum input impedance (in Ω) that this voltmeter must have to meet the 1 % criterion.

3. Solution

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4. Exercise

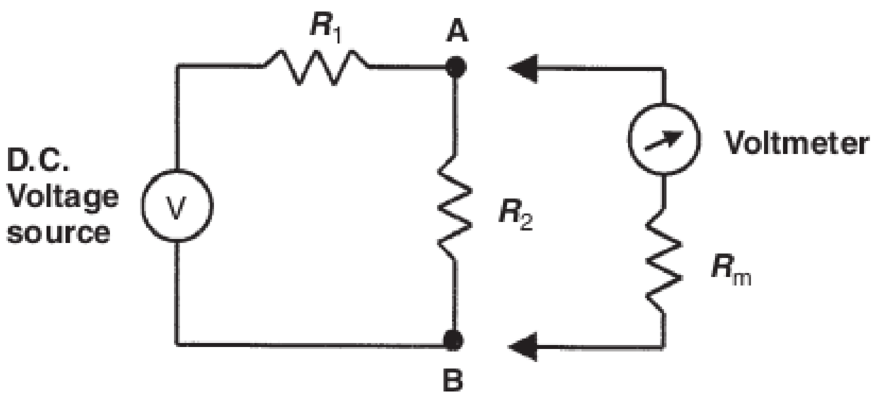

Figure 3: Circuit for Exercise 4

In the circuit shown in Figure 4, the resistor values are given by $\mathrm{R}_1 = 1000\Omega$; $\mathrm{R}_2 = 1000\Omega$; V = 20 volts. The voltage across AB (i.e., across R_2) is measured by a voltmeter whose internal resistance is given by $\mathrm{R}_\mathrm{m} = 9500\Omega$.

1. What will be the reading on the voltmeter?

2. What would the voltage across AB be if the voltmeter was not loading the circuit (i.e., if $\mathrm{R}_\mathrm{m} = \infty$)?

3. show that the voltage $\mathrm{E_m}$ measured across points AB by the voltmeter is related to the true voltage $(\mathrm{E_o})$ by the following expression:

$$\frac{\mathrm{E_m}}{\mathrm{E_o}} = \frac{\mathrm{R_m(R_1 + R_2)}}{\mathrm{R_1(R_2 + R_m) + R_2R_m}} \tag{3}$$

4. What is the measurement error due to the loading effect of the voltmeter?

5. If the parameters in Figure 4 have the following values, $\mathrm{R_1} = 5000\Omega$; $\mathrm{R_2} = 10000\Omega$; what value would the voltmeter internal resistance $\mathrm{R_m}$ need to be in order not to exceed a measurement error of 1%?

4. Solution

5. Exercise

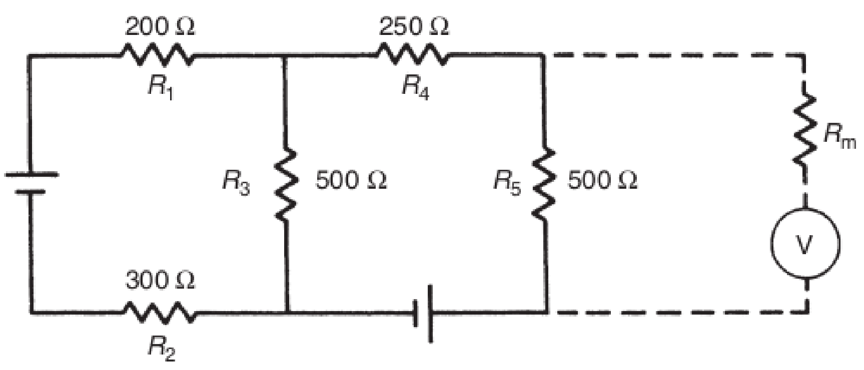

Figure 4: Circuit for Exercise 5

The voltage across a resistance $\mathrm{R_5}$ in the circuit of Figure 5 is to be measured by a voltmeter connected across it.

1. If the voltmeter has an internal resistance ($\mathrm{R_m}$) of 4750Ω, what is the measurement error?

2. What value would the voltmeter internal resistance need to be in order to reduce the measurement error to 1%?

5. Solution

6. Exercise

A requirement for a resistance of 1220Ω in a circuit is satisfied by connecting together resistances of 1000 and 220 Ω in series. If each resistance has a tolerance of $\pm5\%$, what is the likely tolerance in the total resistance?

6. Solution

7. Exercise

In order to calculate the heat loss through the wall of a building, it is necessary to know the temperature difference between inside and outside walls. Temperatures of 5 and 20 °C are measured on each side of the wall by mercury-in-glass thermometers with a range of 0 to $\pm50°\mathrm{C}$ and a quoted inaccuracy of $\pm1\%$ of full-scale reading.

1. Calculate the likely maximum possible error in the calculated value for the temperature difference.

2. Discuss briefly how using measuring instruments with a different measurement range may improve measurement accuracy.

7. Solution