

# Signals and cables

(BME-MIT, P. Sz.)

## 1. Theory

### 1.1 Measurement errors

The **(absolute) measurement error** (error) is the difference between the measured and the real value:

$$H = x_m - x_h ,$$

Where  $H$  is the absolute error,  $x_m$  is the measured value, and  $x_h$  is the real value.

Usually, instead of the absolute error the relative error is used. The  $h$  **relative error**:

$$h = (x_m - x_h) / x_h .$$

### 1.2 Period and frequency

A signal is periodic if the signal value is equal in every  $(t+nT)$  moment, where  $n$  is a integer value:

$$x(t) = x(t+nT); \text{ where } n = \dots -1, 0, 1, 2 \dots$$

Time  $T$  is the period time, while  $f = 1/T$  is the frequency of the signal.

### 1.3 Amplitude, peak value

The **peak value** is the highest value of the signal. For sine wave and square wave this value is also called **amplitude**.

### 1.4 Peak-to-peak value

Peak-to-peak is the difference between the highest positive value and the lowest negative value of the signal. For symmetric signals peak-to-peak value equals to twice of the amplitude (Figure 2.).

Sometimes literature refers peak-to-peak as amplitude, for example the Agilent oscilloscope used measures peak-top-peak with the amplitude option of quick measure function (**Quick Meas/Amplitude**) for noise-free undistorted signals (but a **Peak-to-Peak** option is also available).

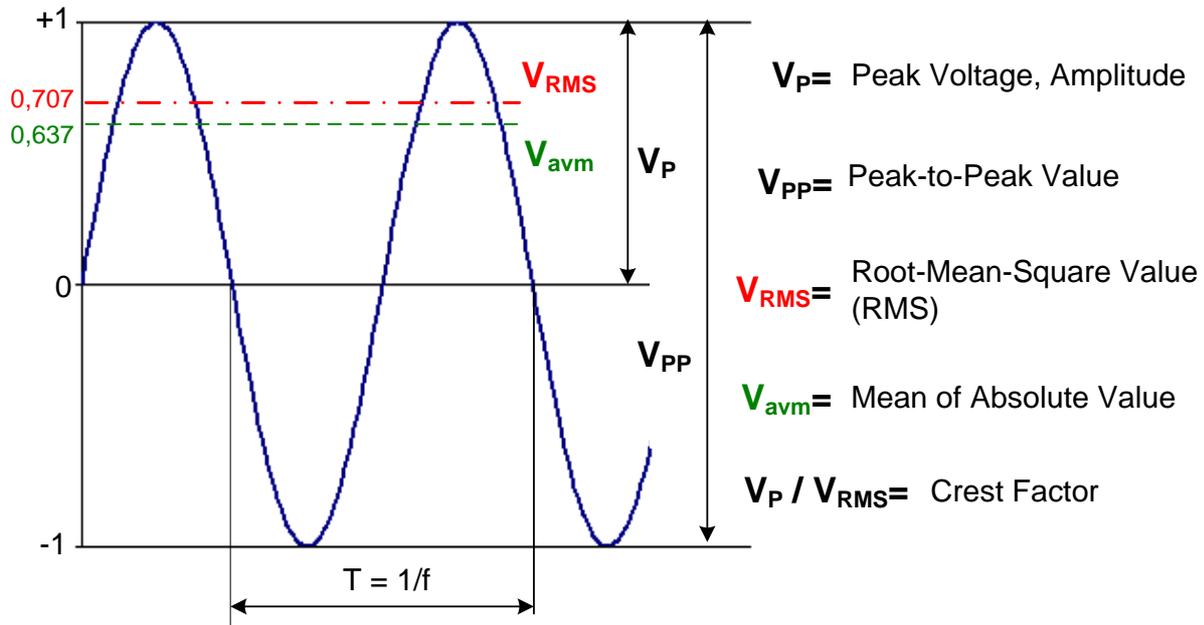


Figure 2. Parameters of a sine wave

### 1.5 Average of alternating signals

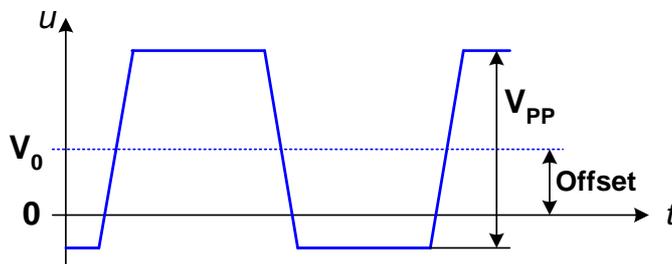
Simple average (which is also known as DC level) is the average of a periodic signal for one period ( $U_0$ ):

$$U_0 = \frac{1}{T} \int_0^T u(t) dt$$

The average of the signal shown in Figure 2. is zero. In real-world the average value of an alternating signal is often not zero. Often such signals are handled as a sum of a symmetric alternating component and an offset. The former is referred to as the AC component, while the latter is called the DC component (Figure 3).

Figure 3.

Offset of an alternating signal



### 1.6 Absolute mean value

The absolute mean value is the average absolute value for one period:

$$U_k = \frac{1}{T} \int_0^T |u(t)| dt$$

On Figure 2. this value is denoted as  $V_{avm}$ . For a sine wave without offset  $V_{avm} = (2/\pi) V_P = 0,637 V_P$ .

### 1.7 Root-Mean-Square (RMS) value

The RMS value represents the power of a signal. On a resistor, the alternating current or voltage dissipates the same amount of heat as the RMS DC value.

According to Ohm rule, power is proportional to the square of current and voltage:

$$p = u \times i = u \times (u/R) = u^2/R$$

$$p = u \times i = (i \times R) \times i = i^2 \times R$$

Average power: 
$$P = \frac{1}{T} \int_0^T \frac{u^2(t)}{R} dt$$

Therefore, the RMS value:

$$U = \sqrt{\frac{1}{T} \int_0^T u^2(t) dt}$$

For a sine wave without offset:  $V_{RMS} = (1/\sqrt{2}) V_P = 0,707 V_P$ .

If the alternating signal has both a DC and an AC component, then the RMS value can be computed:

$$U = \sqrt{U_1^2 + U_2^2} \quad \text{where } U_1 \text{ is the DC component and } U_2 \text{ is the AC component.}$$

### 1.8 Measured values

When set to either DC or AC mode, different instruments measure different properties of a signal. The instruments in the laboratory measures the following parameters:

- Agilent 34401A multimeter **AC V** mode: **RMS value of the AC component**
- Metex ME-22T multimeter AC mode: **RMS value of the AC component**
- Agilent 54622A oscilloscope in **Coupling\_DC** mode, using **Quick Measure > RMS: RMS value of the full signal (DC+AC component)**
- Agilent 54622A oscilloscope in **Coupling\_AC** mode, using **Quick Measure > RMS: RMS value of the AC component**

### 1.9 Reflections

A typical property of a cable is its impedance (e.g. coax cables used in 10 Mb/s Ethernet networks have an impedance of 50Ω, while antenna cables of televisions have 75Ω impedance). If the impedance connected to the cable differs from the cable's own impedance, reflection occurs at the end of the cable. The reflection coefficient shows the ratio of the reflected signal and the generated signal. Let's assume we connect a signal generator to the input of a cable, and the amplitude of the generated signal is  $U_g$ . In this case reflection may occur at the other end of the cable. If the amplitude of the reflected signal is  $U_r$ , the reflection coefficient ( $r$ ) can be computed by:

$$r = \frac{U_r}{U_g}$$

From the above equation, you can conclude that the absolute value of the reflection coefficient is always smaller than 1, as the reflected signal cannot have larger amplitude than the generated one.

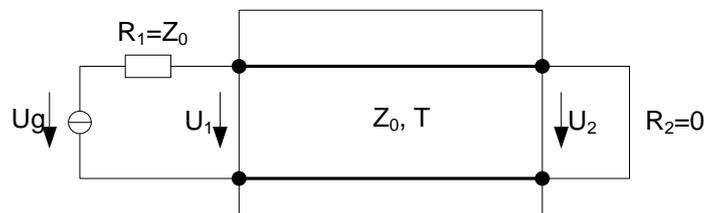
Another way to compute the reflection coefficient is to use the cable impedance ( $Z_0$ ) and the impedance connected to the end of the cable (terminal resistance,  $R$ ).

$$r = \frac{R - Z_0}{R + Z_0}$$

Reflection coefficients for simple cases:

- If the impedance connected to the cable equals to the impedance of the cable ( $R=Z_0$ ), then the reflection coefficient is 0, so there is no reflected signal.
- If the connected impedance is 0 (short circuit,  $R=0$ ) then the reflection coefficient is -1. That is, the absolute value of the reflected signal is the same as the absolute value of generated signal, but the polarity is inverted.
- If the connected impedance is very large ( $R=\infty$ ), the reflection coefficient is 1, so that the reflected signal is the same as the generated signal.

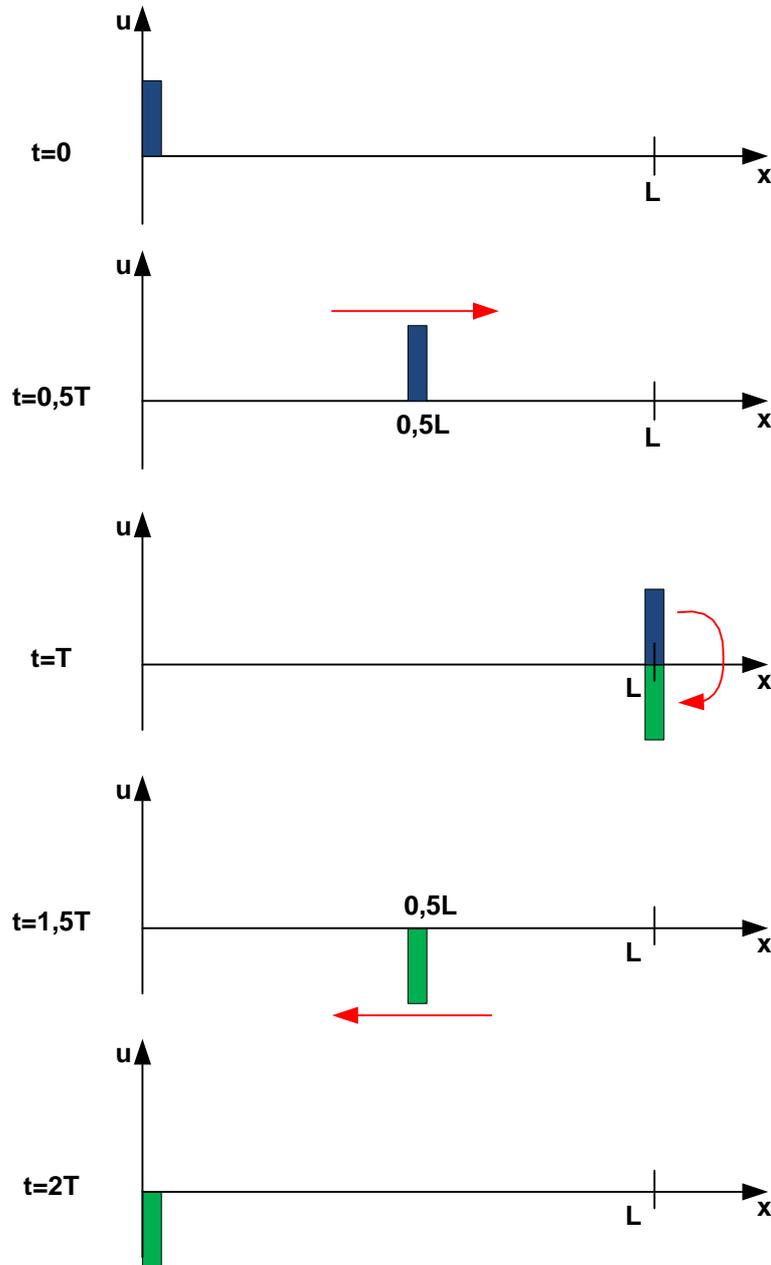
Let's take a look at the following schematic.



As the terminal resistance is 0, the reflection coefficient is:

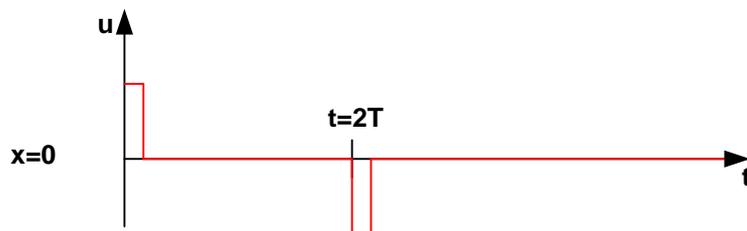
$$r = \frac{R_2 - Z_0}{R_2 + Z_0} = \frac{0 - Z_0}{0 + Z_0} = -1$$

Let's assume the signal generator (left side) outputs a short impulse ( $T$  is the propagation time of the cable,  $L$  is the length,  $x$  is a position on the cable).



At  $t=0$  the generator outputs the short pulse (blue,  $U_g$ ). It takes  $T$  for the pulse to propagate to the other end of the cable, where it is reflected with  $r=-1$  (green,  $U_r$ ). The reflected pulse propagates from the end of the cable to the beginning of the cable, again it takes  $T$ , so the reflected pulse arrives at  $2T$  to the beginning of the cable.

Therefore, if we use an oscilloscope to measure the beginning of the cable ( $x=0$  position), we will have the following waveform (voltage versus time):



## Measurement tasks

### 1. Cables and noises

Set the following sine wave on the signal generator: 200 Hz frequency, 100 mVpp amplitude. As the input impedance of the oscilloscope is way larger than the 50 Ohm output impedance of the generator, you should set the generator output accordingly: **Utility > Output Setup > High Z > Done.**

**1.1** Connect the generator and the oscilloscope with a shielded BNC-BNC cable.

**1.2** Connect the generator and the oscilloscope with a simple, un-shielded cable. Compare the results with 1.1 (for correct triggering, you should probably set **Trigger's Mode/Coupling** menu, **HF\_Reject** mode).

**1.3** Turn on averaging on the oscilloscope (**Acquire** menu, **Average**). What is the difference?

**1.4** Using the un-shielded cable (1.2) how can you increase signal-to-noise ratio?

### 2. Measuring periodic signals

#### 2.1 Sine wave

Generate a sine wave with the following parameters:

frequency: 1 kHz

amplitude: 2 Vpp

offset: +1 V.

Check the signal on the oscilloscope.

Measure the amplitude of the signal with the following instruments and compute the difference (in percent).

Sine wave; 2 Vpp, offset: +1 V, 1 kHz				
Instrument, Mode	Real value	Measured value	Difference [%]	Notes
Agilent 34401A multimeter <b>DC V</b> mode				
Agilent 34401A multimeter <b>AC V</b> mode				
Handheld multimeter: <b>DC V</b> mode				
Handheld multimeter: <b>AC V</b> mode				
Ag. 54622A oscilloscope Input <b>Coupling_AC</b> , <b>Quick Measure &gt; RMS</b>				
Ag. 54622A oscilloscope				

Input Coupling_DC , Quick Measure > RMS				
Ag. 54622A oscilloscope Input Coupling_DC , Quick Meas.> Amplitude				

### 2.2 Square wave

Modify the generator setting to generate a square wave, but leave the other parameters unchanged. Check the duty cycle (should be 50%).

Do the following measurements!

<i>Square wave</i> ; 2 Vpp, offset: +1 V, 1 kHz, 50%				
Instrument, Mode	Real value	Measured value	Difference [%]	Notes
Agilent 34401A multimeter AC V mode				
Handheld multimeter: DC V üzemmód				
Handheld multimeter: AC V üzemmód				
Ag. 54622A oscilloscope Input Coupling_DC , Quick Measure > RMS				
Ag. 54622A oscilloscope Input Coupling_DC , Quick Meas.> Amplitude				

### 3. Generator internal impedance

Measure the output impedance of the signal generator. Create the schematic shown in Figure 5. (SW is not a real switch, you have to make two setups).

Set SW to 0, and measure  $U_0$  internal voltage, then set SW to "1" and measure the voltage of  $R_L$ . Using the two values, compute the output impedance,  $R_L$ .

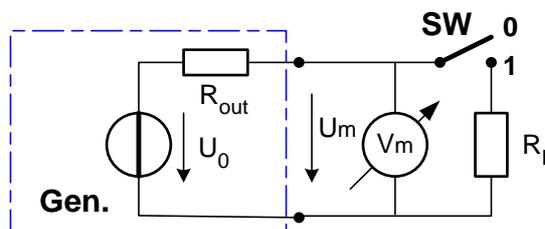


Figure 5. Measuring output impedance

For the measurement, use Agilent 34401A multimeter and set the following signal on the generator: sine wave; frequency: 440 Hz; offset: 0 V, RMS value: 3 V.

Select an  $R_L$  impedance around 100 Ohm, and measure the exact value with the multimeter.

#### 4 Long cables

Assemble the setup on Figure 6.

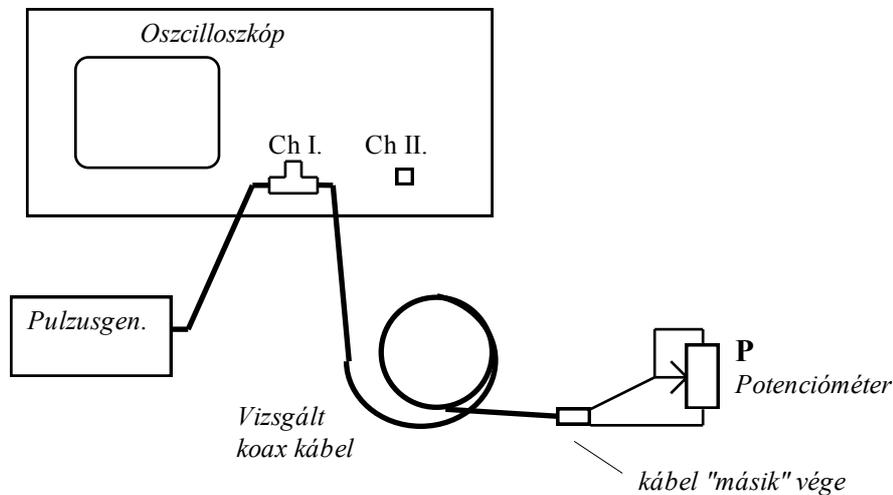


Figure 6. Cable measurements

##### 4.1 Measurement with short impulse

Generate short impulses using the signal generator. Set low level (**LoLevel**) to 0 V, amplitude (**HiLevel**) to +4 V and high impedance (Hi-Z) output.

Measure the waveforms using short-circuit and open-circuit at the end of the long cable (use the potentiometer to set these).

##### 4.2 Propagation time

Form the known cable length and the above measurement results, compute the specific signal propagation time (ns/m).

##### 4.3 Impedance

Using the provided potentiometer, measure the impedance of the cable (find the impedance using the potentiometer when there is no reflection).

##### 4.4 Measurement with square wave

Generate a relatively low frequency square wave (so that the period time of the signal is much longer than the propagation time of the cable) using the signal generator. Set low level (**LoLevel**) to 0 V, amplitude (**HiLevel**) to +4 V and high impedance (Hi-Z) output.

Measure the waveforms using short-circuit and open-circuit at the end of the long cable (use the potentiometer to set these).

## Test questions

1. Let's assume a sine wave with an offset of -1 V, and an AC component with 2 V<sub>pp</sub> (peak-to-peak).
  - What is the RMS value of the DC component?
  - What is the RMS value of the AC component?
  - What value is displayed on the multimeter in AC and DC mode?
  - What value is displayed on the oscilloscope in AC and DC mode?
2. Let's assume a square wave with an offset of 1 V, and an AC component with 2 V<sub>pp</sub> (peak-to-peak).
  - What is the RMS value of the DC component?
  - What is the RMS value of the AC component?
  - What value is displayed on the multimeter in AC and DC mode?
  - What value is displayed on the oscilloscope in AC and DC mode?
3. We have measured the output impedance of a signal generator in accordance to Task 3. The RL impedance is 90 Ohm  
Measured voltages:  $U_0 = 2$  V,  $U_1 = 1,4$  V  
Compute the output impedance!
4. What is the reflection coefficient and how can you compute it?
5. What is the value of the reflection coefficient when there is an open-circuit at the end of the cable?
6. What is the value of the reflection coefficient when there is a short-circuit at the end of the cable?