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LABORATORY OF MEASUREMENTS

EXPERIMENT No **3**

Identification of basic parameters of electrical signals

Goal:

The main goal of the experiment is to familiarise students with measurement of basic parameters of signals and methods for signal identification.

SPECIFICATION:

The following instruments and software are used:

Instruments

1. Digital oscilloscope RIGOL DS1052E
2. Digital Signal generator DDS DF1410
3. Multifunction ADC and DAC module ADVANTECH USB4711
4. Desk top digital sampling multimeter RIGOL DM3051 (5¾ digits, USB interface)

Software:

1. A program DATA4711 to handle ADC/ DAC multifunction module ADVANTECH USB4711
2. Software for oscilloscope ULTRASCOPE FOR DS1000E series type of oscilloscopes.
3. Microsoft Office Excel to handle data collected by instruments

THEORY

INTRODUCTION

One of the main task in measurement technics is characterisation of parameters of signals, which have a various waveform. This is mainly needed for automatic control to identify dynamic properties of processes and objects. Signal generators or function generators are electronic devices that generate repeating or non-repeating electronic signals.

The most common waveform are a sine wave. A half-wave rectified sine, a full-wave rectified sine and others like square, triangular sawtooth, step (pulse), stairs, cardio (representing heartbeat), earth quake, and audio frequency modulation waveforms like amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM) and so on are in use for many purposes in testing and excitation.

Waveform means the shape and form of a signal such as a wave moving in a physical medium or an abstract representation.

BASIC PARAMETERS OF PERIODICAL SIGNALS

Signals are analogue or digital electrical representations of time-varying or space-varying physical quantities. Signals exhibit diversity in function and structure. The two main ways of describing signals concentrate either upon their time domain properties or their frequency domain properties. A complete time-domain description of a sine signal can be represented by (1)

$$x(t) = x(t + kT) \tag{1}$$

where: T – period of the signal.

The relation (1) defines an analogue signal – continuous form. The other form describe range of discrete values stated in particular moments of time. The discrete form of signal presentation is given by Eqn. 2 and it is a series of indexed numerical values x(n)={x(0),x(1) .... x(n)} :

$$x(n) = x(n + kN) \tag{2}$$

where: N – period of discrete signal.

A signal in time domain, which satisfies Dirichlet conditions can be expressed by Fourier series Eqn.3 or as a linear combination of DC and variable components called shortly sine harmonics, harmonic components.

$$x(t) = X_0 + \sum_{n=1}^{\infty} X_{\mathrm{n}} \sin(n\omega t + \varphi_{\mathrm{n}}) \tag{3}$$

where:

X_0 – constant component,

X_n – amplitude of n-th harmonic,

φ_n – phase shift of n-th harmonic,

$n\omega$ – angular frequency of n-th harmonic .

If a signal contains more then one harmonic, then is called multi-harmonic.

In engineering practice, the multi-harmonic signals are very commonly used. Response of nonlinear system (do not satisfy the principle of superposition) to induced a sine signal will be distorted

The parameters listed below are used to describe periodical waveforms: sinusoidal and non-sinusoidal (multi-harmonic signals):

The maximum value of signal:

$$X_{\mathrm{MAX}} = \max|x(t)| \tag{4}$$

$$X_{\mathrm{MAX}} = \max|x(n)| \tag{5}$$

The average value of signal calculated over one period of waveform:

$$X_0 = \frac{1}{T}\int_0^T x(t)dt \tag{6}$$

The average value of signal calculated as the modulus over one period of the waveform:

$$X_{\mathrm{AVG}} = \frac{1}{T}\int_0^T |x(t)|dt \tag{8}$$

$$X_{\mathrm{AVG}} = \frac{1}{N-1}\sum_{n=0}^{N-1} |x(n)| \tag{9}$$

RMS value of the signal calculated over one period of waveform:

$$X_{RMS} = \sqrt{\frac{1}{T}\int_0^T x^2(t)dt} \tag{10}$$

$$X_{RMS} = \sqrt{\frac{1}{N-1}\sum_{n=0}^{N-1} x^2(n)} \tag{11}$$

Waveform Factor:

$$\mathrm{k_k} = \mathrm{k_{WF}} = \frac{X_{\mathrm{RMS}}}{X_{\mathrm{AVG}}} \tag{12}$$

Crest Factor:

$$\mathrm{k_S} = \mathrm{k_{CF}} = \frac{X_{\mathrm{MAX}}}{X_{\mathrm{RMS}}} \tag{13}$$

The total harmonic distortion, or THD, of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency given by 14 or 15. It might be expressed in percentage.

$$\mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} X_n^2}}{X_1} \tag{14}$$

$$\mathrm{THD_{RMS}} = \frac{\sqrt{X_{\mathrm{RMS}}^2 - X_{1\,\mathrm{RMS}}}}{X_{1\,\mathrm{RMS}}} \tag{15}$$

Distortion factor of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the waveform (the fundamental frequency and all harmonic components. It might be expressed in percentage.:

$$\mathrm{THD_n} = \frac{\sqrt{\sum_{n=2}^{\infty} X_n^2}}{\sqrt{\sum_{n=1}^{\infty} X_n^2}} \tag{16}$$

A decibel scale is used to determine the values of signals changing in very broad range in relation to the agreed reference value. Formulae (17) and (18) define the effective values of the signal level, relative to 1V and 1μV expressed in decibels respectively

$$X_{\mathrm{dBV}} = 20 \cdot \log_{10}\left(\frac{X_{\mathrm{RMS}}}{1\mathrm{V}}\right) \tag{17}$$

$$X_{\mathrm{dB}\mu\mathrm{V}} = 20 \cdot \log_{10}\left(\frac{X_{\mathrm{RMS}}}{1\mu\mathrm{V}}\right) \tag{18}$$

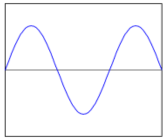
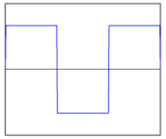
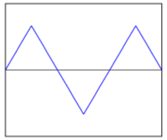
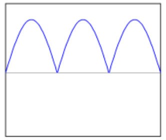
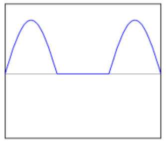
Attenuation or gain presented as a ratio of the amplitudes of the output signal to the input signal expressed in decibels is given by:

$$X_{\mathrm{dB}} = 20 \cdot \log_{10}\left(\frac{X_{\mathrm{OUT}}}{X_{\mathrm{IN}}}\right) \tag{19}$$

Signal to Noise Ratio (dynamics of the signal) expressed as the ratio of the square of the amplitude of the signal to square of noise, or as the ratio of the amplitude of the signal to amplitude of noise is given by:

$$\mathrm{SNR}_{\mathrm{dB}} = 10 \cdot \log_{10}\left(\frac{X_{\mathrm{MAX}}^2}{X_{\mathrm{NOISE}}^2}\right) = 20 \cdot \log_{10}\left(\frac{X_{\mathrm{MAX}}}{X_{\mathrm{NOISE}}}\right) \tag{20}$$

Table 1. Table of typical parameters for a selection of periodic signals

Waveform / Waveform type		*Mean magnitude (rectified)* X_{AVG}	*RMS value* X_{RMS}	Waveform factor k_k	Crest factor k_s	Crest factor k_s in dB	Total harmonic Distortion THD	Distortion factor: Total harmonic Distortion THD_n
	Sine wave	$\frac{2}{\pi} \approx 0{,}637$	$\frac{1}{\sqrt{2}} \approx 0{,}707$	$\frac{\pi}{2\sqrt{2}} \approx 1{,}11$	$\sqrt{2} \approx 1{,}414$	3.01 dB	0	0
	Square wave	1	1	1	1	0 dB	$\approx 0{,}483$	$\approx 0{,}435$
	Triangle wave	$\frac{1}{2} = 0{,}5$	$\frac{1}{\sqrt{3}} \approx 0{,}577$	$\frac{2}{\sqrt{3}} \approx 1{,}155$	$\sqrt{3} \approx 1{,}732$	4.77 dB	$\approx 0{,}121$	$\approx 0{,}120$
	full-wave rectified sine	$\frac{2}{\pi} \approx 0{,}637$	$\frac{1}{\sqrt{2}} \approx 0{,}707$	$\frac{\pi}{2\sqrt{2}} \approx 1{,}11$	$\sqrt{2} \approx 1{,}414$	3.01 dB	$\approx 0{,}225$	$\approx 0{,}219$
	half-wave rectified sine	$\frac{1}{\pi} \approx 0{,}318$	$\frac{1}{2} = 0{,}5$	$\frac{\pi}{2} \approx 1{,}571$	2	6.02 dB	$\approx 0{,}441$	$\approx 0{,}401$

EXPERIMENT:

TASK 1:

Determination of the mean value and RMS by different measurement techniques

RMS value X_{RMS} and average value X_{AVG} of a periodic signal might be determined by the following methods:

A) **Method "A"** using an automatic measurement functions of the oscilloscope,
B) **Method "B"** by means of two multimeters, RIGOL and METES
C) **Method "C"** by means of dedicated transducers IC RMS / DC AD637,
D) **Method "D"** by collecting discrete values using ADC, followed by calculations. Use EXCEL for calculations.

Method "A" – Wire the output terminal of the signal generator to oscilloscope input and use the automatic measurement function of the oscilloscope. Record values of: amplitude, peak to peak, frequency, RMS and the average of the selected signals, (Table 2):

- 1: SIN (Sine wave)
- 2: SQUARE (Square wave)
- 3:TRIANG (Triangle wave)
- 14 COMMUTE - FU (full-wave rectified sine)
- 15 COMMUTE - HH (half-wave rectified sine)

Waveform parameters: frequency of 50 Hz, Voltage peak-to-peak equal to 2 V.

Table 2. Measurement results from oscilloscope.

Type of signal	Generator DF1410 function	V_{AMP}	V_{PP}	f	*RMS value* V_{RMS}	*Mean* V_{AVG}
-	-	V	V	Hz	V	V
Sine wave	1: SIN					
Square wave	2: SQUARE					
Triangle wave	3:TRIANG					
Full-wave rectified sine	14 COMMUTE - FU					
Half-wave rectified sine	15 COMMUTE - HH					

Method "B" - For the same selection of signals as in method A determine RMS and frequency of the signals by means of multimeters: RIGOL and METEX.

Measurement results record In Table 3.

Table 3. Measurement results from multimeters

Type of signal	Generator DF1410 function	(RIGOL DM3051)		METEX 3270D	
		RMS value V_{RMS}	f	*RMS value* V_{RMS}	f
-	-	V	Hz	V	Hz
Sine wave	1: SIN				
Square wave	2: SQUARE				
Triangle wave	3:TRIANG				
Full-wave rectified sine	14 COMMUTE - FU				
Half-wave rectified sine	15 COMMUTE - HH				

Method "C" For the same selection of signals as in method A determine RMS of the signals using "RMS/DC transducer". RMS/DC transducer is based on IC AD637 and is placed inside a grey box. Wire DC voltmeter (RIGOL DM3051) to the out of transducers. Inputs and outputs according to terminals presented in Fig. 1. Wiring of "RMS/DC transducer" based on IC AD637. IC diagram is given in Fig.2.

Wire the output of signal generator to V_{IN}AD637 a BNC5 input of "grey box

Wire Rigol input – VDC mode to 3A & 3B – OUTPUT V_{RMS}[V] in Volts of "RMS/DC transducer" of grey box

Rigol (DC input) indicates the RMS value of the signals applied to the input of "RMS transducers". Record measurements in the table 4.

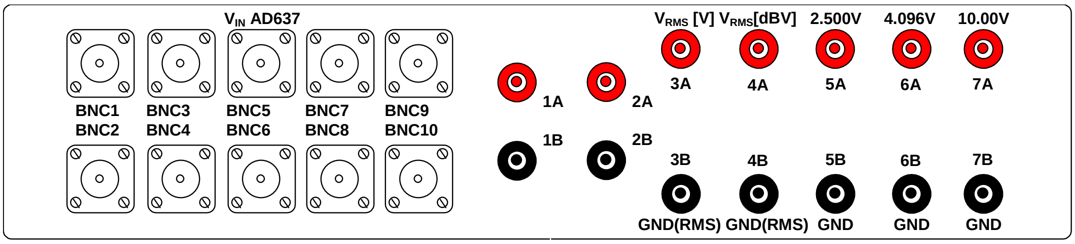


Fig. 1. Terminals of laboratory measurement devices housing – to wire RMS/DC

Application scheme of IC AD637 is presented in Fig. 2.

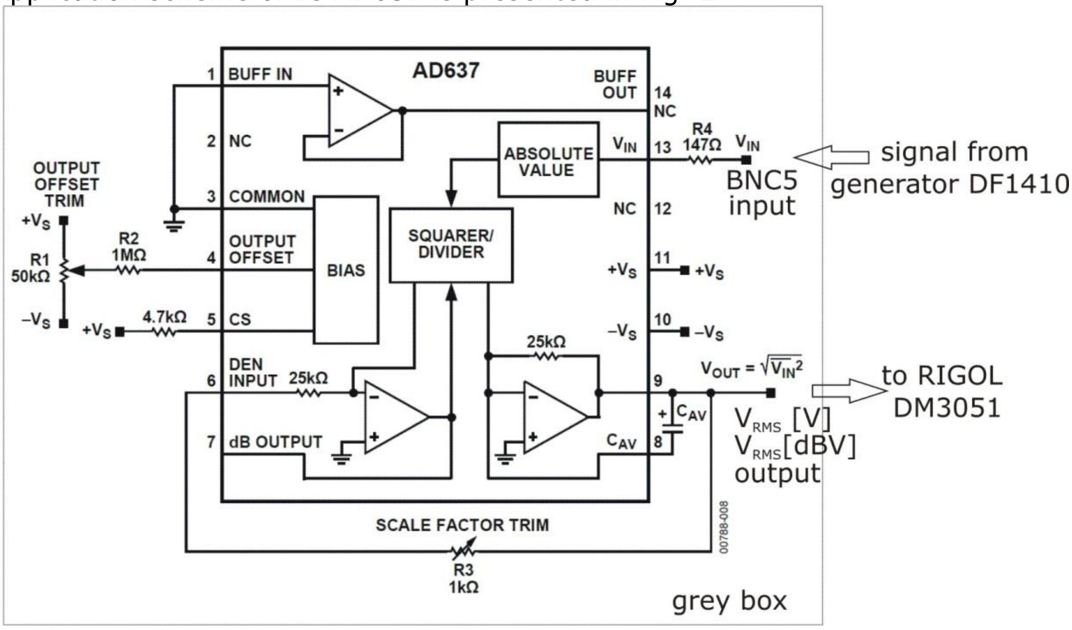


Fig. 2. Application scheme of Analog Devices IC AD637 (RMS/DC transducer)

Table 4. Measurement results of signals – RMS/DC transducer readings from RIGOL DM3051.

Type of signal	Generator DF1410 function	*RMS value* V_{RMS} (RIGOL DM3051)	*RMS value* V_{RMS} (calculated based on formula 17)
-	-	V	dBV
Sine wave	1: SIN		
Square wave	2: SQUARE		
Triangle wave	3:TRIANG		
full-wave rectified sine	14 COMMUTE - FU		
half-wave rectified sine	15 COMMUTE - HH		

Method "D" Use the ADC/DAC multifunction module of Advantech type: USB4711 to sample 5 waveforms (Sampling rate: 20000 Sa/s and collect discrete values for one period). Next, using Microsoft EXCEL or any other calculation supporting package, calculate parameters of tested signals. Record calculation results in Tab. 5.

Wire the output of signal DF1410generator to $V_{IN\ A}$ of USB4711 of of terminal is placed at front terminal panel (see Fig. 3.) Multifunction ADC card USB4711 is connected to PC computer using USB interface. The sampled data are handled by a specialised piece of software (via USB using " program DATA4711 to handle ADC/ DAC multifunction module ADVANTECH USB4711"), which collected data stores in text file of *.txt format.

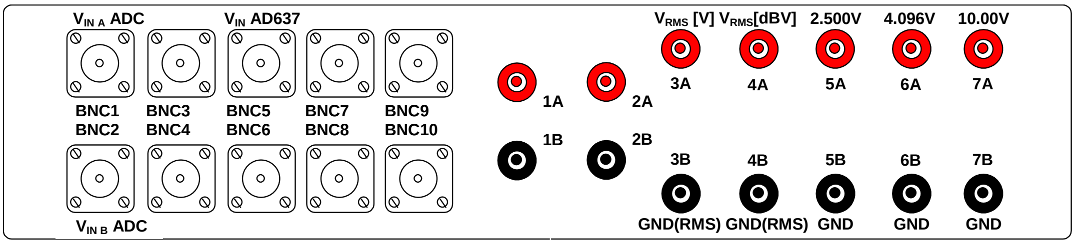


Fig . 3. Output of signal Generator connect to "V_{INA} ADC" terminals which is an input of USB4711 ADC; output of USB4711 ADC is connected to PC via USB; use application: "DATA4711.exe" to control ADSC from PC.

To set up parameters of US4711 proceed as follows:

- Select INPUT A as a ADC input
- Set the input voltage range of the optimal value according to the V_{pp} from signal generator DDS DF1410,
- From the list of sampling frequency of USB 4711 select a frequency at least 10 times higher then signal frequency,
- Select the number of samples to be collected during data acquisition for two periods of signal under test.

Using Office Excel spreadsheet calculate the average, RMS, waveform factor, crest factor using the formulas 9, 11, 12 and 13. Record calculation results in Table 5

Table 5 The results of calculations of signal parameters using the measurement card Advantech USB4711

Type of signal	Generator DF1410 function	*RMS value* V_{RMS}	*Mean* V_{AVG}	Waveform factor k_k	Crest factor k_s	Crest factor k_s
-	-	V	V	-	-	in dB
Sine wave	1: SIN					
Square wave	2: SQUARE					
Triangle wave	3:TRIANG					
Full-wave rectified sine	14 COMMUTE - FU					
Half-wave rectified sine	15 COMMUTE - HH					

Comparison of results and error of <u>4 "A", "B", "C" and "D" methods</u>

Applying formula (21) and values indicated in Tab. 1 as a reference value for all applied methods, please complete tab. 6.

Explain the dispersion of RMS values obtained by various methods. Indicate the most accurate method.

Table 6 Comparison of measurements and calculations of effective runs by all methods

RMS value/ error	Theoretical Value	Method **A** **Oscilloscope (Measure)**	Method **B** **RIGOL DM3051**	Method **B** **METEX 3270D**	Method **C** **IC RMS / DC AD637**	Method **D** **ADC & calculation**
	1: SIN - Sine wave signal					
V_{RMS} [mV]	0707					
δV_{RMS} [%]						
	2: SQUARE - Square wave					
V_{RMS} [mV]	1000					
δVRMS [%]						
	3:TRIANG - Triangle wave					
V_{RMS} [mV]	57 0					
δV_{RMS} [%]						
	14 COMMUTE - FU full-wave rectified sine					
V_{RMS} [mV]	707					
δV_{RMS} [%]						
	15 COMMUTE - HH half-wave rectified sine					
V_{RMS} [mV]	500					
δV_{RMS} [%]						

Use Equ. (21) to calculate relative RMS measurement error:

$$\delta \mathrm{V}_{\mathrm{RMS}} = \left(\frac{V_{\mathrm{RMS}} - V_{\mathrm{RMS\ (table\ 1)}}}{V_{\mathrm{RMS\ (table\ 1)}}} \right) 100\% \qquad (21)$$

TASK 2

THD coefficients

In order to determine the values of THD% THDN% THDRMS of multi-harmonic signals you can use the FFT RIGOL DS1052E Digital Oscilloscope menu MATH/OPERATE -> FFT. A spectrum of input signal can be presented on oscilloscope screen. Amplitudes of Fast Fourier Transform components are displayed vs. Frequency. Using the XY cursors, it is possible identify precisely values of amplitude and frequency of the individual harmonics. Figure 4 presents an example of the spectrum of the triangular signal.

Use : Ultrascope for DS 1000E Series. Exe application to cobtrol osclioscope from PC. Export .bmp format files of performed measurements.

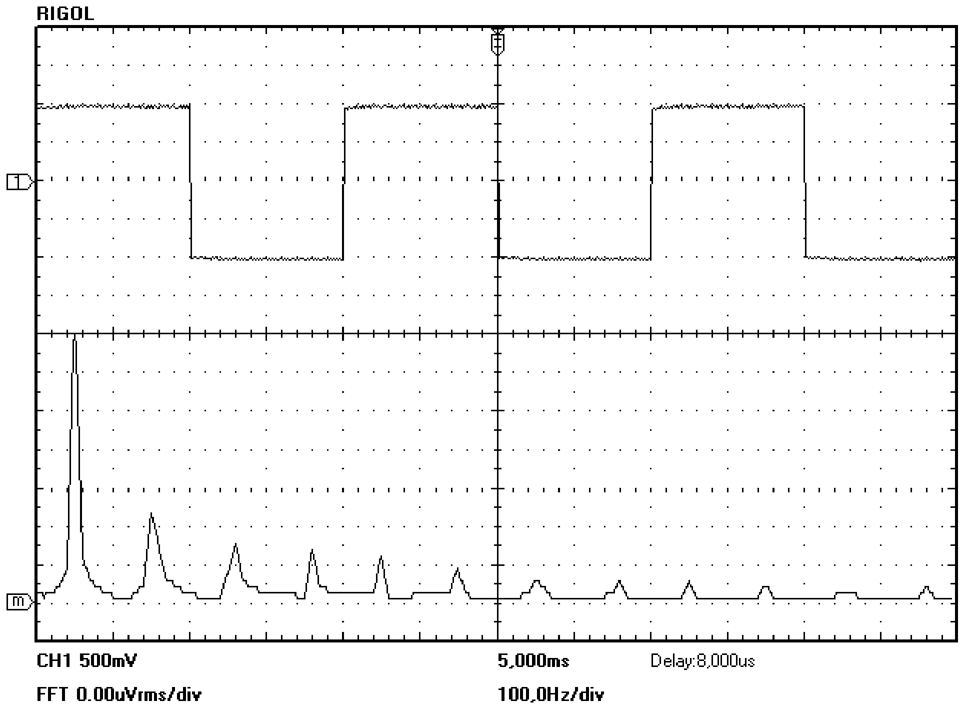


Fig. 4. Spectrum of the Square wave signal with identification of harmonics to THD calculation.

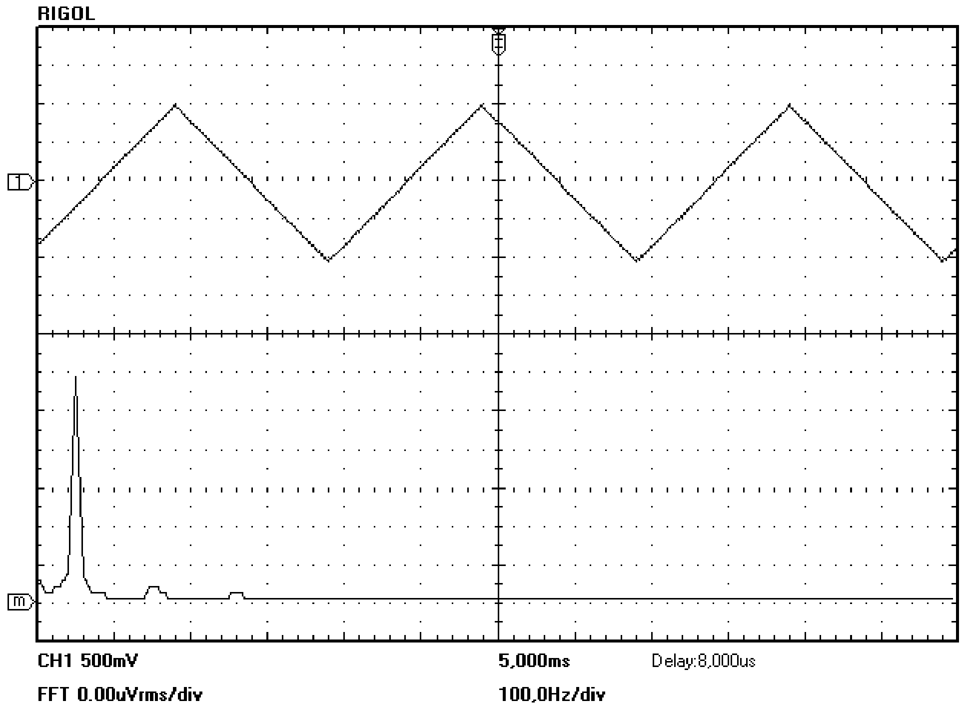
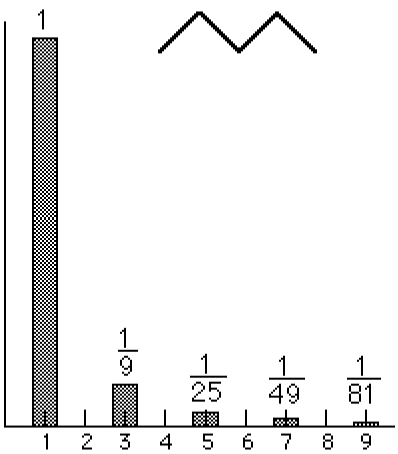


Fig. 5. Spectrum of the Triangle wave with identification of harmonics to THD calculation

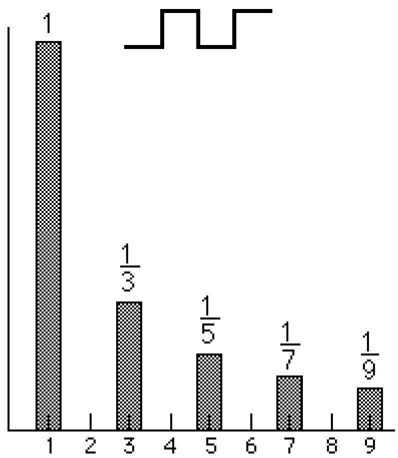


Harmonics for Triangle wave

The triangle wave contains only odd harmonics with the amplitudes

$$A_n = \frac{1}{n^2} A_1$$

http://hyperphysics.phy-astr.gsu.edu/hbase/audio/geowv.html#c1

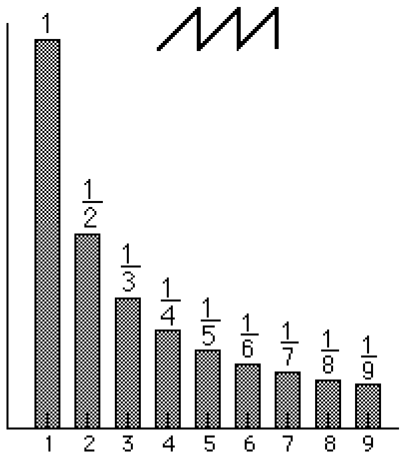


Harmonics for Square wave

The square wave contains only odd harmonics with the amplitudes

$$A_n = \frac{1}{n} A_1$$

the transform of a square wave shows that is has only odd harmonics and that the amplitude of those harmonics drops in a geometric fashion, with the nth harmonic having 1/n times the amplitude of the fundamental



$A_n = \frac{1}{n} A_1$ The sawtooth wave is useful for synthesis since it contains all harmonics in the geometric ratio

Table 7. The results of measured harmonic components and calculations of $THD_{\%}$, $THD_{N\%}$, THD_{RMS} coefficients.

	V_N Amplitude of the n-th harmonic	$V_{N\ RMS}$ RMS value of the n-th harmonic	f_N Frequency of the n-th harmonic	THD	THD_n	THD_{RMS}
	V	V	Hz	-	-	-
Signal / harmonic	2: SQUARE - Square wave					
V_1						
V_3						
V_5						
V_7						
V_9						
V_{11}						
......						
Signal / harmonic	3:TRIANG - Triangle wave					
V_1						
V_3						
V_5						
V_7						

......						

USEFULL FORMULAS

Several useful formulas to calculate parameters o signals presented in discrete form:

Average value over an internal

$$\bar{x} = \frac{1}{n_2 - n_1 + 1} \sum_{n=n_1}^{n_2} x(n)$$

Average value over the whole signal

$$\bar{x} = \lim \frac{1}{2N+1} \sum_{n=-N}^{N} x(n)$$

Average value over a period of signal

$$\overline{x_N} = \frac{1}{N} \sum_{n=n_0}^{n_0+(N-1)} x(n), \quad N - period$$

Power of the whole signal expressed in a discrete form

$$E_x = \sum_{n=-\infty}^{+\infty} x^2(n)$$

Average power of the signal over an interval

$$P_x = \overline{x^2} = \frac{1}{n_2 - n_1 + 1} \sum_{n=n_1}^{n_2} x^2(n)$$

Average power of the whole signal over an interval

$$P_x = \bar{x} = \lim \frac{1}{2N+1} \sum_{n=-N}^{N} x^2(n)$$

Average power of the periodical signal (over a period)

$$P_x = \overline{x^2{}_N} = \frac{1}{N} \sum_{n=n_0}^{n_0+(N-1)} x^2(n), \quad N - period$$

RMS value signal in a discrete form

$$x_{RMS} = \sqrt{P_x}$$

FINAL CONCLUSIONS AND REMARKS

LITERATURE AND OTHER RECOMMENDED MATERIAL

1. Joseph McGhee, Wlodek Kulesza, M. Jerzy Korczyński, I. A. Henederson, Scientific Metrology, Published by Technical University of Lodz, printed by: ACGM LODART S. A. Łódź, 1998, ISBN 83-904299-9-**3,**
2. Joseph McGhee, Wlodek Kulesza, M. Jerzy Korczyński, I. A. Henederson, Measurement Data Handling Theoretical Technique, Published by Technical University of Lodz, printed by: ACGM LODAR S. A. Łódź, 2001, ISBN 83-7283-007-X, pages 267

Additional information:

1. http://support.elmark.com.pl/advantech/pdf/iag/USB-4711-manual.pdfInstruments' manuals
2. DS1000D-DS1000E Manual.pdf http://www.rigolusa.com/support/usermanuals.html

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LABORATORY OF MEASUREMENTS

EXPERIMENT NO:	**3**
EXPERIMENT TITLE:	**Identification of basic parameters of electrical signals**

LABORATORY GROUP		***Program/Term***	
No.	***STUDENT'S NAME***		***ID***
1			
2			
3			
4			

Lecturer:	
Data date of experiment:	
Data of submitted report :	
Mark:	
Comments	