Technical University of Lodz

Department of Semiconductor and Optoelectronics Devices, K-27

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MEASUREMENTS –
LABORATORY EXPERIMENTS

LABORATORY EXPERIMENT No **2**

CALIBRATION OF DIGITAL MEASURING INSTRUMENTS

Lodz; spring term 2009/10

Goal:

The main goal of the experiment is to familiarise students with digital measuring instruments calibration methods and with application of electronic reference working standards to verify accuracy of instruments specified in instrument technical data.

SPECIFICATION OF USED INSTRUMENTS:

The following instruments and software are used:

Instruments

1. Desk top digital sampling multimeter RIGOL DM3051 (5¾ digits, USB interface)
2. Hand held digital multimeter APPA model 109N (4 digits of reading)
3. Hand held digital multimeter Metex model M-3278 (3½ digits)
4. Hand held analogue multimeter type PROTEK HD-3030S
5. Set of working standards – reference sources of voltage, resistance and frequency (artefact standards)

Software:

1. Data acquisition software data logger DATALOG do collecting data from multimeter RIGOL DM3051
2. Software DATA4711 to control waveform generator of type DS1307
3. Microsoft Office Excel to handle data collected from instruments

THEORY

Calibration is one of the very basic metrological activity to assure accuracy of measuring equipment. and is very important from the point of view of technical supervision of measuring instruments and indicators. Calibration is carried out primarily to ensure the reliability of measurement results indicated by instruments.

Definition of calibration:
Calibration by definition is an operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

It is very important not to confuse calibration confused with adjustment of a measuring system, often mistakenly called "self-calibration", nor with verification of calibration

Calibration consists of two steps but the first step alone in the above definition is perceived as being calibration.

Calibration assures tractability to the International Standards via unbroken chain of comparisons.

Documentation from the calibration process is used to issue certificate of calibration. If a certificate of calibration has been carried out and proves that the instrument comply certain metrological requirements by legal notified measurement body (in Poland GUM Central Office of Measures and regional offices or other authorised body) then the instrument may get **certificate of legalisation**. Especially it is required for all instruments used for commercial purposes.

As far as all measuring equipment is concern there is a general rule, that instruments should be calibrated periodically to check their specified accuracy stated in technical specification delivered by instrument manufacturer. Instruments used in quality control process, measurement results must be traceable to International standards, and it must be confirmed by legal documentation.

Most of measuring instruments specification suggest to perform calibration process yearly.

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Some important remarks referred to calibration;

1. The instruments used In:
   - Half and life protection purposed and for environment monitoring,
   - Public safety ,
   - Protection of consumer rights,
   - Fees, legal taxes and other public duties purposes
   - custom duty purposes,
   - public trade

   must have a valid legalisation documents
2. Always calibration process must be traceable to the International Standards
3. Tradability to International standards must be documented and any stage of calibration
4. Calibration might be performer by end user if the reference standard is have a valid calibration certificate.
5. Verification of accuracy parameters specified by instrument manufacturer is a statement that instrument after calibration confirm specified data presented by manufacturer
6. Calibration certificate Has a special form and the example is presented in task 1 of the experiment

EXPERIMENT:

TASK 1:

DC Calibration of resistance of nominal value of 1000Ω as working standard

The procedure of calibration is performed as direct comparison of resistor vs. Reference resistor with valid certificate off calibration, using digital multimeter RIGOL DM3051.

Unit Under Test, UUT, (resistor) R_{WX} and reference resistor R_{WREF} should be wired applying 4-wire connection (Kelvin 4-wire) as it is presented in Fig. 1. Before calibration is performed UUT R_{WX} should be thermally stabilised for 15 minutes in measurement laboratory environment (room temperature).

Next required adjustments:

- Choose relevant range of multimeterDM3051,
- Switch mode of 4-wire resistance measurement,
- Note the average room temperature as a mean between temperature at the beginning of stabilisation process and after 15 minutes,

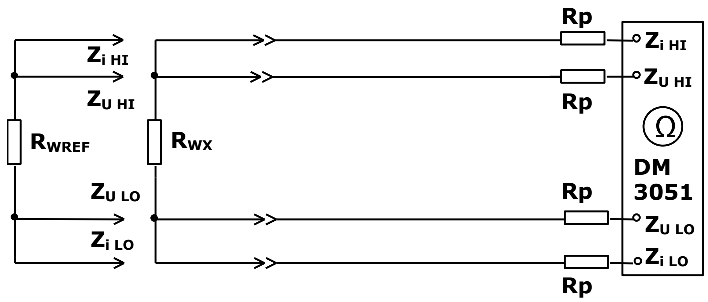

Fig.1 $-wire connection of UUT and Reference resistor with ohmmeter of DM3051

R_{WX} – Unit under test (UUT); R_{WREF} – working standard, reference resistance;

R_P – wiring resistance; Z_I – multimeter terminals;

$Z_{U\ Hi}$, $Z_{U\ Lo}$, - Voltage terminals of the multimeter;

$Z_{I\ Hi}$, $Z_{I\ Lo}$, - Current terminals of the multimeter;

Parameters of UUT (tested resistor) type RN37 by Tyco Electronics:

- R_N = R_{NX} =R_{NREF}=1000Ω (nominal resistance of both resistors)
- Accuracy: ±0,01%
- Temperature coefficient ΔR_T: 5ppm/°C (ΔR_{TWX}, ΔR_{TWREF})
- Nominal reference temperature 23°C
- Maximum power consumption at 70°C: 0,1W
- Withstand voltage: 100V

Carry out 5 measurements at internal of 1 minute and record data In Tab. 1.

i-number of measurement	$R_{i\ WX}$	$R_{i\ WREF}$	r	r_C	ΔR_{TWX} ΔR_{TWREF}	ΔR_{DWREF}
	Ω	Ω	-	-	Ω	Ω
1						
2						
3						
4						
5						

The resistance of resistor under test R_{WX} can be calculated from Equ. (1):

$$R_{WX} = \left(R_{WREF} + \Delta R_{DWREF} + \Delta R_{TWREF}\right) \cdot r \cdot r_C - \Delta R_{TWX} \tag{1}$$

where:

R_{WX} – resistance value of the resistor under test,

R_{WREF} – resistance value of the standard resistor,

r_i – a quotient of resistances of UUT to standard resistor given by (2)

$\bar{r}$ – average value of the quotient from 5 observations in this case given by (3),

$s(\bar{r})$ – experimental standard deviation of the quotient given by (4),

$$r_i = \frac{R_{i\,WX}}{R_{i\,WREF}} \tag{2}$$

$$\bar{r} = \frac{1}{i}\sum_{n=1}^{i} r_n \tag{3}$$

$$s(\bar{r}) = \sqrt{\frac{\frac{1}{i-1}\sum_{n=1}^{i}(r_n - \bar{r})^2}{i}} \tag{4}$$

r_C – correction coefficient taking into account resolution of applied measuring instrument (multimeter) given by (5),

$$r_C = 1 + \frac{s(\overline{R_{i\,WX}}) - s(\overline{R_{i\,WREF}})}{R_N} \tag{5}$$

$\overline{R_{\text{i WX}}}$ – average value tested resistor under test; $R_{\text{i WX}}$ calculated in this case for 5 observations ,

$\overline{R_{\text{i WREF}}}$ – average value reference resistor $R_{\text{i WREF}}$ calculated in this case for 5 observations,

$s(\overline{R_{\text{i WX}}})$ – experimental standard deviation of UUT R_{WX} calculated in this case for 5 observations (6),

$$s(\overline{R_{\text{iWX}}}) = \sqrt{\frac{\frac{1}{\text{i-1}}\sum_{n=1}^{\text{i}}(R_{\text{nWX}} - \overline{R_{\text{iWX}}})^2}{\text{i}}} \quad (6)$$

$s(\overline{R_{\text{i WREF}}})$ – experimental standard deviation of reference resistor R_{WREF} calculated in this case for 5 observations (7),

$$s(\overline{R_{\text{iWREF}}}) = \sqrt{\frac{\frac{1}{\text{i-1}}\sum_{n=1}^{\text{i}}(R_{\text{nWREF}} - \overline{R_{\text{iWREF}}})^2}{\text{i}}} \quad (7)$$

ΔR_{DWREF} – error due to drift of reference resistance

ΔR_{TWREF} – error due to temperature drift of reference resistance (8)

ΔR_{TWX} – error due to temperature drift of resistor under test. (8)

T – room temperature at the time of calibration

T_{REF} – reference room temperature in which standard resistor was calibrate - 23°C

$$\Delta R_{\text{TWX}} = \Delta R_{\text{T}} \cdot R_{\text{NX}}(T - T_{\text{REF}})$$
$$\Delta R_{\text{TWXREF}} = \Delta R_{\text{T}} \cdot R_{\text{NREF}}(T - T_{\text{REF}}); \quad 1\text{ppm} = 10^{-6} \quad (8)$$

$R_{\text{i WX}}$ – i- number of measurement observation result of resistor under test

$R_{\text{i WREF}}$ – i- number of measurement observation result of reference resistor

ΔR – error due to finite resolution of instrument RIGOL (data from specification))

R_{N},R_{NWX},R_{NWREF} – nominal resistance , nominal resistance of resistor under test and reference resistor(1000Ω)

Table 2. Budget of uncertainties of Unit under test – resistor of 1000 Ω

Symbol of quantity	Quantity value	Standard uncertainty		Type of distribution	Sensitivity factor	Uncertainty contributing Value $u_i(R_{WX})$
	Ω	Ω		-	-	Ω
R_{WREF}		$u(R_{WREF})$		Normal	1.0	
ΔR_{DWREF}		$u(R_{DWREF})$		Uniform	1.0	
ΔR_{TWREF}		$u(R_{TWREF})$		Uniform	1.0	
ΔR_{TWX}		$u(R_{TWX})$		Uniform y	1.0	
r_C		$u(r_C)$		Triangular	1000 Ω	
r		$s(\bar{r})$		Normal	1000 Ω	
R_{WX}						

Combined standard uncertainty $u_i(R_{WX})$ of type A and B perform according information delivered in Exp. 1. Value of each contributing component is a product of standard uncertainty and sensitivity factor. For rectangular distribution: type B uncertainty is calculated as follows: ΔR_{DWREF} / √3; ΔR_{TWREF}/ √3; ΔR_{TWX}/ √3. Value of standard uncertainty of $u(r_c)$ is given by (9),

$$u(r_C) = \sqrt{\frac{2C_R^{\ 2}}{R_N^2}} \tag{9}$$

C_R – resolution of used instrument in this case C_R =0.01 Ω,

$R_N=R_{NWX}=R_{NWREF}$=1000Ω – nominal resistance of resistor under test and reference resistor(1000Ω)

Calculation of expanded uncertainty U_{RW} is given (10) in which k – is an expanded coefficient and $u_i(R_{WX})$ is a combined standard uncertainty:

$$U_{RW} = k \cdot u_i(R_{WX}) = \\ = k \cdot \sqrt{u(R_{WREF})^2 + u(R_{DWREF})^2 + u(R_{TWREF})^2 + u(R_{TWX})^2 + u(r_C)^2 + u(r)^2} \tag{10}$$

Final presentation the result of calibration should be quoted as follows:

The measured resistance of calibrated 1000Ω standard resistor at a temperature of ....°C and a measuring current of mA is (............ ± ....)Ω.

The uncertainty of measurement stated by multiplying the standard uncertainty of measurement by coverage factor k=..... For a normal it corresponds to a coverage probability of ... %. The standard uncertainty of measurement was determined in accordance with a Gudline EA-4/02.

TASK 2

Veryfication of instrument indications of ohmmeters ranges of multimeters

Check indication of ohmmeters ranges of multimeters, each multimeter should be warmed-up not less ten 1 min. Indication record in tab. 3

Table 3. Cheking multimeters (ohmmeter ranges)

Instrument type	Instrument indication $R_{i\,WX}$	Reference value R_{WX}	Apparent error $\Delta R = R_{WX} - R_{iWX}$	Max. permissible instrument error $\Delta_{lim}R$	Verification result passed/faild
Sub-Ranges	Ω	Ω	Ω	Ω	-
Rigol DM3051					
I - Range 4kΩ					
II - Range 40kΩ					
III - Range 400kΩ					
APPA 109N					
I - Range 2000Ω					
II - Range 20kΩ					
III - Range 200kΩ					
METEX 3270D					
Range (auto)					
PROTEK HC3030S					
I - Range x10Ω					
II - Range x1kΩ					

R_{iWX} – instrument indication of standard resistor R_{WX} AT sub-ranges: I, II, or III
R_{WX} – Value of reference resistor data from TASK 1,
ΔR – *apparent* error ,
$\Delta_{lim}R$ – maximum permissible error – calculation based on instrument technical specification,

Verification result: passed if *ΔR below max. Permissible error otherwise failed*

TASK 3

Verification of instrument indications of DC ranges 2.5÷10V of multimeters

Verification of multimeters working at DC modes is possible to perform with a use of precise voltage reference artefacts. Most of Artefacts are made with an integrated specific sources

1 st. Electronic voltage reference source (working standard):

I. Integrated High Precision Reference Voltage AD780 (Analog Devices) 2.5V/3.0V

Parameters:

- Output voltage at 23°C: Vref=2.500V/3.000V
- Output voltage Accuracy ±0.005V
- Long term stability: ±20ppm/1000 Hrs.
- Output voltage drift for temperature range –40°C+85°C: 7ppm/°C
- Output noise for frequency 0.1-10Hz: 4μVp-p

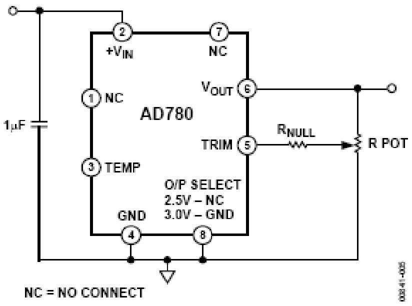

Fig. 2 The artefact standard of 2.500V/3.000V reference voltage based Fine-Trim Circuit of AD780.

2nd. Low Noise Micropower Precision Voltage Reference ADR292 (Analog Devices) 4.096V
Parameters:

- Output voltage at 23°C: U_{rev}=4.096V
- Output voltage Accuracy ±0.006V
- Long term stability: ±50ppm/1000Hrs.
- Output voltage drift for temperature variation –40°C+85°C: 25ppm/°C (max.)
- Output noise for frequency 0.1-10Hz: 12µVp-p
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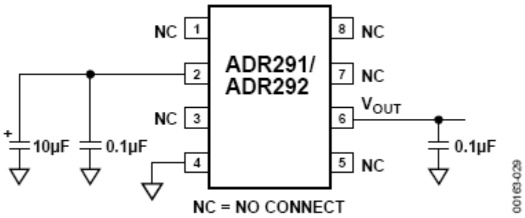


Fig. 3 The artefact standard of 4.096V reference voltage based on IC ADR292.

3rd. Industry-standard precision voltage references REF01C (Analog Devices) 10.00V
Parameters:

- Output voltage at 23°C: U_{rev}=10.00V
- Output voltage accuracy ±0.10V
- Long term stability: ±50ppm/1000godz.
- Output voltage drift for temperature variation –40°C+85°C: 65ppm/°C (max.)
- Output noise for frequency 0.1-10Hz: 15µVp-p

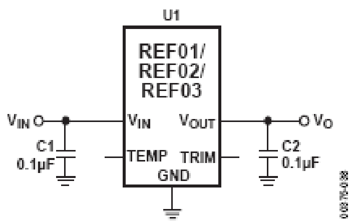
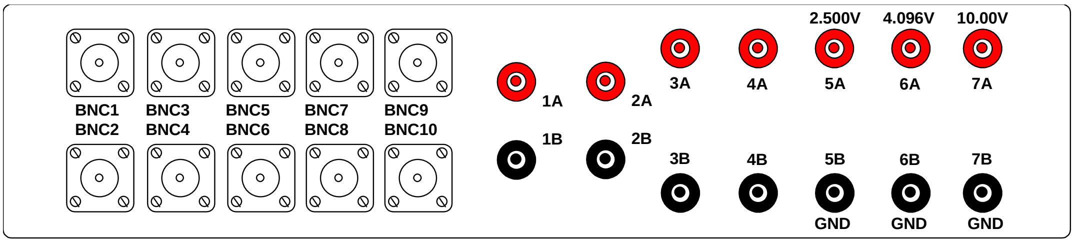


Fig. 4 The artefact standard of 10.00V reference voltage based on IC REF01C.



Terminal at front panel:

- Terminal No 5A – 2.500V/3.000V output (V_{OUT}) of AD780
- Terminal No 6A – 4.096V output (V_{OUT}) of ADR292
- Terminal No 7A – 10.00V output (V_{OUT}) of REF10C
- Terminal No 7B – GND

Wire reference voltage sources to instruments as it is stated in table 4 and record readings from instruments. Data record in Table 4.

Table 4. Data from verification of multimeters at DC modes

Instrument type	Instrument indication $V_{i\ REF}$	Reference value V_{REF}	Apparent error $\Delta V = V_{REF} - V_{i\ REF}$	Max. permissible instrument error $\Delta_{lim}V$	Verification result passed/faild
-	mV	mV	mV	mV	-
Voltmeter Rigol DM3051					
AD780/2.5		2500			
AD292		4096			
REF01C		10000			
Voltmeter APPA 109N					
AD780/2.5		2500			
AD292		4096			
REF01C		10000			
Voltmeter METEX 3270D					
AD780/2.5		2500			
AD292		4096			
REF01C		10000			
Voltmeter PROTEK HC3030S					
AD780/2.5		2500			
AD292		4096			
REF01C		10000			

$V_{i\ REF}$ – i-th instrument indication V_{REF} – best sub-range only
V_{REF} – Reference value
ΔV – apparent error,
$\Delta_{lim}V$ – maximum permissible error – calculation based on instrument technical specification

Verification result: passed if *ΔV below max. Permissible error otherwise failed.*

TASK 4

Verification of instrument indications of frequency modes of instruments by means of reference frequency electronic sources 1,000Hz / 4096Hz / 8192Hz / 32768Hz

The reference frequency appears at the output of pulse train reference generator of which frequencies are fixed to values: 1,000Hz, 4096Hz, 8192Hz, 32768Hz and are generated by IC timer: DS1307 (Maxim IC).

IC timer: RTC DS1307 is wired in the following configuration given in Fig. 5.

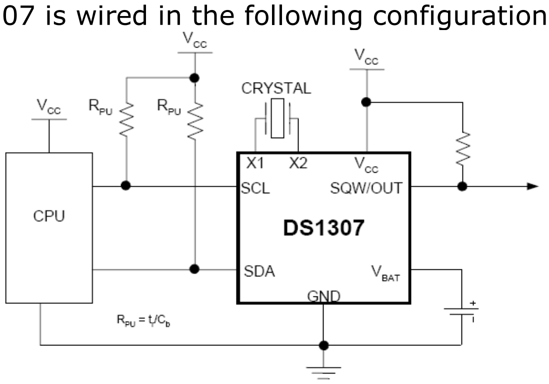


Fig. 5 Electric scheme of artefact standard of frequency based on DS1307.

SQW/OUT is an signal output of reference frequency connected to front panel of laboratory stand at BNC7 terminal.
Output frequency choosing values and switching on-off of output at SQW/OUT is performed from software packed DATA4711.exe/ Generator DS.

Reading from instruments record in Table 5

Table 5. Verification of frequency ranges of multimeters.

Reference frequency	Instrument indication $f_{i\ REF}$	Reference value f_{REF}	Apparent error $\Delta f = f_{REF} - f_{i\ REF}$	Max. instrument permissible error $\Delta_{lim} f$	Verification test passed/faild
Hz	Hz	Hz	Hz	Hz	-
Rigol DM3051					
1.000					
4096					
8192					
32768					
APPA 109N					
4096					
8192					
32768					

$f_{i\ REF}$ – Reading from measurement instrument from the most suitable sub-range of f_{REF} wired to input terminals

f_{REF} – value of reference frequency stated in technical specification of the artefact standard.

Δf – apparent error,

$\Delta_{lim} f$ – *Maximum instrument permissible error calculated based on measuring instrument specification.*

u,

Verification result: passed if *ΔV below max. Permissible error otherwise failed.*

FINAL REMARKS

LITERATURE AND OTHER RECOMMENDED MATERIAL

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Additional information:

Prawo o miarach - Dz.U. 2004 Nr 243 poz. 2441 z 4 listopada 2004

Norma PN-EN ISO 10012:2004 **Systemy zarządzania pomiarami** -- Wymagania dotyczące procesów pomiarowych i wyposażenia pomiarowego

Technical University of Lodz
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ELECTRONIC MEASUREMENT LAB.

EXPERIMENT No:	
TITLE:	

Laboratory Group		***Telecommunication and Computer Science***	
no.	***Name and Surname***		***Student ID***
1			
2			
3			
4			

Lecturer:	
Date of experiment:	
Date of report presentation:	
Mark:	
Remarks:	