The Essential Reference Guide to

SOURCES OF UNCERTAINTY IN MEASUREMENT FOR EVERY Uncertainty Budget

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Sources of Uncertainty in Measurement
For Every Uncertainty Budget

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Introduction

Have you ever wondered what sources of uncertainty in measurement to include in your uncertainty budget? I have, and I am sure that you have too.

Today, I am going to teach you 8 sources of uncertainty in measurement that should be include in **every** uncertainty budget. The reason that you should include these uncertainty sources each time is because they typically influence every measurement that you will ever make.

To give you another reason to use these sources of uncertainty in measurement, consider that these are common uncertainty contributors that are being required by many accreditation bodies. Just check A2LA's R205 Requirements Document and scroll down to section 6.7.1.

6.7 Requirements for CMC Uncertainty Calculations on the Scope of Accreditation

6.7.1 CMC Uncertainty Contributors

1) Every CMC uncertainty shall take into consideration the following standard contributors, even in cases where they are determined to be insignificant, and documentation of the consideration shall be made:

- Repeatability (Type A)[3]
- Resolution
- Reproducibility
- Reference Standard Uncertainty
- Reference Standard Stability
- Environmental Factors

Note: It should be noted that scope components such as resolution, may also contribute to other components such as repeatability. Therefore simply combining all components on an equal basis could result in an overstatement of the measurement uncertainty.

2) The CMC uncertainty shall also:

- Include those significant contributors that apply to the measurement.
- Include those significant contributors required by a method/procedure associated with the measurement.

To help you create better uncertainty budgets and more appropriately estimate measurement uncertainty, I have created a list of 8 sources of uncertainty in measurement that should be in every uncertainty budget.

Furthermore, I am going to go beyond just telling you what these uncertainty sources are, I am going to give you the proper definitions to these uncertainty sources and teach you how to estimate their magnitude.

Sources of Uncertainty

Uncertainty in measurement can be influenced by many different factors. Below is a list of the 6 most common sources of uncertainty in measurement. When you begin to identify sources of measurement uncertainty, you should start by think about influences that are in these categories.

6 common sources of uncertainty in measurement:

- Equipment
- Unit Under Test
- Operator
- Method
- Calibration
- Environment

Sources for Every Uncertainty Budget

Now, I mentioned earlier that I am going to teach you the 8 Sources of Uncertainty in Measurement that should be included in **every** uncertainty budget. The influences that I will cover today are provide in the list below. So, take a look and let me know if I skip anything.

8 Sources of Uncertainty in Measurement that should be included in **every** uncertainty budget:

- Repeatability
- Reproducibility
- Stability
- Bias
- Drift
- Resolution
- Reference Standard
- Reference Standard Stability

Repeatability

Repeatability is a source of uncertainty in measurement that should be included in the every uncertainty budget. It is an influence that you can test yourself to see how much variability is in your measurement results under repeatable conditions.

Most accreditation bodies now require that repeatability is included in your uncertainty analysis. With this type of demand, you will notice more assessors asking to see your Type A data and checking to verify that it is included in your uncertainty budget.

Definition of Repeatability

1: *Measurement precision under a set of repeatability conditions of measurement* (2.20)

To simplify, repeatability is the measurement precision under a set of repeatable conditions. So, to perform a repeatability test, you must continually repeat the measurement process until you record your desired number of samples.

After you have collected your desired number of samples, you can begin to analyze the data to find the random error or variance of your measurement process. This can be accomplished by simply calculating the standard deviation of the set of samples that you have collected.

How to Calculate Repeatability

Follow this instructions to calculate repeatability:

1. Repeat a measurement ‘n’ number of times

2. Record the results of each measurement.

3. Calculate the standard deviation.

Example

Imagine that you need to perform a repeatability test where you collect 20 samples. To find the repeatability of your measurement process, just collect the 20 samples and calculate the standard deviation of your results. The result will be your repeatability.

In the image below, I simulated a set of 20 samples, normally distributed, where the nominal value was 10 and the standard deviation was 5 parts-per-million or ppm. Once the 20 samples were simulated, I calculated the standard deviation of my sample set to determine that repeatability is 4.5 ppm with 19 degrees of freedom. See the highlight red rectangle.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

Just accomplish this using Microsoft Excel, I used the formula:

=stdev(cell1:celln)

	A	B	C	D	E	F	G	H	I	J
1	REPEATABILITY TEST 1									
2										
3	1	10.000038		Mean	10.000005					
4	2	9.999943		StDev	0.000045					
5	3	10.000103		Dof	19					
6	4	10.000022								
7	5	9.999988								
8	6	10.000005								
9	7	9.999977								
10	8	9.999980								
11	9	10.000096								
12	10	9.999943								
13	11	10.000016								
14	12	9.999993								
15	13	10.000072								
16	14	10.000005								
17	15	9.999992								
18	16	9.999992								
19	17	9.999955								
20	18	10.000023								
21	19	9.999997								
22	20	9.999954								
23										

Reproducibility

Reproducibility is a source of uncertainty in measurement that should be included in the every uncertainty budget. It is an influence that you can test yourself to see how much variability is in your measurements under reproducible conditions.

Most accreditation bodies now require that reproducibility is included in your uncertainty analysis. With this type of demand, you will notice more assessors asking to see your Type A data and checking to verify that it is included in your uncertainty budget.

What makes reproducibility different from repeatability is you need to change something (a variable) in your measurement process. Here is a list of the **5 most common comparisons for reproducibility testing**.

5 most common comparisons for reproducibility testing:

- Operator vs Operator Reproducibility
- Equipment vs Equipment Reproducibility
- Method vs Method Reproducibility
- Day vs Day Reproducibility
- Environment vs Environment Reproducibility

Definition of Reproducibility

1: *Measurement precision under reproducibility conditions of measurement* (2.21)

How to Calculate Reproducibility

Follow this instructions to calculate reproducibility:

1. Perform a Repeatability Test

2. Calculate the mean of average

3. Change a variable and repeat the Repeatability Test

4. Calculate the mean or average.

5. Calculate the standard deviation of the test averages.

Example

Imagine that you need to perform a reproducibility test where you want to learn how reproducible your measurement results are when performed with different methods. Let's find the reproducibility of your measurement process.

In the image below, I simulated 2 sets of 20 samples, normally distributed, where the nominal value was 10 and the standard deviation was 5 parts-per-million or ppm. Once the 20 samples were simulated, I calculated the mean (i.e. average) of each sample set.

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

Next, I calculated the standard deviation of the two calculated means to determine that the reproducibility is 14 ppm with 1 degrees of freedom. See the highlight red rectangle.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

Just accomplish this using Microsoft Excel, I used the formula:

=stdev(cell1,cell2)

	A	B	C	D	E	F	G	H	I	J
1	REPRODUCIBILITY TEST 1									
2		Test 1	Test 2		Test 1					
3	1	10.000038	10.000005		Mean	10.000005				
4	2	9.999943	10.000068		StDev	0.000045				
5	3	10.000103	9.999997		Dof	19				
6	4	10.000022	9.999988							
7	5	9.999988	9.999957		Test 2					
8	6	10.000005	9.999973		Mean	9.999985				
9	7	9.999977	9.999999		StDev	0.000042				
10	8	9.999980	9.999959		Dof	19				
11	9	10.000096	9.999959							
12	10	9.999943	9.999914							
13	11	10.000016	10.000037		Reproducibility	0.000014				
14	12	9.999993	9.999954							
15	13	10.000072	10.000043							
16	14	10.000005	9.999918							
17	15	9.999992	9.999982							
18	16	9.999992	9.999994							
19	17	9.999955	9.999945							
20	18	10.000023	10.000027							
21	19	9.999997	9.999950							
22	20	9.999954	10.000028							
23										

Stability

Stability is a source of uncertainty in measurement that should be included in the every uncertainty budget. It is an influence that you can test yourself or calculate from your calibration data to see how much variability is in your measurements over time.

Stability is a random uncertainty. It is commonly confused with Drift, which is a systematic uncertainty (we will cover this later). Essentially, stability determines how stable your measurement process is over time.

Stability can be determined in two ways. However, to keep it simple, I will only teach you the easy way to estimate stability.

Most accreditation bodies do not require you to include stability in your uncertainty budget. However, many assessors consider stability a significant contributor to uncertainty in measurement. So, I recommend that you include it in your measurement uncertainty analysis.

Definition of Stability

1: *Property of a measuring instrument, whereby its metrological properties remain constant in time* (4.19)

How to Calculate Stability

Follow this instructions to calculate stability:

1. Review your last 3 calibration reports.

2. Record the results from each calibration report.

3. Calculate the standard deviation of the calibration results.

Example

Imagine that you need to determine the stability of your measurement process. So, you grab your last three calibration reports and record the values reported from calibration. Find the stability of your measurement process.

In the image below, I grabbed 3 calibration reports for one of my Keysight 34401A Multimeters and placed the data side by side. The parameter that I focused on was the 10 Volt measurement for the DC Voltage function.

2015	2014	2013
100.0029	100.0045	100.0026
1.000014	0.999991	1.000022
10.00007	9.99998	10.00004
-10.00010	-9.99996	-10.00005
7.00005	6.99992	7.00003
-7.00007	-6.99998	-7.00004
3.00002	2.99994	3.00002
-3.00003	-2.99996	-3.00002
99.9989	99.996	99.9979
950.037	950.030	950.038

Now, you can see that there was some variation in measurement capability from 2013 to 2015. This is what we want to evaluate.

So, look at the image below. I calculated the standard deviation of the 3 measurement results in the image above to determine stability. As a result, we have determined that the stability of this instrument is 4.6 ppm. See the highlight red rectangle.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

To accomplish this using Microsoft Excel, I used the formula:

=stdev(cell1:celln)

	A	B	C	D	E	F	G	H	I
1	STABILITY TEST 1								
2		2015	2014	2013		Test 1			
3	1	10.000070	9.999980	10.00004		Mean	10.000030		
4						StDev	0.000046		
5						Dof	2		
6									
7									
8									
9									
10									

Bias

Bias is a source of uncertainty in measurement that can be optionally added to your uncertainty budget. Whether or not you decide to make it part of your estimation of measurement uncertainty depends on how you use your equipment to perform measurements.

To determine whether or not you should include bias in your uncertainty budget, read the follow scenarios and see which best applies to your measurement process.

Scenario 1*: I calibrate equipment using a known reference standard and report the result only.*

If this describes you, then **add bias to your uncertainty budget**.

In Scenario 1, you would add bias to your uncertainty budget because you do not account for it when reporting your measurement results. Therefore, the bias of the reference standard could further contribute to the uncertainty in measurement results.

Scenario 2*: I calibrate equipment using a known reference standard and report both the Standard value and the Unit Under Test value.*

If this describes you, then **DO NOT add bias to your uncertainty budget**.

In Scenario 2, you would not add bias to your uncertainty budget because you have already accounted for it in your reported measurement results. Therefore, the bias of the reference standard can be eliminated as a contributor to the uncertainty in measurement results.

Bias is really a systematic error rather than an uncertainty. It informs you of how accurate your measurements are compared to the target value. However, depending on how you perform comparison measurements, bias may be a contributor to measurement uncertainty.

Definition of Bias

1: *Estimate of systematic measurement error* (2.18)

2: *Average of replicate indication minus a reference quantity value* (4.20)

How to Calculate Bias

Follow these instructions to calculate bias:

1. Review your latest calibration report.

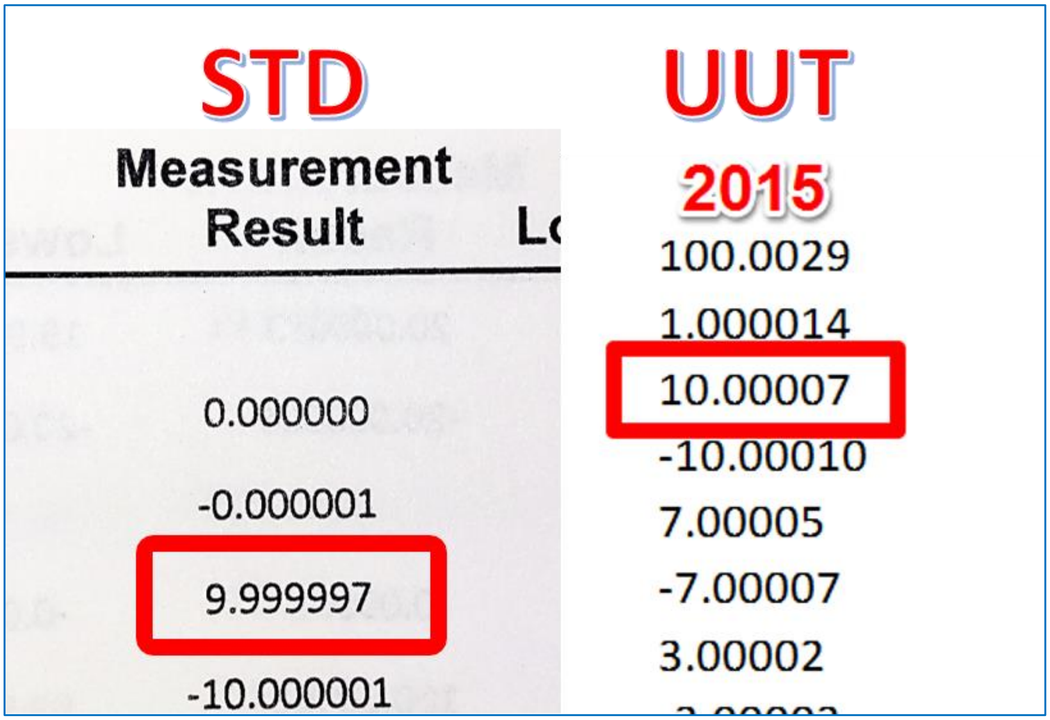
2. Find the As Left value or measurement result.

3. Find the Nominal value or standard value.

4. Calculate the difference.

Example

In the image below, I grabbed 2 calibration reports and compared the results side by side. The first report (left image) is from my Fluke 5720A Calibrator and the second report (right image) is from my Keysight 34401A Multimeter.



Using the data from the image above, I calculated bias using Microsoft Excel in the image below. To calculate bias, all you need to do is subtract the standard value from the measured result of the unit under test. In this case, we determined that the bias of this instrument was 7.3 ppm. See the highlight red rectangle.

$$bias = measured\ value - standard\ value$$

$$b = mv - sv$$

To accomplish this using Microsoft Excel, I used the formula:

=cell2 - cell1

	A	B	C	D	E	F	G	H
1	BIAS TEST 1							
2		STD	UUT		Test 1			
3	1	9.999997	10.000070		Delta	0.000073		
4								
5								
6								
7								
8								

Drift

Drift is a source of uncertainty in measurement that should be included in the every uncertainty budget. It is an influence that you can calculate from your calibration data to see how much the error in your measurements changes over time.

Drift is a systematic uncertainty. It is commonly confused with Stability, which is a random uncertainty. Essentially, drift determines how the error in your measurement process changes over time, and how much it can contribute to your estimate of uncertainty in measurement.

Definition of Drift

1: *Continuous or incremental change over time in indication, due to changes in metrological properties of a measuring instrument* (4.21)

How to Calculate Drift

Follow these instructions to calculate drift:

1. Review your last 3 calibration reports.

2. Record the results from each calibration report.

3. Record the date each calibration was performed.

4. Calculate the average daily drift rate.

5. Multiply the average daily drift rate by your calibration interval (in days).

Example

In the image below, I grabbed 3 calibration reports for one of my Keysight 34401A Multimeters and placed the data side by side. The parameter that I focused on was the 10 Volt measurement for the DC Voltage function.

2015	2014	2013
100.0029	100.0045	100.0026
1.000014	0.999991	1.000022
10.00007	9.99998	10.00004
-10.00010	-9.99996	-10.00005
7.00005	6.99992	7.00003
-7.00007	-6.99998	-7.00004
3.00002	2.99994	3.00002
-3.00003	-2.99996	-3.00002
99.9989	99.996	99.9979
950.037	950.030	950.038

Now, you can see that there was some change in measurement performance from 2013 to 2015. Using this data, you can calculate the average drift rate.

$$drift = I \cdot \frac{1}{n}\sum_{i=1}^{n}\frac{\delta y}{\delta t}$$

First, calculate the daily drift rate from 2014 to 2015.

	A	B	C	D	E	F	G	H
1	STABILITY TEST 1							
2		02/10/15	02/21/14	02/14/13		2014 to 2015		
3	1	10.000070	9.999980	10.00004		Drift 1	=(B3-C3)/(B2-C2)	
4								
5								
6								

Then, calculate the daily drift rate from 2013 to 2014.

	A	B	C	D	E	F	G	H
1	STABILITY TEST 1							
2		02/10/15	02/21/14	02/14/13		2014 to 2015		
3	1	10.000070	9.999980	10.00004		Drift 1	0.00000025	
4						2013 to 2014		
5						Drift 2	=(C3-D3)/(C2-D2)	
6								
7								

Next, calculate the average daily drift rate.

	A	B	C	D	E	F	G	H
1	STABILITY TEST 1							
2		02/10/15	02/21/14	02/14/13		2014 to 2015		
3	1	10.000070	9.999980	10.00004		Drift 1	0.00000025	
4						2013 to 2014		
5						Drift 2	-0.00000016	
6						Avg Daily Drift		
7						Drift avg	=(ABS(G3)+ABS(G5))/2	
8								
9								

Finally, multiply the daily drift rate by 365.25 days to calculate the **average drift rate per year**.

	A	B	C	D	E	F	G	H
1	STABILITY TEST 1							
2		02/10/15	02/21/14	02/14/13		2014 to 2015		
3	1	10.000070	9.999980	10.00004		Drift 1	0.00000025	
4						2013 to 2014		
5						Drift 2	-0.00000016	
6						Avg Daily Drift		
7						Drift avg	0.00000021	
8						Avg Annual Drift		
9						Drift avg	=G7*365.25	
10								
11								

Look at the image below. I calculated the average, annual drift rate from my calibration report data. As a result, we have determined that the average drift of this instrument is 7.6 ppm. See the highlight red rectangle.

To accomplish this using Microsoft Excel, use the equations that I used in the images above.

	A	B	C	D	E	F	G	H
1	STABILITY TEST 1							
2		02/10/15	02/21/14	02/14/13		2014 to 2015		
3	1	10.000070	9.999980	10.00004		Drift 1	0.00000025	
4						2013 to 2014		
5						Drift 2	-0.00000016	
6						Avg Daily Drift		
7						Drift avg	0.00000021	
8						Avg Annual Drift		
9						Drift avg	0.000076	
10								
11								

Resolution

Resolution is a source of uncertainty in measurement that must be include in every uncertainty budget. To perform uncertainty analysis, you must include the resolution of the standard and the unit under test. However, whether or not you decide to include UUT resolution uncertainty as part of your estimation of measurement uncertainty depends on your process for estimating measurement uncertainty.

To determine whether or not you should include UUT resolution in your uncertainty budget, read the follow scenarios and see which best applies to your measurement process.

***Scenario 1**: I estimate measurement uncertainty for one single measurement process, or a process where the type of UUT never changes.*

If this describes you, then **add UUT Resolution to your uncertainty budget**.

In Scenario 1, you would add UUT resolution to your uncertainty budget because you are evaluating the uncertainty of a single process (e.g. on-time measurement) or your measurement process always tests the same type of UUT.

This prevents you from **calculating measurement uncertainty after every test or calibration**.

Scenario 2*: I estimate measurement uncertainty for a single measurement function or parameter where the UUT type can vary.*

If this describes you, then **DO NOT add UUT Resolution to your uncertainty budget**.

In Scenario 2, you would not add UUT resolution to your uncertainty budget because you will account for it later when calculating measurement uncertainty after each test or calibration. To learn more about this, make sure you read the **ILAC P14 policy** for calculating calibration uncertainty.

If you are ISO/IEC 17025 accredited, you must meet the requirements of the ILAC P14 policy.

Definition of Resolution

1: *Smallest change in a quantity being measured that causes a perceptible change in the corresponding indication* (4.14)

How to Find Resolution

Follow these instructions to calculate resolution:

1. Look at your measurement system or equipment

2. Find the least significant digit

3. Observe the smallest incremental change

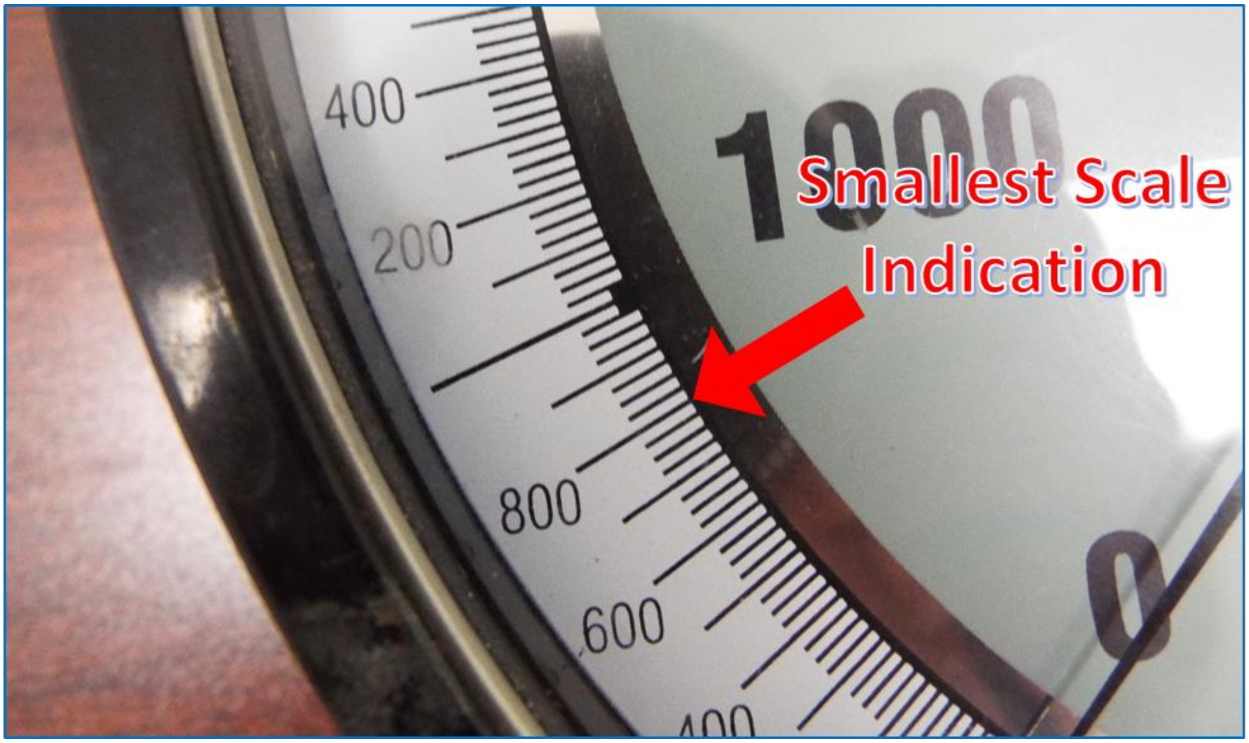
Example

Determining resolution is not always as simple as you may think. In some scenarios, you can quickly find the resolution by looking at your measurement equipment and the unit under test. However, other times it can be a little more complicated; especially for artifacts and analog devices.

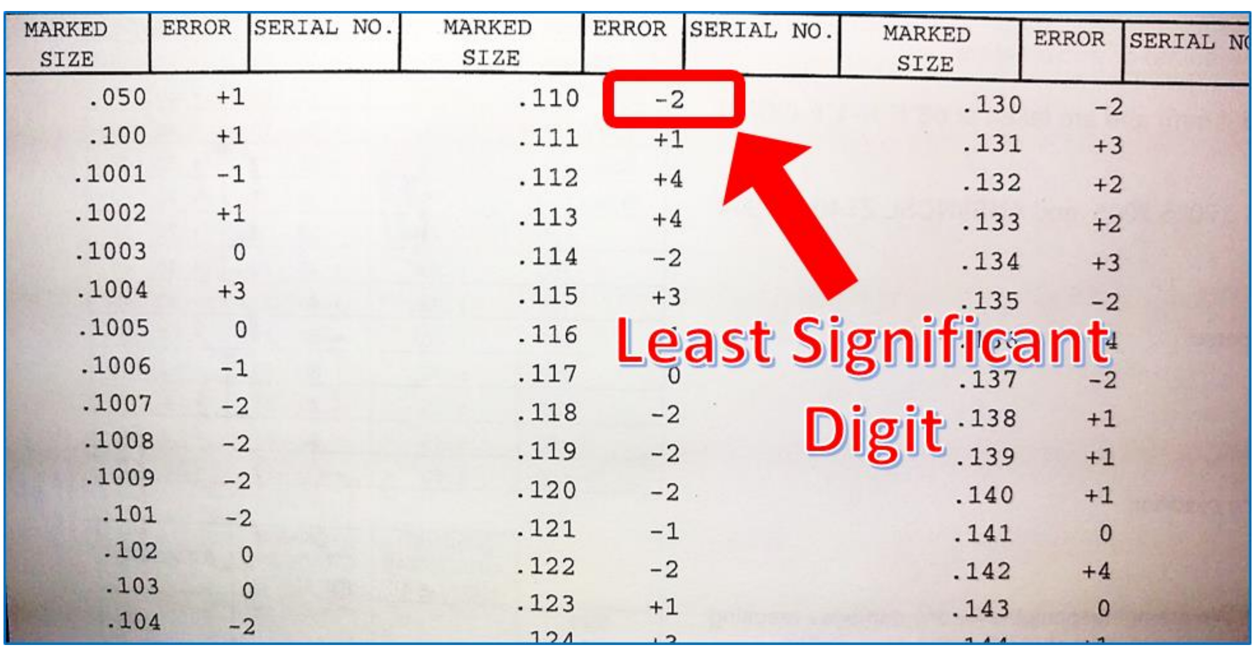
Finding the resolution of digital devices is pretty easy. Look at the digital display of the device and observe either the least significant digit or the smallest change of the least significant digit.

In the image below is a digital multimeter. Looking at the digital display, we can observe the least significant digit and the smallest change. From the observations, you can see that the resolution is 10 micro-volts.

For devices with an analog scales, you will need to observe the marker spacing of the scale, the width of the markers, and the width of the needle or pointer. From these factors, you can determine the resolution uncertainty of your measuring equipment or the unit under test.



When using artifacts, you need to look at your calibration reports to determine the least significant digit of the reported calibration value. Since artifacts do not have scales or displays, you can only determine your resolution from the known value of the artifact.



MARKED SIZE	ERROR	SERIAL NO.	MARKED SIZE	ERROR	SERIAL NO.	MARKED SIZE	ERROR	SERIAL NO.
.050	+1		.110	-2		.130	-2	
.100	+1		.111	+1		.131	+3	
.1001	-1		.112	+4		.132	+2	
.1002	+1		.113	+4		.133	+2	
.1003	0		.114	-2		.134	+3	
.1004	+3		.115	+3		.135	-2	
.1005	0		.116	[illegible]		[illegible]	[illegible]	
.1006	-1		.117	0		.137	-2	
.1007	-2		.118	-2		.138	+1	
.1008	-2		.119	-2		.139	+1	
.1009	-2		.120	-2		.140	+1	
.101	-2		.121	-1		.141	0	
.102	0		.122	-2		.142	+4	
.103	0		.123	+1		.143	0	
.104	-2							

Reference Standard Uncertainty

Reference standard uncertainty is a source of uncertainty in measurement that should be included in the every uncertainty budget. It is an influence that you can find by looking at your calibration reports.

Reference standard uncertainty is a systematic uncertainty. It is introduced from the calibration of your equipment or certified reference material. Additionally, its value is traceable to a national or international standard which is why it is so important.

"I see more laboratories get deficiencies for leaving reference standard uncertainty out of their uncertainty budget."

Do not make the same mistake. Get your equipment calibrated by an ISO/IEC 17025 accredited laboratory and include the reference standard uncertainty in your uncertainty budget.

Definition of Reference Standard Uncertainty

1: *Uncertainty of a measurement standard designated for the calibration of other measurement standards for quantities of a given kind in a given organization or at a given location* (5.6)

How to Calculate Reference Standard Uncertainty

Follow these instructions to find reference standard uncertainty:

1. Review your latest calibration report.

2. Find the reported estimate of measurement uncertainty

Example

When your equipment is calibrated by an ISO/IEC 17025:2005 accredited laboratory or a national metrology institute, you receive a report with measurement results and estimates of uncertainty in measurement. Each reported estimate of measurement uncertainty is your reference standard uncertainty.

In the image below, you will see a section of a calibration report for a Keysight 34401A Digital Multimeter. In the report is a series of measurement results, each with an estimate of uncertainty in measurement.

DC Voltage Calibration					
100 mV	100.0000	100.0029	0.0080	99.9915	100.0085
1 V	1.000000	1.000014	0.0000061	0.999953	1.000047
10 V	10.00000	10.00007	0.000043	9.99960	10.00040
10 V	-10.00000	-10.00010	0.000043	-10.00040	-9.99960
10 V	7.00000	7.00005	0.000032	6.99970	7.00030
10 V	-7.00000	-7.00007	0.000032	-7.00030	-6.99970
10 V	3.00000	3.00002	0.000018	2.99984	3.00016
10 V	-3.00000	-3.00003	0.000018	-3.00016	-2.99984
100 V	100.0000	99.9989	0.00058	99.9949	100.0051
1000 V	950.000	950.037	0.0070	949.947	950.053

Since we have been evaluating the uncertainty at 10 VDC, I will select the uncertainty for the 10 VDC measurement result. This will be your reference standard uncertainty. See the red rectangle.

DC Voltage Calibration					
100 mV	100.0000	100.0029	0.0080	99.9915	100.0085
1 V	1.000000	1.000014	0.0000061	0.999953	1.000047
10 V	10.00000	10.00007	0.000043	9.99960	10.00040
10 V	-10.00000	-10.00010	0.000043	-10.00040	-9.99960
10 V	7.00000	7.00005	0.000032	6.99970	7.00030
10 V	-7.00000	-7.00007	0.000032	-7.00030	-6.99970
10 V	3.00000	3.00002	0.000018	2.99984	3.00016
10 V	-3.00000	-3.00003	0.000018	-3.00016	-2.99984
100 V	100.0000	99.9989	0.00058	99.9949	100.0051
1000 V	950.000	950.037	0.0070	949.947	950.053

Expert Tip:

Now, some people will average the last three values of their reference standard uncertainty and put the calculated average in their uncertainty budget.

Other people will use the most recently reported reference standard uncertainty value in their uncertainty budget.

Either approach is acceptable. So, use the method that works best for you. If you are seeking for **lower your estimates of measurement uncertainty**, use the method that gets you the smallest result.

Reference Standard Stability

Reference standard stability is a source of uncertainty in measurement that should be included in the every uncertainty budget. It is an influence that you can calculate using data from your calibration reports to see how much variability is in your reference standard.

Reference standard stability is a random uncertainty. It is similar to calculating stability, but you calculate the standard deviation of your reference standard uncertainty instead of your measurement results. Essentially, your goal is to determine how stable your reference standard is over time.

If you are wondering why this is important, let me explain. There are two scenarios that make this contributor to measurement uncertainty relevant.

Scenario 1: *Your equipment is calibrated by the same laboratory, but their reported estimate of uncertainty in measurement changes each time.*

Sometimes the reported measurement uncertainty in your calibration report changes, even if only slightly with each calibration. In this scenario, the goal is determine the stability of your calibration laboratory's reference standard.

Scenario 2: *Your equipment is calibrated by different laboratories, each with a different reported estimate of uncertainty in measurement.*

Sometimes your equipment is calibrated by different laboratories (for whatever reason). Each laboratory will report their own value of estimated uncertainty. In this scenario, the goal is to determine the stability of your traceable uncertainty.

Definition of Reference Standard Stability

1: *stability of a measurement standard designated for the calibration of other measurement standards for quantities of a given kind in a given organization or at a given location* (5.6)

How to Calculate Reference Standard Stability

Follow these instructions to calculate reference standard stability:

1. Review your last 3 calibration reports.

2. Record the uncertainty estimate from each calibration report.

3. Calculate the standard deviation.

Example

In the image below, you will see that I have collected the reported estimates of measurement uncertainty from my last 3 calibration reports. The data is from one of my Keysight 34401A Digital Multimeters.

2015	2014	2013
0.0080	0.00089	0.00089
0.0000061	0.0000068	0.0000068
0.000043	0.000048	0.000048
0.000043	0.000048	0.000048
0.000032	0.000036	0.000036
0.000032	0.000036	0.000036
0.000018	0.000020	0.000020
0.000018	0.000020	0.00020
0.00058	0.00065	0.00065
0.0070	0.0078	0.0078

In the next image, I have calculated reference standard stability by calculating the standard deviation of the three values highlighted in the image above. As a result, the reference standard stability is 0.29 ppm.

To accomplish this using Microsoft Excel, I used the formula:

=stdev(cell1:celln)

	A	B	C	D	E	F	G	H
1	REFERENCE STANDARD STABILITY TEST 1							
2		2015	2014	2013		Test 1		
3	1	0.000043	0.000048	0.000048		Mean	0.000046	
4						StDev	0.0000029	
5						Dof	2	
6								
7								

Other Uncertainty Sources

There are many other contributors to uncertainty in measurement results. There is no way that I could list them all here. So, I recommend that you always start your uncertainty analysis with the sources I have given you.

Afterward, evaluate your measurement process to identify additional sources of measurement uncertainty. If you get stumped, do some research.

Some great places to find sources of measurement uncertainty;

- Online Search
- Uncertainty Guides
- Textbooks
- Journal Articles
- Conference Papers
- Other Laboratories

If you are still stuck after searching all of these information sources, then **contact me**! I will be glad to help you or even **create an uncertainty budget** for you.

Conclusion

In this article, I have provided you with 8 sources of uncertainty in measurement that should be included in every uncertainty budget. Additionally, I have given you detailed information and shown you to quantify each source.

Now, I want you to **download my guide** and try these calculations yourself. Then, I want you to include these contributors to measurement uncertainty in your next uncertainty budget.

References

A2LA. (2015). *R205 - Specific Requirements: Calibration Laboratory Accreditation Program.* Frederick: A2LA.

JCGM. (2012). *International Vocabulary of Metrology: Basic and General Concepts and Associated Terms.* Sèvres: BIPM.

Help & Feedback

All good things have to come to an end, including this Measurement Uncertainty guide. Don't worry. If you need additional help, I am only an email or phone call away from helping you overcome your challenges. Enjoy this measurement uncertainty guide, share it with your friends, and be sure give me feedback.

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Feedback

Please tell me what you think.

1. What do you like?
2. What do you hate?
3. What improvements you would suggest?
4. What are your biggest problems?
5. Leave me a testimonial.

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