Uncertainty Calculator: A Freeware Tool for Expressing Measurement Uncertainty

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Uncertainty Calculator is a Windows™ compatible software program that calculates measurement uncertainty as required by ISO Tag 4/WG 3 and NIST Technical Note 1297. It was developed by the author for use at Compaq Computer Corporation, that company has graciously allowed distribution of the program as FREEWARE through Norfox Software, Inc. A software program previously developed by Mr. Grachanen, Tolerance Calculator, has also been distributed as freeware and is now in use in hundreds of labs around the world.

Laboratory Accreditation, as issued by NVLAP or A2LA, requires a laboratory to review their current operating procedures and practices to insure compliance with applicable published guidelines. A calibration laboratory seeking accreditation whose current operating procedures and practices are congruent with applicable ISO 9000 series requirements and other associated guidelines, such as ISO Guide 25 or ANSI/NCSL Z540-1, will find that a major portion of their preparation activities will center around technical issues. This is mainly due to accreditation requirements to document measurement uncertainties for those measurement parameters under consideration.

The methodologies in determining and expressing measurement uncertainties may be found in ISO Tag 4/WG 3 "Guide to the Expression of Uncertainty in Measurement" (commonly called the GUM), NIST Technical Note 1297 "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," and NCSL's recommended practice, RP-12 "Determining and Reporting Measurement Uncertainties."

A typical first impression of GUM methodology requirements was best expressed by Ian Instone of Hewlett Packard in his informative paper "Simplified Method for Assessing Uncertainties in a Commercial Production Environment," when he wrote, "The assessment of uncertainties of measurement has become a task more suited to a mathematician rather than the average calibration engineer."

Gone are the familiar random and systematic uncertainties replaced now with nondescript Type A and Type B uncertainties. Coverage factor, coverage probability and sensitivity coefficients are just a few of the terminologies one must be comfortable with in determining measurement uncertainties per GUM requirements. Probability distributions for each element of a measurement uncertainty ensemble must be identified, effective standard deviations computed and these results combined and manipulated to give a single expanded uncertainty per GUM requirements. It was in light of the number of measurement parameters my laboratory was submitting for NVLAP accreditation that I decided on developing a tool to help ease the GUM burden. This decision led to the development of the "Uncertainty Calculator."

Development Parameters

Uncertainty Calculator was developed to address the majority of common measurements performed in commercial/in-house calibration laboratories. Correlation correction methodologies and in-depth analysis tools have been omitted for the sake of brevity and are available in other commercial software packages. The development of Uncertainty Calculator centered around three major themes: GUM requirements, common sense ergonomics and the ability to input/export data from other software platforms.

Other ancillary requirements were for the Uncertainty Calculator to operate in both Windows™ 3.1 and Windows 95™ environments, compress to one 3.5 inch floppy disk, have an on-line users manual and provide data and calculated results in an easily understandable format that can be submitted to auditors without the need for further manipulation. It was with laboratory accreditation in mind that this last requirement was added. This point was further emphasized after I learned that one of the most common discrepancies flagged by accreditation auditors was inadequate or poorly written uncertainty statements.

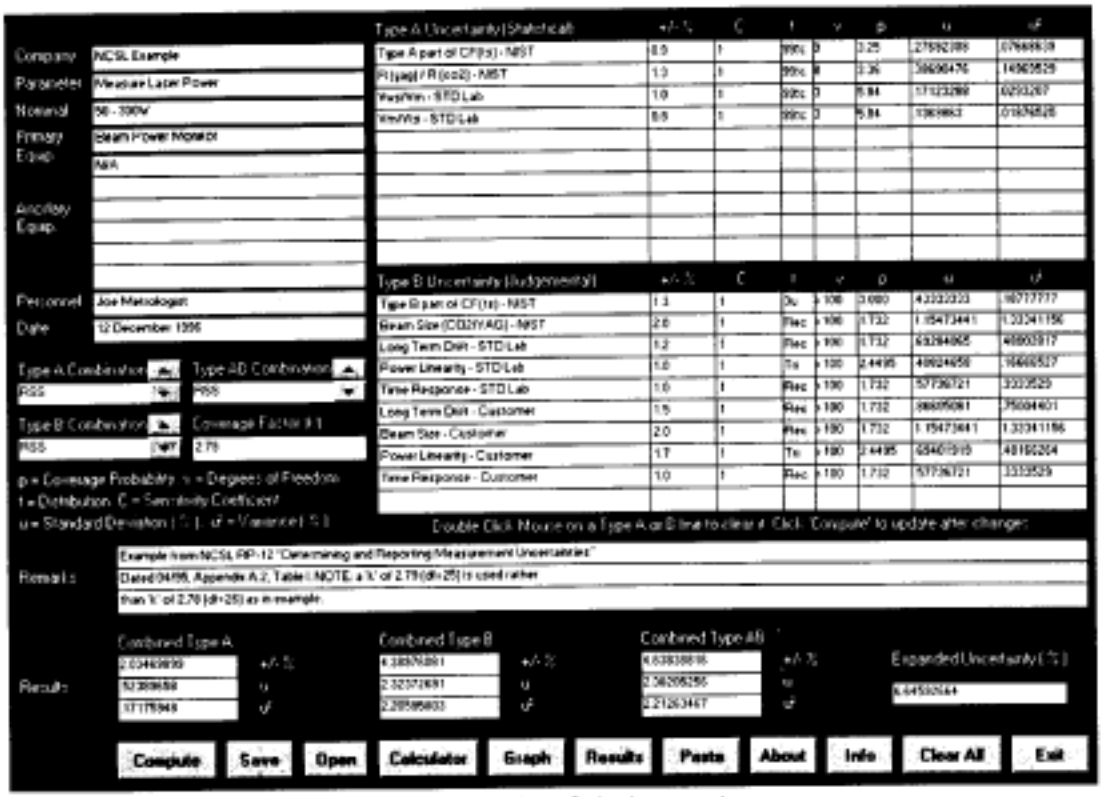

Figure 1. Uncertainty Calculator main screen.

The sticking points of the GUM were becoming apparent as my investigations and development efforts neared completion.

Using Uncertainty Calculator

Uncertainty Calculator is composed of four major sections: information and remarks entry fields, combination selection and coverage factor (k) fields, Type A and B entry fields and computed results (Figure 1). Information and remarks fields allow entry of pertinent information associated with an uncertainty analysis such as the parameter being evaluated, the nominal or range of interest, primary and ancillary equipment applicable to the analysis, comments, etc. The combination section of the Uncertainty Calculator determines how Type A and Type B within group elements are combined and how the results of these combinations are themselves combined. The two choices are algebraic (worst case) and the GUM recommended "square root sum of the squares" (rss). The rss selection is the system's default.

The coverage factor (k) entry selection is obtained from the Uncertainty Calculator's distribution screen. Coverage factor (k) is a numerical factor used as a multiplier of the combined Type A and Type B standard uncertainty in order to obtain an expanded uncertainty. Coverage factor (k) selection is based on the desired level of confidence associated with the expanded uncertainty interval y-U to y+U. The expanded uncertainty is the final product of the GUM's analysis.

Type A and Type B entry fields are at the heart of the GUM building block methodology for obtaining an expanded uncertainty. Type A are those uncertainties obtained by statistical analysis of a series of observations and Type B uncertainties are those obtained by other means. In order for the Uncertainty Calculator to perform GUM manipulation of Type A and Type B uncertainties, entries and selections must be made. These entries and selections are used in determining each uncertainty's standard uncertainty (uncertainty of a measurement result expressed as a standard deviation) and standard variance (the square of the standard uncertainty).

The first required entry is an information field for descriptive information about an uncertainty. The second entry field is the uncertainty's numerical value expressed as a percentage (±%). This field may require prior computations in order to obtain a percentage such as when uncertainties are expressed in decibels (dB). The "Paste" command allows numerical data that was previously copied to the Windows clipboard, such as from a spreadsheet or statistical program, to be directly entered into the ±% field. This feature is especially timesaving when used with Uncertainty Calculator's companion program, Tolerance

Factional 'p' in percentage (Normal Distribution unless noted)

v	68.27% 1u	90%	95%	95.45% 2u	99%	99.73% 3u
1	1.84	6.31	12.71	13.97	63.66	235.80
2	1.32	2.92	4.30	4.53	9.92	19.21
3	1.20	2.35	3.18	3.31	5.84	9.22
4	1.14	2.13	2.78	2.87	4.60	6.62
5	1.11	2.02	2.57	2.65	4.03	5.51
6	1.09	1.94	2.45	2.52	3.71	4.90
7	1.08	1.89	2.36	2.43	3.50	4.53
8	1.07	1.86	2.31	2.37	3.36	4.28
9	1.06	1.83	2.26	2.32	3.25	4.09
10	1.05	1.81	2.23	2.28	3.17	3.96
15	1.03	1.75	2.13	2.18	2.95	3.59
20	1.03	1.72	2.09	2.13	2.85	3.42
25	1.02	1.71	2.06	2.11	2.79	3.33
30	1.02	1.70	2.04	2.09	2.75	3.27
40	1.01	1.68	2.02	2.06	2.70	3.20
50	1.01	1.68	2.01	2.05	2.68	3.16
100	1.005	1.660	1.984	2.025	2.626	3.077
Infinity	1.000	1.645	1.960	2.000	2.576	3.000

Rectangular	1.732	Infinity
Triangular	2.4495	Infinity
U - Shaped	1.414	Infinity

OK

Note: Infinity denoted as >100 in printouts

Figure 2. Probability distribution screen.

Calculator, which can calculate a single uncertainty from an ensemble of uncertainties using its Accumulative Uncertainty command.

The next Type A and Type B field is the sensitivity coefficient (C) field. Sensitivity coefficient (C), which in most cases can be assumed to be unity (1), is a numerical factor used as a multiplier to weight an uncertainty composed of more than one element, as to influence contributions. An example where the sensitivity coefficient (C) would not be unity (1) is in the evaluation of a spectrum analyzer's resolution bandwidth which is defined by two different units, amplitude ratio (usually in dB) and frequency (Hz.)

The next Type A and Type B entry field deals with an uncertainty's coverage probability (p). Coverage probability is a level of confidence associated with an uncertainty expressed as a fraction of the probability distribution characterized by the measurement result and its combined standard uncertainty. Upon selecting the coverage probability field, the distribution screen appears (Figure 2). This screen gives the user choices about the distribution (normal, rectangular, triangular and u-shaped) and degree of freedom (far left column) to associate with an uncertainty. This screen is also used for selecting a coverage factor (k), as previously discussed. Once a selection is made, the distribution type, degree of freedom and fraction (p) are copied to the main screen and the standard uncertainty and standard variance are computed. This sequence of entries and selections is repeated for each Type A and Type B uncertainty.

Once all applicable Type A and Type B uncertainties have been entered, clicking on the "Compute" button will calculate summary results. Prior to calculating summary results, each individual Type A and Type B uncertainties are recalculated to ensure that any changes made to an uncertainty's numerical field (±%) and sensitivity coefficient (C) have been taken into consideration. Summary results consist of Type A and Type B within group combined uncertainties, standard uncertainties and variances. The combined results are then used to calculate Type A & B summary results (combined uncertainty, standard uncertainty and variance).

The combination methodology for summary results are determined by the Type A, Type B and Type A & B combination selections as previously discussed.

The last summary result calculated is expanded uncertainty. Expanded uncertainty is a measure of uncertainty that defines an interval about

TYPE A UNCERTAINTY	+/- %	C	t	v	u	u²
Type A part of CF(ta) - NIST	0.9	1	99%	9	.27652308	.07646639
R (yes) / R (no2) - NIST	1.3	1	99%	8	.38650476	.14969529
Rws/Rm - STD Lab	1.1	1	99%	3	.17173208	.0293207
Rm/Rts - STD Lab	0.8	1	99%	3	.1369863	.01876526

TYPE B UNCERTAINTY	+/- %	C	t	v	u	u²
Type B part of CF(ta) - NIST	1.3	1	3u	>100	.43333333	.18777777
Beam Size (CO2/TAG) - NIST	2.0	1	Rec	>100	1.15473441	1.33341156
Long Term Drift - STD Lab	1.2	1	Rec	>100	.69284065	.48002817
Power Linearity - STD Lab	1.0	1	Tri	>100	.40824658	.16666527
Time Response - STD Lab	1.0	1	Rec	>100	.57736721	.3333529
Long Term Drift - Customer	1.5	1	Rec	>100	.86605081	.75004401
Beam Size - Customer	2.0	1	Rec	>100	1.15473441	1.33341156
Power Linearity - Customer	1.7	1	Tri	>100	.69403919	.48168264
Time Response - Customer	1.0	1	Rec	>100	.57736721	.3333529

RESULTS

TYPE A COMBINATION METHOD	RSS
COMBINED TYPE A +/- %	2.03469899
COMBINED TYPE A u	.52309158
COMBINED TYPE A u²	.17175948
TYPE B COMBINATION METHOD	RSS
COMBINED TYPE B +/- %	4.38976081
COMBINED TYPE B u	2.32372691
COMBINED TYPE B u²	2.20696803
TYPE AB COMBINATION METHOD	RSS
COMBINED TYPE AB +/- %	4.83838816
COMBINED TYPE AB u	2.38286256
COMBINED TYPE AB u²	2.21263467
COVERAGE FACTOR (k)	1.732
EXPANDED UNCERTAINTY (%)	6.64592664

REMARKS

Example from NCSL RP-12 "Determining and Reporting Measurement Uncertainties"

Figure 3. Formatted Results screen.

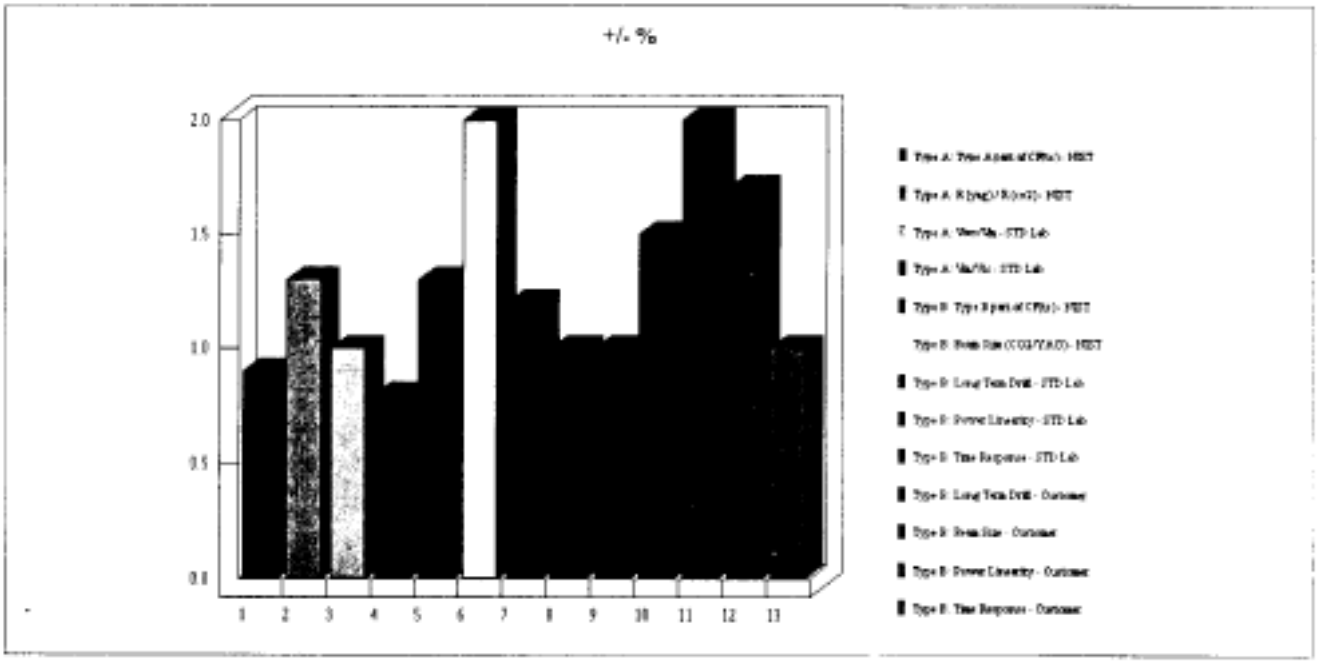

Figure 4. Bar graph display of Type A and B uncertainties.

a measurement result within which the value of the measurand is confidently believed to lie. Expanded uncertainty is calculated by multiplying the Type A & B standard uncertainty by the selected coverage factor (k). This is done to obtain a single, all-encompassing uncertainty for a particular measurement. Using GUM standardized methodologies and formats for deriving expanded uncertainties greatly reduces ambiguity and helps to insure universal acceptance.

Uncertainty Calculator computed results can be displayed in a draft format using the "Results" command button (Figure 3). Upon clicking the "Results" command button, all individual entries, calculations and summary results are displayed for easy inspection. Clicking the left mouse key on the formatted display will transfer it to the Windows Write™ (Wordpad for Windows 95) application where it can be edited, printed (Uncertainty Calculator uses Windows Write for printing results) and saved.

Uncertainty Calculator results may also be displayed graphically using the "Graph" command button. Clicking the Graph button displays a selection screen for plotting either Type A and B numerical values (±%), standard uncertainties or variances. Upon making a selection, the appropriate 3D bar graph is displayed (Figure 4). The displayed graph may be viewed as a 2D bar graph, copied to the Windows Clipboard or printed. Archiving and retrieval of results is accomplished using the "Save" and "Open" command buttons, respectively.

Each command button will open its appropriate Windows dialog box, giving access to drives and directories. To perform extraneous computations the "Calculator" command button will activate the Windows calculator application. Results of the Windows calculator can be copied and pasted into the Uncertainty Calculator's Type A and Type B numerical fields (±%).

Uncertainty Calculator's comes with an on-line manual that can be printed using the Windows Write application.

Conclusion

Uncertainty Calculator was written to provide a user friendly, intuitive tool for performing GUM uncertainty statements. As a FREEWARE application, Uncertainty Calculator may be distributed and copied (without modifying its contents) at no cost. Copies of Uncertainty Calculator and Tolerance Calculator may be obtained through Norfox Software Inc. at (206) 774-9118, Fax (206) 774-9118. Norfox Software Inc. provides distribution of these applications as a public service to the measurement community.

It is the author's hope that Uncertainty Calculator will help ease the GUM burden for laboratories pursuing accreditation and encourage others to consider "Freewaring" their software applications.

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