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Measurement Uncertainty - Construction of a calculator

Many important decisions are based on the results of measurements; the results are used, for example, to estimate yields, to check materials against specifications or statutory limits, or to estimate monetary value. Whenever decisions are based on measurement results, it is important to have some indication of the quality of the results, that is, the extent to which they can be relied on for the purpose in hand.
Therefore there is a requirement to establish the confidence of results such as traceability to a defined standard. It's getting more and more important to demonstrate the quality of a result, and in particular to demonstrate the fitness for purpose by giving a measure of the confidence that can be placed on the result. This is expected to include the degree to which a result would agree with other results, normally irrespective of the methods used. One useful measure of this is measurement uncertainty.
The way to calculate the overall measurement uncertainty for any type of a measurement was only developed recently. In 1995 the International Standardization Organization (ISO) published the 'Guide to the Expression of Uncertainty in Measurement' (GUM[1]). The described uncertainty calculation method in the GUM is based on a Taylor expansion (Error Propagation). All involved quantities have to be quoted in terms of standard deviation and the resulting overall measurement uncertainty is then given as a Gaussian shaped distribution (Student t). In this fact lies one of the main problems of the GUM method. Even for a simple measurement system the resulting probability density function (pdf) has not to be Gaussian shaped.
As an example a Gaussian shaped input quantity with a model function of $\frac{1}{x}$ results in a pdf like shown in figure 1. It is obvious that the resulting density function is no longer symmetrical and therefore other methods have to be developed to take this problem into account. The approach with maybe the largest potential is based on a Monte Carlo method to simulate the pdf. At the NPL[2] supplements to the GUM are developed that describe the usage of such simulations for the calculation of measurement uncertainty. The main task of this method is the generation of random numbers for various distributions. One of the challenges is the generation of correlated random numbers for different pdf's. Therefore we are in cooperation with Wesley Petersen[3]. The need for correlated input quantities, and therefore correlated random numbers is getting obvious in the measurement of high frequency properties. In such measurements the involved quantities (r, φ) are modeled as complex values and the real- and imaginary part are correlated. In cooperation with METAS[4] several benchmark examples are elaborated, where the problems of the GUM method, and therefore the need for other solutions can be demonstrated.

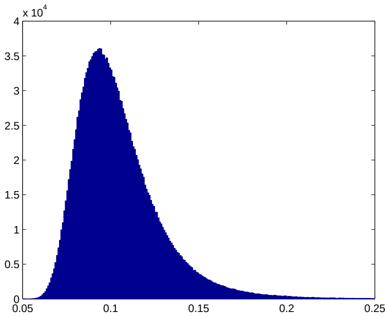

Figure 1: Resulting density function of $\frac{1}{x}$.

[1] Guide to the Expression of Uncertainty in Measurement. International Organization for Standardization (ISO), Central Secretariat, Geneva, 1 edition, 1995.
[2] Peter Harris, National Measurement Laboratory, www.npl.co.uk, Personal communication 2005.
[3] Wesley Petersen, ETH Zürich, Seminar für Angewandte Mathematik, www.sam.math.ethz.ch, Personal communication 2005.
[4] Markus Zeier, Metrology And Accreditation Switzerland (METAS), www.metas.ch, Personal communication 2004-2005.