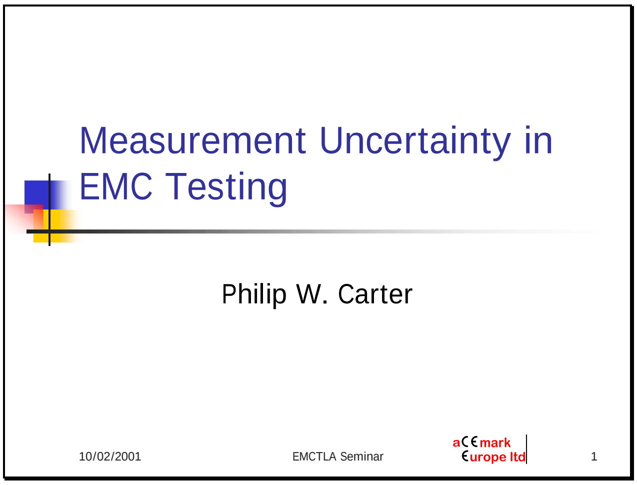
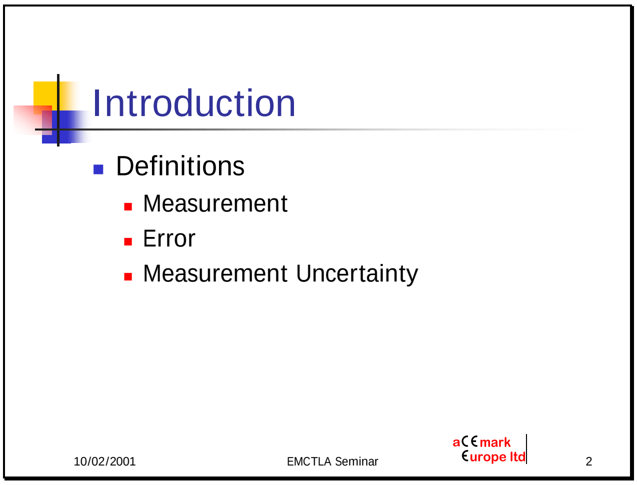
Slide 1



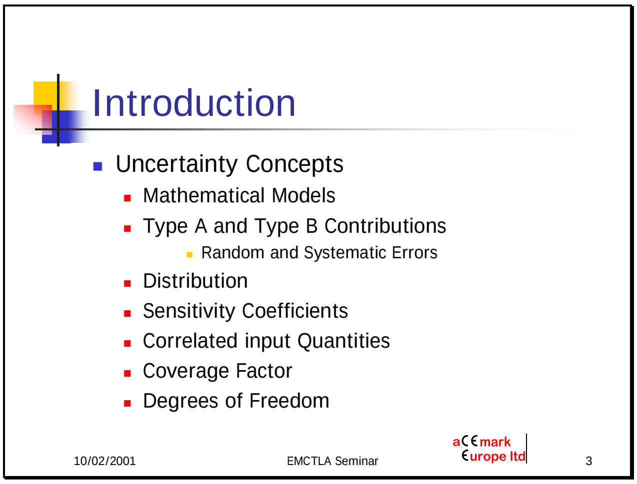
This presentation seeks to explain the approach taken to measurement uncertainty in EMC Testing in the soon to be published UKAS Document Lab 34 (Edition 2 of NIS 81).

Slide 2



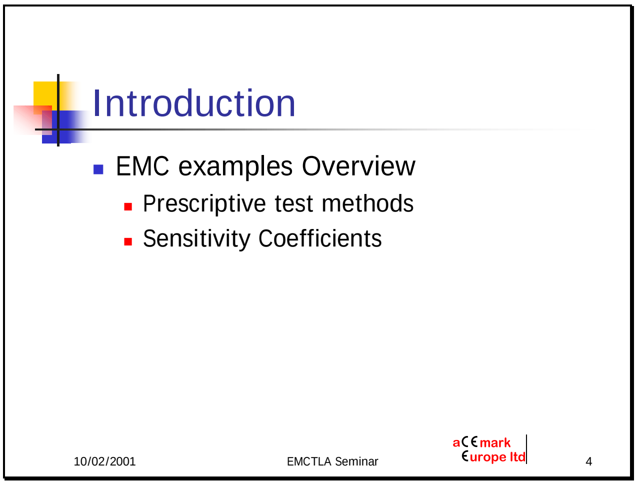
We will start by reviewing some definitions.

Slide 3



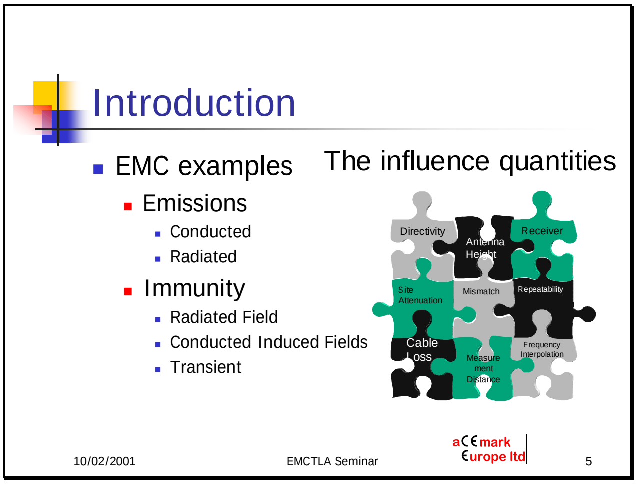
Then as an introduction to the examples we will see later, we will consider some of the important concepts in the evaluation of measurement uncertainty.

Slide 4



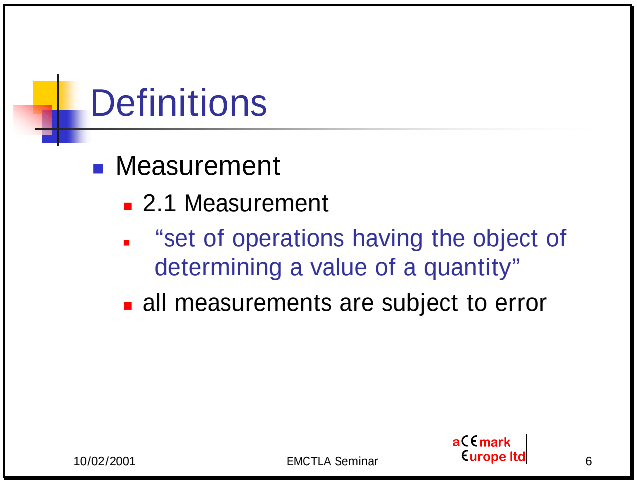
Prior to looking at the example budgets, we will discuss some of the issues associated with EMC testing and the complexities involved.
Where we have taken a simplified approach, we will consider the reasons behind that decision.

Slide 5



Finally, several examples will be considered which will explain some of the rationale used.
We will look at the model developed to address the uncertainty, the influence quantities and the uncertainty budget.

Slide 6



Defined in the international vocabulary of metrology (VIM) as:
2.1 Measurement
"Set of operations having the object of determining a value of a quantity"
All measurements are subject to error

Slide 7

Definitions

- 3.10 Error (of measurement).
  - result of a measurement minus a true value of the measurand.
    - NOTE Since a true value cannot be determined, in practice a conventional true value is used e.g. assigned value, best estimate, reference value etc.
  - errors are subject uncertainty.

10/02/2001 EMCTLA Seminar aCEmark Europe ltd 7

Defined in the VIM as:
3.10 Error (of measurement).
"Result of a measurement minus a true value of the measurand"
NOTE Since a true value cannot be determined, in practice a conventional true value is used e.g. assigned value, best estimate, reference value etc.
Errors are subject uncertainty.

Slide 8

Definitions

- 3.9 Uncertainty of Measurement
  - "parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand"
  - "measurand" refers to the quantity that is to be measured

10/02/2001 EMCTLA Seminar aCEmark Europe ltd 8

3.9 Uncertainty of Measurement
"Parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand"
"Measurand" refers to the quantity that is to be measured
This is now the official definition of uncertainty of measurement as given in the VIM. However, some people were unhappy with this new definition because it suggested that uncertainty was only concerned with the randomness of a measurement process

Slide 9

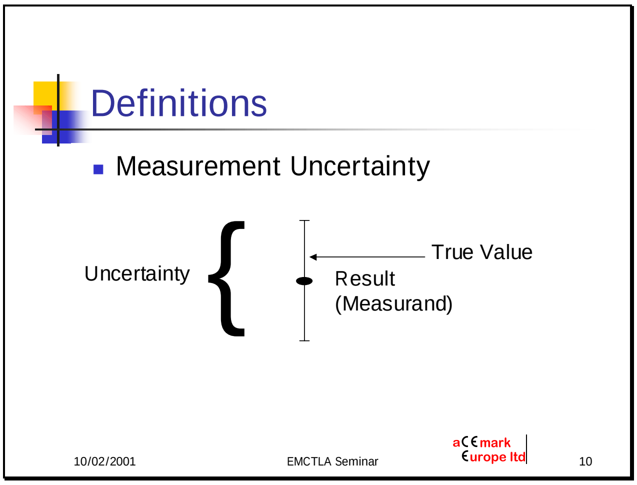
Definitions

- Uncertainty of Measurement
- An alternative definition is given in the forward to the BSI version of VIM:
  - "result of the evaluation aimed at characterising the range within which the true value of a measurand is estimated to lie, generally with a given confidence"

10/02/2001 EMCTLA Seminar aCEmark Europe ltd 9

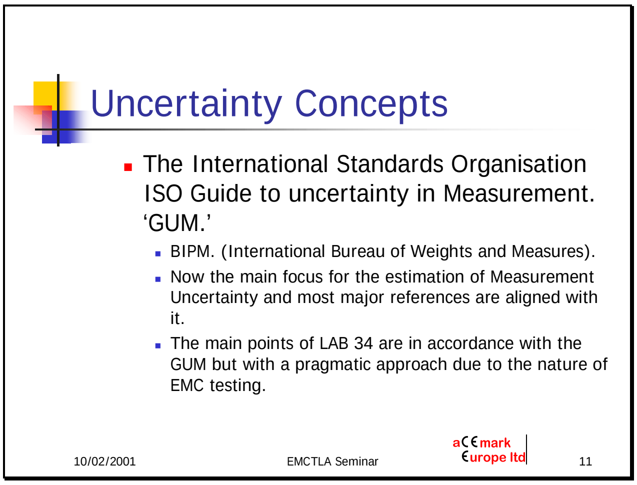
An alternative definition is given in the forward to the BSI version of VIM:
"Result of the evaluation aimed at characterising the range within which the true value of a measurand is estimated to lie, generally with a given confidence"
They preferred the more traditional definition of uncertainty that included a reference to a "true" value, which implies traceability of the measurement result and that some measure of confidence should be assigned to our knowledge of the uncertainty

Slide 10



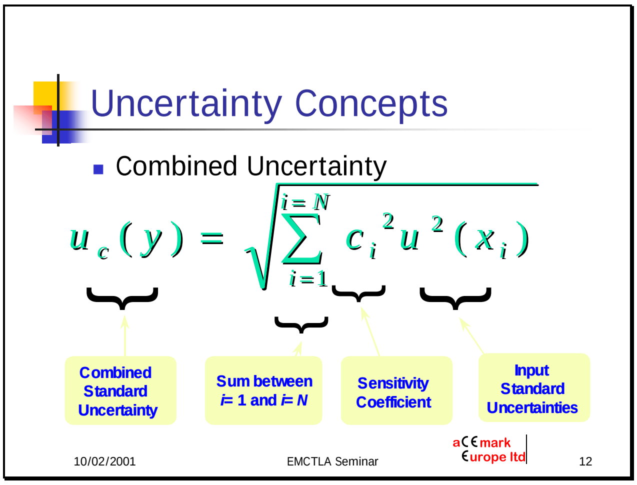
Knowing then that all measurements contain error, our job is to quantify in what range do we expect our True Value to lie, and with a 95% confidence.

Slide 11



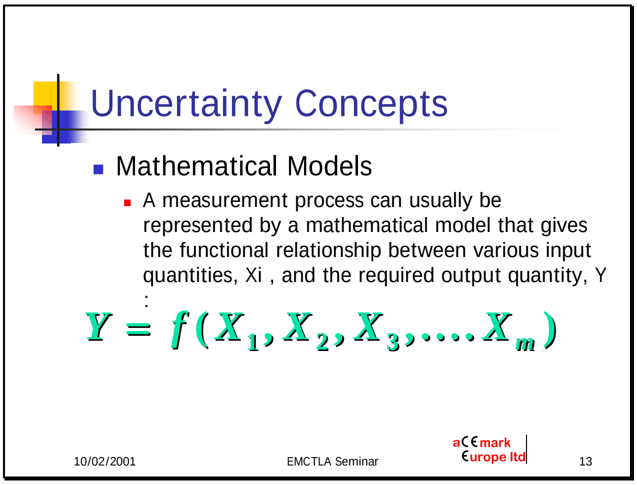
The need for an internationally accepted approach to the calculation and expression of measurement uncertainty led in 1981 to the international authority in metrology, the BIPM approving brief outline recommendations made by a working group of representatives from the major national standards laboratories and others concerned with metrology. It took some considerable time for a consensus view to emerge and even now, the adoption of the BIPM recommendations is by no means universal. However, it did prove to be a strong impetus for national standards laboratories, accreditation bodies and other authorities concerned with metrology to adopt the BIPM principles.

Slide 12



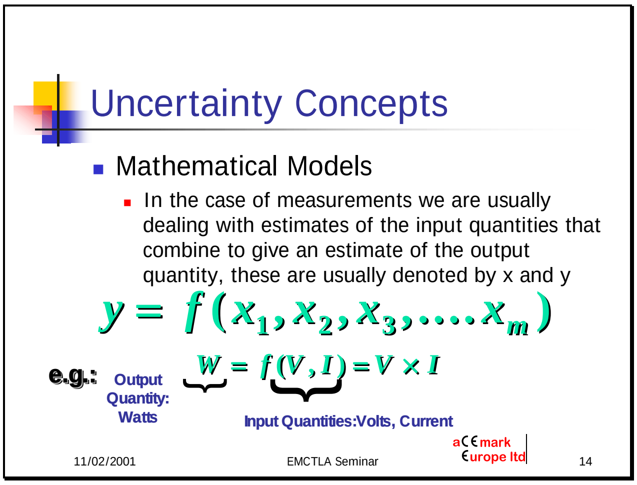
The 'GUM' is then the adopted methodology for uncertainty and the basis for our calculations. The individual standard uncertainties, both Type A and Type B are combined by root-sum-of-squares (RSS) to give a single uncertainty referred to as the Combined Standard Uncertainty, $u_c(y)$.
We gather all of our uncertainties get them all onto the same scale or units and RSS them!

Slide 13



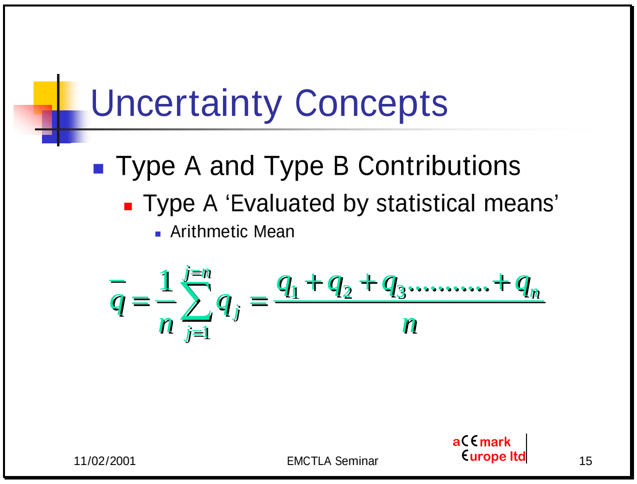
The mathematical model of a measurement should be the starting point for all uncertainty estimations since it is this that determines how the combination of uncertainties should be treated. For relatively simple measurement systems, it may not be necessary to define the model exactly or to write it down at all and still be able to construct an adequate uncertainty budget. However, it is recommended that an attempt is made to represent the measurement process as an equation involving the measured quantity and all the sources of possible error since this generally leads to a better understanding of the measurement process

Slide 14

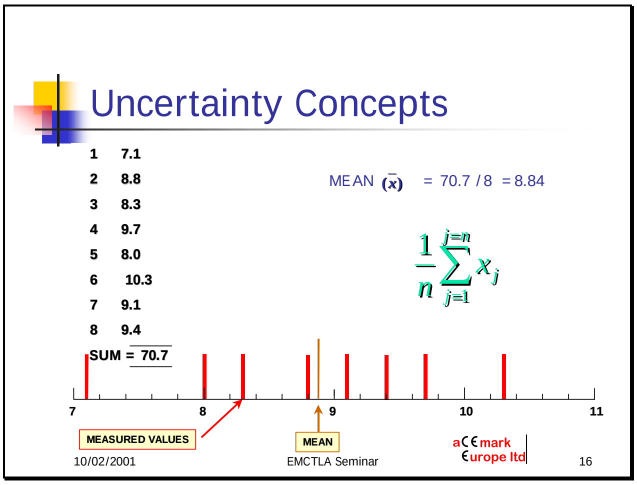


The mathematical model for a measurement process may be very simple as in this example or can be very complex.

Slide 15

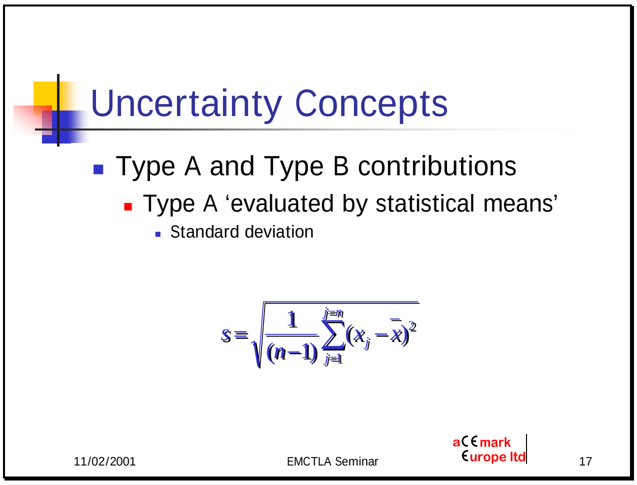


Mean Value
The arithmetic sum of all the values in a series of observations divided by the number of observations is the mean value and usually represents the most likely value of the measured quantity. The more observation or readings that are made usually increases the knowledge of the measured quantity and reduces the uncertainty.



Slide 16

This shows an example of a series of readings and how they might be presented on a scale. The mean is calculated by dividing the sum of the measurement values by the number of readings. The formulae in statistics are always much harder to look at than to use.

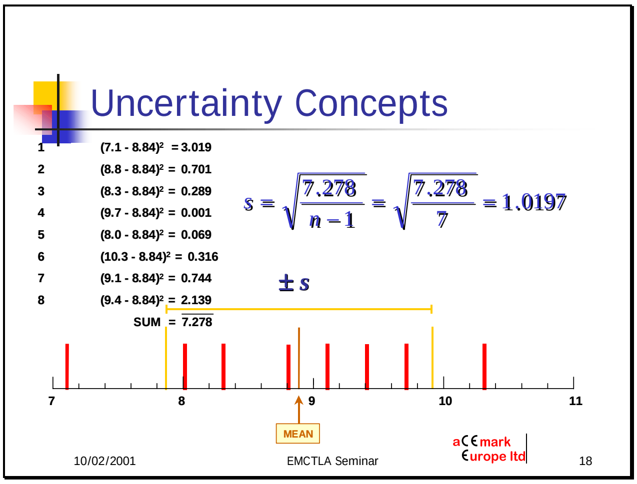


Slide 17

Standard deviation

The standard deviation is a measure of the spread or range of independent values or results. It is not the only statistical way to express the variation in a series of values but it is the correct method for values that are expected to have a normal distribution. Most electronic calculators have the facility to calculate standard deviation but it is usually given the more familiar symbol δ (sigma).

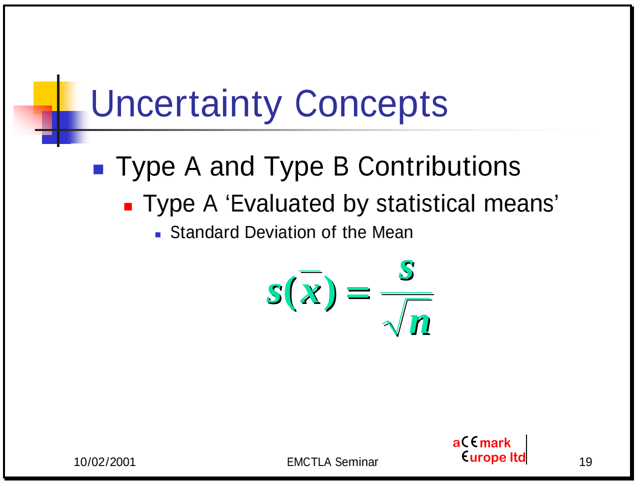
Standard deviation will sometimes be expressed as "one standard deviation", which is the same thing



Slide 18

This shows the calculation for standard deviation and its relative spread with respect to the range of results. Note that by its very nature some result will lie outside the standard deviation

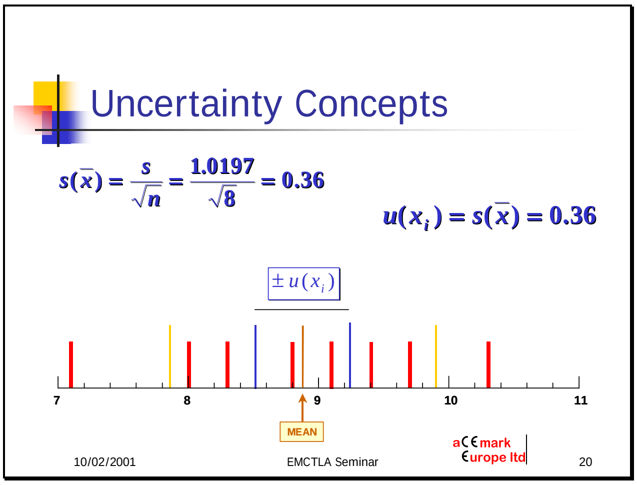
Slide 19



When a series of readings are made of the same quantity under essentially the same conditions, the mean value of the readings will increasingly represent the most probable value of the quantity. As more readings are taken, the mean value becomes a more reliable representation of the actual value of the quantity. This increased reliability is another way of saying that the uncertainty in the mean is reducing. The standard deviation of the mean value is obtained by dividing the standard deviation by the square root of the number of readings, so the more readings that are taken the lower the standard deviation of the mean.

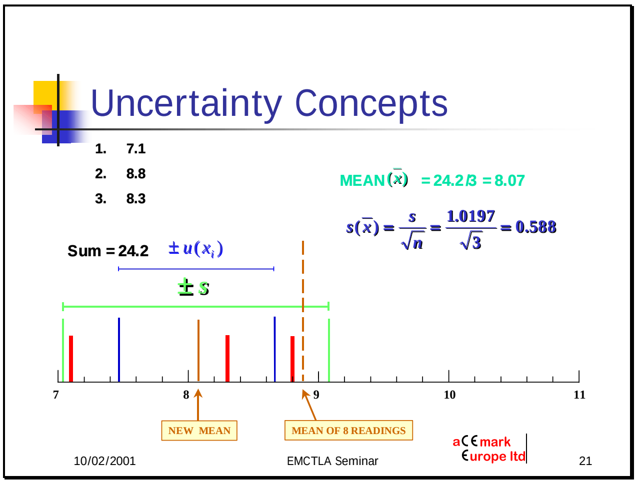
The standard deviation of the mean is the standard uncertainty for that particular series of readings.

Slide 20



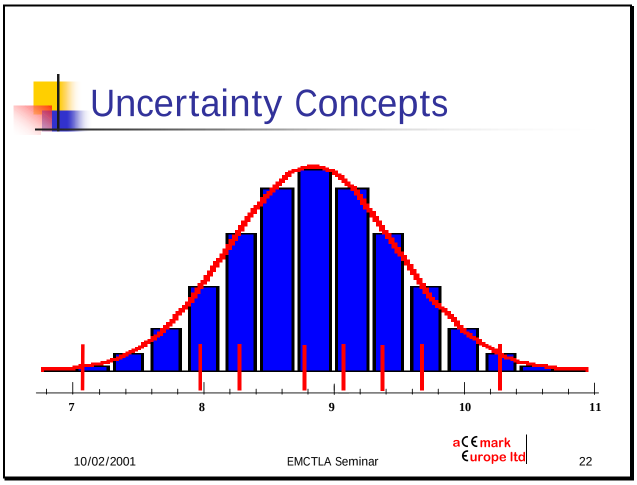
This shows the calculation for the standard deviation of the mean, which is the standard uncertainty, and how much smaller this is than the standard deviation, when the number of readings is relatively large. This reduction is achieved if a series of measurements are made on the same EUT within the same measurement series. It is not considered appropriate to reduce previously taken or historical data by the same means, so if we have our system repeatability characterised by taking repeated measurements over a period of time we would use our Standard deviation as our Standard Uncertainty.

Slide 21



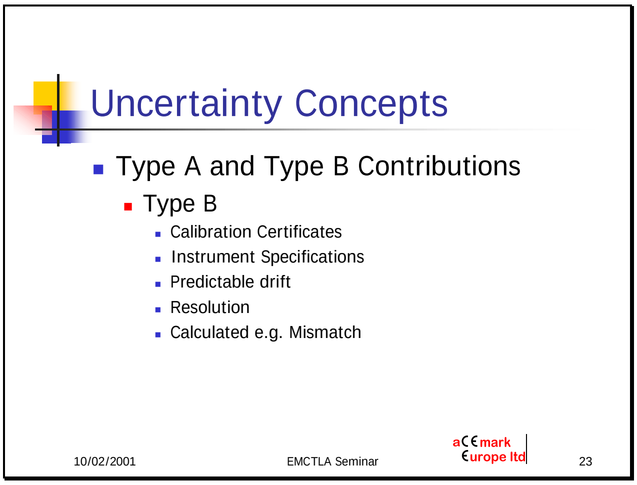
This shows what can happen to our measurement results if only a few readings are taken!

Slide 22



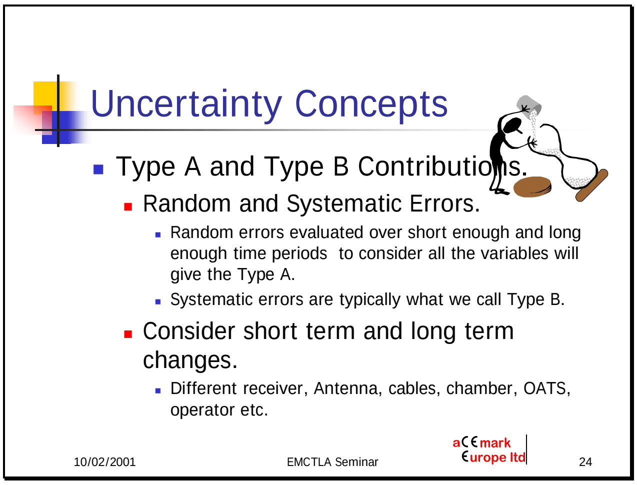
So clearly, we should take as many reading as we can to evaluate our standard uncertainty. If we take sufficient readings and group them in to intervals such as a bar chart, we would see a gaussian or normal distribution take shape centred on the mean.

Slide 23



Typical sources of Type B information is shown, these are basically those that are taken from Calibration certificates, equipment specifications, calculated, or by other means than that of statistical analysis.

Slide 24

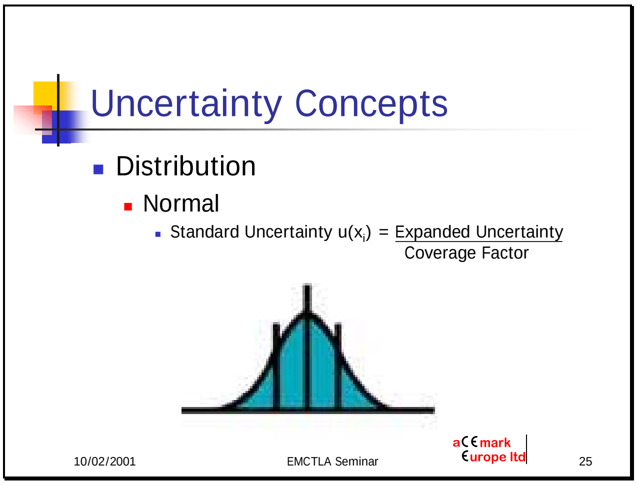


The conditions under which an error can be regarded as random will vary from one measurement system to another. In some cases, variations in a measured value may appear to be random but are in fact the result of a systematic influence that has not been fully investigated. The most common of these influences is probably temperature or other environmental effects

It is important to consider that some influences may be systematic but because they change under different conditions that are still seen in the day-to-day and month-to-month testing cycle they may be more evident as Type A contributions.

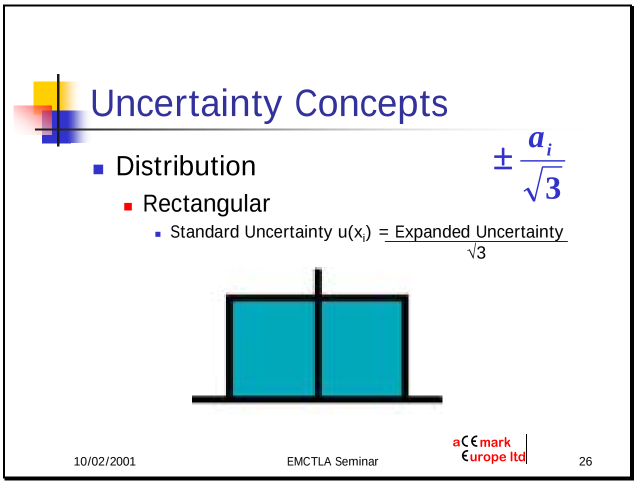
How about the technique used by an operator to make his final measurements in emissions. Different operators could systematically obtain different results, each being repeatable in their own right.

Slide 25



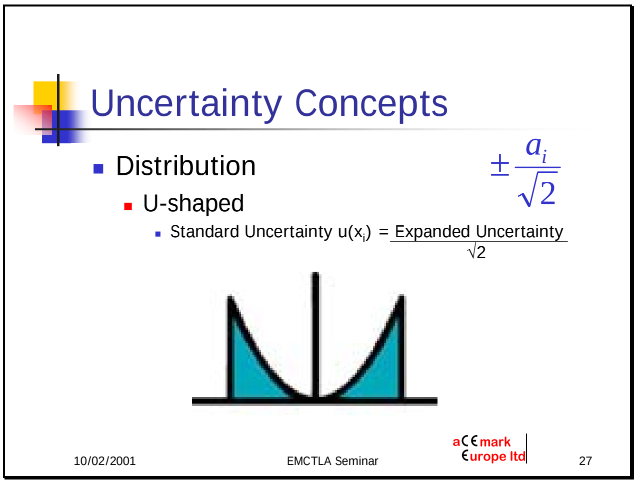
In the case of calibration certificate from an accredited laboratory the coverage factor or level of confidence will be given so there should be no problem obtaining the standard uncertainty using the calculation shown.

Slide 26



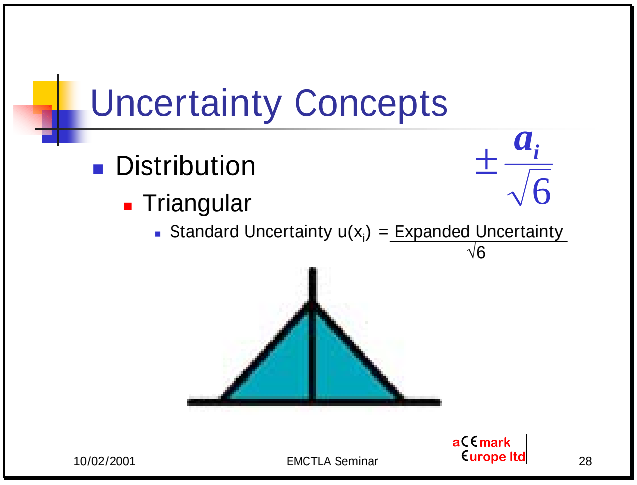
If there is equal probability of the true value lying anywhere between defined limits then the distribution is described as rectangular. In theory, the probability of the true value lying outside these limits is zero.
This tends to be a conservative estimate, however, it is the one that we should use when we have no other information.

Slide 27



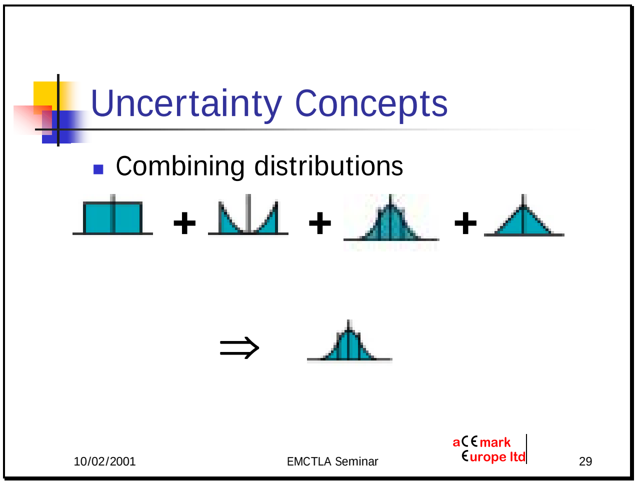
U-shaped distribution is used when it is known there is a better probability of finding values close to the variation limits than around the mean value. This is the distribution associated with Mismatch errors. Consider the addition of two mismatch vectors separated in distance from the source; one vector will effectively rotate around the other adding and subtracting.

Slide 28



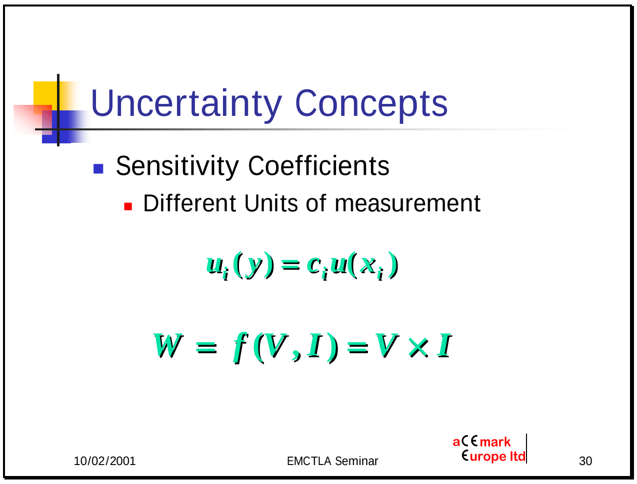
Triangular distribution is used when it is known that there is a better probability of finding values close to the mean value than further away from it, and one is more comfortable estimating the width of the variation by estimating "hard" limits rather than a certain number of standard deviations. Consider for example the measurement of Site Attenuation here we have a window outside of which our site fails and typically, the results will tend toward the centre line.

Slide 29



As we combine more and more contributions with differing distributions together, our resulting distribution tends more and more toward a normal distribution.

Slide 30



A measurement will often involve input quantities of different units compared to the required output quantity. This is a simple example where it is obvious that uncertainties expressed in volts and amps cannot be directly combined together. However, in some situations it is not so obvious that the input quantities cannot be combined.

Slide 31

Uncertainty Concepts

- Sensitivity Coefficients
  - Partial differentiation
    - Sensitivity coefficients can be obtained by partial differentiation of the functional relationship between input quantities and output quantity:

$$u_i(y) = c_i u(x_i) \qquad c_i = \frac{\partial f}{\partial x_i}$$

$$W = f(V, I) = V \times I \qquad c_V = \frac{\partial f}{\partial V} = I \qquad c_I = \frac{\partial f}{\partial I} = V$$

10/02/2001 EMCTLA Seminar aCЄmark Єurope ltd 31

The combined standard uncertainty will need to be expressed in the same terms as the quantity being measured. However, the input standard uncertainties may not be measured or given in the these terms, for example:
If Power is measured in terms of Voltage and Current, the input standard uncertainties will probably be in Volts and Amps and cannot be directly combined to give the uncertainty in terms of Watts. The Sensitivity Coefficients c_i convert the input standard uncertainties to their equivalent values as output standard uncertainties:
If the functional relationship between the input quantity and the output quantity is known then the sensitivity coefficients can be obtained by partial differentiation.

Slide 32

Uncertainty Concepts

- Sensitivity Coefficients
  - By experiment

$$c_i = \frac{\Delta y}{\Delta x_i} = \frac{\text{Change in Output Quantity}}{\text{Change in Input Quantity}}$$

10/02/2001 EMCTLA Seminar aCЄmark Єurope ltd 32

However, the calculation of partial derivatives will be difficult and liable to error if the functional relationship is not known exactly or if it is complicated. There are some techniques that can be used to simplify the process
Obtain the sensitivity coefficients by experiment.
Re-arrange the functional relationship so that the sensitivity coefficients are unity.

Slide 33

Uncertainty Concepts

- Sensitivity Coefficients
  - Re-arrange the functional relationship

$$y = cx_1^{p_1} . x_2^{p_2} \ldots\ldots x_m^{p_m}$$

$$\frac{u_c(y)}{|y|} = \sqrt{\sum_{i=1}^{i=m} \left[\frac{p_i u(x_i)}{|x_i|}\right]^2}$$

10/02/2001 EMCTLA Seminar aCЄmark Єurope ltd 33

Where the input quantities are multiplied or divided together, even if the indices are greater than one, then the calculation will be simplified if relative values are used instead of absolute values. In effect, this transforms the functional relationship into an additive series where the sensitivity coefficients are unity. Consider relative values as % or ppm
NB. We cannot use relative values when our input quantities are additions or subtractions

Slide 34

Uncertainty Concepts

- Correlated input Quantities
  - Uncertainty contributions not related
    - Usual assumption
  - Uncertainty Contributions related
    - Negative Correlation
    - Positive Correlation

10/02/2001 EMCTLA Seminar aCEmark Europe ltd 34

Our general expression for standard uncertainty of the output relies on there being no correlation between any of the input uncertainty estimates. This is not always the case, e.g. in our EMC examples we often have a series of relative measurements performed using the same measuring instrument, such as characterising the uniform field of a semi anechoic chamber. Here the power meter errors are applicable in the same way to each of the successive measurements. This would be negative correlation and although we generally miss the step out, we should really consider the error in each measurement but subtract the correlated quantity before combining the resultant (in our case zero) in our expression for standard uncertainty. Likewise there are occasions where measurement errors will always combine in the same direction in these cases we should add the contributions arithmetically before combining them.

Slide 35

Uncertainty Concepts

- Coverage Factor
  - For most measurements
    - K=2 gives level of confidence close to 95%
  - In some cases k=2 is not sufficient
    - t-distribution

ν_{eff}	1	2	3	4	5	6	7	8	10	12	14	16
k_{95}	13.97	4.53	3.31	2.87	2.65	2.52	2.43	2.37	2.28	2.23	2.20	2.17

ν_{eff}	18	20	25	30	35	40	45	50	60	80	100	∞
k_{95}	2.15	2.13	2.11	2.09	2.07	2.06	2.06	2.05	2.04	2.03	2.02	2.00

10/02/2001 EMCTLA Seminar aCEmark Europe ltd 35

In general it is reasonable to consider our combined Type B contributions as normal distributions and likewise if we have taken sufficient measurements to evaluate our type A contributions then the use of a coverage factor of k=2 will mean that the expanded uncertainty, U, will provide a level of confidence close to 95%. (The coverage of a normal distribution by a value of k=2 is 95.45%)

In some cases, where for example we could not make a large number of measurements to evaluate our Type A contributions, and it is large compared to the overall uncertainty then we may need to use a value of k higher than 2 to give the 95% confidence. This value would be established by making an estimate of the effective degrees of freedom.

Slide 36

Uncertainty Concepts

- Degrees of Freedom
  - Effective Degrees of Freedom

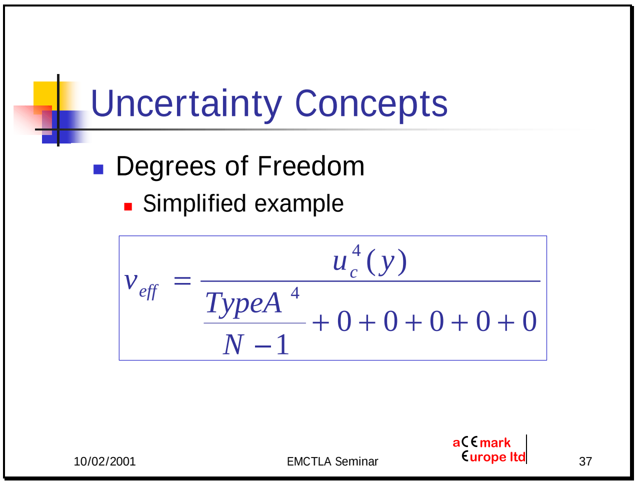
$$\nu_{eff} = \frac{u_c^4(y)}{\sum_{i=1}^{N} \frac{u_i^4(y)}{\nu_i}}$$

  - Where
    - *N* = Number of input estimates
    - *Vi* = Degrees of Freedom for input quantity *i*
      - For Type A = *N-1*
      - For Type B = ∞

10/02/2001 EMCTLA Seminar aCEmark Europe ltd 36

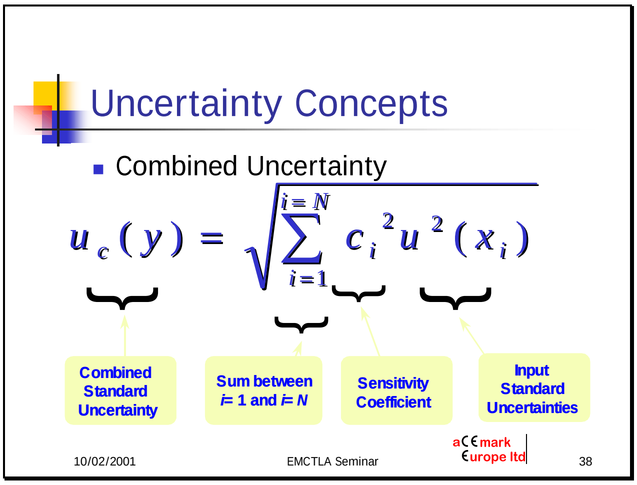
Again, our equation looks very intimidating but it looks worse than it is!

Slide 37



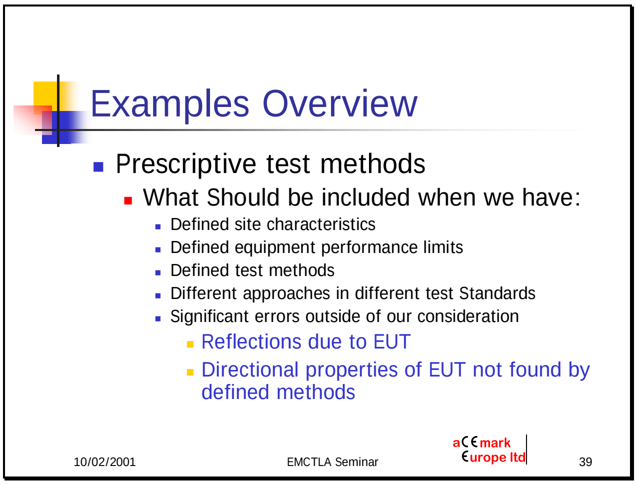
We can generally simplify our expression by assuming our type B contributions have an infinite V_i they become zero. This results in considering just our type A assessment of Repeatability. We can quickly decide if we need to worry about the degrees of freedom by dividing our combined uncertainty by our Type A standard uncertainty. If this is > 2 and our number of measurements to establish our type A was > 2 then assuming all other contributions to have infinite degrees of freedom then we have a result of at least 2^4 or 32. K=2.09 or less which is small enough to approximate to 2.

Slide 38



So going back to the horror slide from earlier we can now see that the individual standard uncertainties are modified by their distributions and then by their sensitivity coefficients to put them on the same units scale, then all the Type A and Type B contributions are combined by root-sum-of-squares (RSS) to give a single uncertainty referred to as the Combined Standard Uncertainty, u_c(y). This is then modified by our coverage factor k to give our final Expanded Measurement uncertainty with a confidence of approximately 95%. U = ku_c(y)

Slide 39



One of the problems associated with some of the EMC tests is the inconsistent approach that has been adopted by the different test Specifications or Standards. Some are very prescriptive and even include a defined approach to measurement uncertainty while others are very vague. We are left to decide how rigorous the approach should be and what can be achieved. We will see later in the examples how we have considered different test standards in very different ways depending on many contributions other that the measurement model.

It is with this in mind that a pragmatic view has developed, which, while still requiring a defined and consistent approach, maintains a more simplistic stance with respect to some of the following areas particularly in deriving our sensitivity coefficients.

Slide 40

Examples Overview

- Sensitivity Coefficients
  - Simple approach
    - Mostly set as 1
  - Consider distance errors in field strength

$$\Delta E \approx \frac{d_0}{d} \quad \text{and} \quad \Delta E^{db} \approx 20\log_{10}\frac{d_0}{d}$$

$$C_d = \frac{\partial E^{db}}{\partial d} = \frac{\partial}{\partial d}\left(20\log_{10}\frac{d_0}{d}\right) = -\frac{20}{d\log_e 10}$$

10/02/2001 EMCTLA Seminar aCEmark Europe ltd 40

In the examples that we have considered we have taken a simple approach to establishing the sensitivity coefficients. In the majority of cases, they have been set as 1. This has been done because of the significant complexity involved in calculating some of these coefficients. For example in the radiated emissions example the uncertainty associated with the EUT distance from the antenna is a function of how the field strength varies with distance, this is shown here, for a standard deviation of the error in distance of 0.058m on 10m will give the final sensitivity coefficient of –0.87. The change this makes to the overall uncertainty is not significant.
This is not advised however, if the uncertainty is large in proportion to the combined uncertainty.

Slide 41

Examples Overview

- Emissions
  - Consideration to the Test Specification
    - CISPR 16-3
- Immunity
  - Radiated EM Fields
  - Conducted EM Fields
  - Transients

10/02/2001 EMCTLA Seminar aCEmark Europe ltd 41

In the Emission examples that follow, consideration has been given to the measurement uncertainty budgets and methodology included in the forthcoming revision to CISPR 16-3. This document is currently out for voting CISPR/A/291/CDV Closing Date for Voting 2001/05/25.
For the Immunity tests we have two different approaches:
The first for tests where we calibrate a field and then re-establish that field for the EUT Test, we have considered our measurement uncertainty in the normal way.
The second is where test equipment is specified in the test standard to achieve performance within defined limits. In this case we have ensured through calibration that our equipment meets the performance requirement.

Slide 42

Conducted Emissions

- Measurement Model

$C_{FS} = R_I + L_C + L_{AMN} + dV_{SW} + dV_{PA} + dV_{PR} + dV_{NF} + d_Z + F_{STEP} + M + R_S + R_{EUT}$

- Where:
  - C_{FS} = Conducted Field Strength
  - R_I = Receiver Indication
  - L_C =Attenuation AMN-Receiver
  - L_{AMN} =AMN Voltage Division Factor
  - dV_{SW} =Receiver Sine Wave
  - dV_{PA} = Receiver Pulse
  - dV_{PR} = Receiver Pulse repetition
  - dV_{NF} = Receiver Noise Floor
  - d_Z =AMN Impedance
  - F_{STEP} =Frequency Step v BW
  - M =Mismatch
  - R_S =System Repeatability
  - R_{EUT} = EUT Repeatability

10/02/2001 EMCTLA Seminar aCEmark Europe ltd 42

The emission examples Use the same nomenclature as pr CISPR 16-3.
The output quantity we are trying to measure is conducted Field Strength in terms of dBuV.
All the input quantities can be calculated as dBuV variations, considering each of the contributions CISPR have decided that the sensitivity coefficients can all be treated as unity.
The receiver indication in the CISPR example combines several indicated errors into the one quantity even the repeatability contribution, we have decided to keep these separate and the Receiver Indication error quantity here is simply the resolution. The other receiver errors are split into its behaviour to sine waves and to pulsed signals. If the signals being measured is not pulsed and does not vary with Quasi Peak measurement versus Peak then we can remove the Pulsed contributions from our budget for those results. In the following example this would reduce the expanded uncertainty from 4.3dB to 3.6dB

Slide 43

Conducted Emissions

Conducted Disturbances from 9 kHz to 150 kHz using 50Ohm/50uH AMN

Symbol	Source of Uncertainty	Value	Probability distribution	Divisor	c_i	$u_i(y)$	$(u_i(y))^2$	v_i or v_{eff}	ui^4(y)
RI	Receiver Reading	0.05	rectangular	1.732	1	0.03	0.001	∞	0
LC	Attenuation AMN-reciever	0.40	normal 2	2.000	1	0.20	0.040	∞	0
LAMN	AMN Voltage division factor	0.20	normal 2	2.000	1	0.10	0.010	∞	0
dVSW	Receiver Sine Wave	1.00	rectangular	1.732	1	0.58	0.333	∞	0
dVPA	Receiver Pulse Amplitude	1.50	rectangular	1.732	1	0.87	0.750	∞	0
dVPR	Receiver Pulse repetition	1.50	rectangular	1.732	1	0.87	0.750	∞	0
dVNF	Noise Floor Proximity	0.00	rectangular	1.732	1	0.00	0.000	∞	0
dZ	AMN Impedance	3.60	triangular	2.449	1	1.47	2.160	∞	0
f	Frequency step error	0.00	rectangular	1.732	1	0.00	0.000	∞	0
M	Mismatch	-0.89	U-shaped	1.414	1	-0.63	0.397	∞	0
	Receiver VRC 0.15		-						0
	AMN+Cable 0.65		-						0
R_S	Measurement System Repeatability	0.50	normal 1	1.000	1	0.50	0.250	9	0.006944444
R_{EUT}	Repeatability of EUT	0.00	normal 1	1.000	1	0.00	0.000		0
$u_c(F_S)$	Combined Standard Uncertainty		normal			2.17	4.691	3169	0.006944444
$U(F_S)$	**Expanded Uncertainty**		**normal k=**	**2.00**		**4.3**		3169	

10/02/2001 EMCTLA Seminar aCEmark Europe ltd 43

Our System repeatability was based on a number of measurements over time and as modified by our weekly checks, however because it is based on passed history we do not divide it by the $N^{0.5}$.
Our EUT repeatability should be considered if the result is varying and close to the limit, here our uncertainty will be based on the number of readings we take and will reduce by dividing by $N^{0.5}$.
The Frequency Step error should be considered if we use an automated Receiver with a programmed step size. The possible error can be found by injecting a signal into the receiver and off tuning the receiver High and Low by half the step size, the lower of the two reading indicting the amplitude change should be used.

Slide 44

Radiated Emissions

Symbol	Source of Uncertainty	Value	Probability distribution	Divisor	c_i	$u_i(y)$	$(u_i(y))^2$	v_i or v_{eff}	ui^4(y)
Radiated Field Strength 30 dBµV/m to 60 dBµV/m (Biconical antenna 30 MHz to 300 MHz - Vertical Polarisation at 3 m and 10 m)									
RI	Receiver Indication	0.05	rectangular	1.732	1	0.03	0.001	∞	0
dVsw	Receiver Sine Wave	1.00	normal 2	2.000	1	0.50	0.250	∞	0
dVpa	Receiver Pulse Amplitude	1.50	rectangular	1.732	1	0.87	0.750	∞	0
dVpr	Receiver Pulse repetition	1.50	rectangular	1.732	1	0.87	0.750	∞	0
dVnf	Noise Floor Proximity	0.50	normal 2	2.000	1	0.25	0.063	∞	0
AF	Antenna Factor Calibration	1.00	normal 2	2.000	1	0.50	0.250	∞	0
CL	Cable Loss	0.50	normal 2	2.000	1	0.25	0.063	∞	0
AD	Antenna Directivity	0.50	rectangular	1.732	1	0.29	0.083	∞	0
AH	Antenna Factor Height Dependence	2.00	rectangular	1.732	1	1.15	1.333	∞	0
AP	Antenna Phase Centre Variation	0.00	rectangular	1.732	1	0.00	0.000	∞	0
AI	Antenna Factor Frequency Interpolation	0.25	rectangular	1.732	1	0.14	0.021	∞	0
SI	Site Imperfections	4.00	triangular	2.449	1	1.63	2.667	∞	0
DV	Measurement Distance Variation	0.60	rectangular	1.732	1	0.35	0.120	∞	0
Fstep	Frequency step error	0.00	rectangular	1.732	1	0.00	0.000	∞	0
M	Mismatch	-1.25	U-shaped	1.414	1	-0.88	0.781	∞	0
	Receiver VRC 0.2		-						0
	Antenna +Cable VRC 0.67		-						0
R_S	Measurement System Repeatability	0.50	normal 1	1.000	1	0.50	0.250	9	0.006944444
R_{EUT}	Repeatability of EUT	0.00	normal 1	1.000	1	0.00	0.000		0
$u_c(F_S)$	Combined Standard Uncertainty		normal			2.72	7.381	7845	0.006944444
$U(F_S)$	**Expanded Uncertainty**		**normal** k=	**2.00**		**5.4**		7845	

10/02/2001 EMCTLA Seminar 44

The same approach was taken for Radiated emissions, a model was developed and the input quantities identified. Again, we have followed CISPR in our example and maintained the Sensitivity Coefficients at unity. As we saw earlier however, strictly speaking, the quantities where measurement distance or phase centre is included should in fact be calculated, but the impact on the final expanded uncertainty will be insignificant.

One other comment to consider is that the mismatch contribution shows as a negative this is simply because we have taken the worst case of the + or – additions to calculate mismatch. The – sign itself has no impact on the budget as everything is squared anyway.

Note also that Site attenuation has been entered as the full 4dB variation but here is treated as a triangular distribution. This is based on the acceptance limits for site attenuation removing the possibility of falling outside these values, whilst this is hard to prove it is reasonable as it is also covered by the fact that some error for the antenna and receiver is included in this 4 dB which we have already included elsewhere in our budget.

Slide 45

Radiated EM Fields

Symbol	Source of Uncertainty	Value	Probability distribution	Divisor	c_i	$u_i(y)$	$(u_i(y))^2$	v_i or v_{eff}	ui^4(y)
Re-establishment of pre-calibrated field level									
FSM	Felds Strength monitor	1.20	Normal 2	2.000	1	0.60	0.360	∞	0
FSAW	Field Strength acceptability window	0.50	Rectangular	1.732	1	0.29	0.083	∞	0
PD	Forward power Measurement Drift	0.20	Rectangular	1.732	1	0.12	0.013	∞	0
PAH	Power Amplifier Harmonics	0.35	Rectangular	1.732	1	0.20	0.041	∞	0
FD	Effect of field disturbance	0.35	Rectangular	1.732	1	0.20	0.041	∞	0
RS	Measurement System Repeatability	0.50	normal 1	1.000	1	0.50	0.250	9	0.006944444
REUT	Repeatability of EUT	0.00	normal 1	1.000	1	0.00	0.000		0
$u_c(F_S)$	Combined Standard Uncertainty		normal			0.65	0.428	26	0.006944444
$U(F_S)$	**Expanded Uncertainty**		**normal k=**	**2.13**		**1.39**		26	

Specified Level	**Test level**
For 1 Volts	***1.17***
For 3 Volts	***3.52***
For 10 Volts	***11.74***

10/02/2001 EMCTLA Seminar 45

Here we are showing the budget for establishing the field strength level after calibration of the uniform Field. The budget for the uniform field has been omitted, as it is in fact a very accurate process. Remember the discussion on correlated quantities, and all 16 points in our field are being measured by the same instrument in the same set-up in the same way. The –ve correlation cancels the errors relative to each measurement and leaves just a repeatability contribution combined with any drift. The main errors for the radiated immunity test are shown above which are involved in establishing the uniform field at a known level. If we increase our test level to offset the applied field strength by our measurement uncertainty, we can achieve our 95% confidence that the correct test level was applied.

Slide 46

Conducted EM Fields

Specified Level	Test level
For 1 Volts	1.33
For 3 Volts	4.00
For 10 Volts	13.34

Case A Re-establishment of pre-calibrated Conducted field level

Symbol	Source of Uncertainty	Value	Probability distribution	Divisor	c_i	$u_i(y)$	$(u_i(y))^2$	v_i or v_{eff}
VRMS	RMS Voltmeter	0.70	Rectangular	1.732	1	0.40	0.163	∞
FSAW	Field Strength acceptability window	0.50	Rectangular	1.732	1	0.29	0.083	∞
PD	Signal generator Drift	0.20	Rectangular	1.732	1	0.12	0.013	∞
PAH	Power Amplifier Harmonics	0.70	Rectangular	1.732	1	0.40	0.163	∞
M_{VC}	Mismatch	-0.54	U-shaped	1.414	1	-0.38	0.144	∞
	rms Voltmeter= 0.2		-					
	CDN= 0.3		-					
M_{AC}	Mismatch	-1.16	U-shaped	1.414	1	-0.82	0.673	∞
	Amplifier= 0.5		-					
	CDN+6dB attenuator= 0.25		-					
R_S	Measurement System Repeatability	0.50	normal 1	1.000	1	0.50	0.250	9
R_{EUT}	Repeatability of EUT	0.00	normal 1	1.000	1	0.00	0.000	
$u_c(F_S)$	Combined Standard Uncertainty		normal			1.22	1.490	320
$U(F_S)$	**Expanded Uncertainty**		**normal k=**	**2.05**		**2.5**		320

10/02/2001 EMCTLA Seminar aCЄmark Єurope ltd 46

For our Conducted Induced EM fields example we have chosen a similar approach to the radiated example where we are re-establishing a pre-calibrated field.
The method does not require us to level the field after the Amplifier to improve the mismatch error to the range of EUT impedances that may be experienced. We have therefore included a mismatch term assuming a worst case EUT close to a short circuit.
We have again decided to increase our test level by our uncertainty to provide us with the necessary confidence that the EUT is subjected to the test level.
However there is another consideration with this measurement and that is the need to consider a different budget should the current limiting circuit used when injecting via coils or clamps. This budget is shown in the next example.

Slide 47

Conducted EM Fields 2

Uo/150	Limit level
6.67mA	8.73
20mA	26.18
60mA	78.53

Case B Limiting of Maximum Induced current level by monitor coil

Symbol	Source of Uncertainty	Value	Probability distribution	Divisor	c_i	$u_i(y)$	$(u_i(y))^2$	v_i or v_{eff}
S_A	Spectrum Analyser	1.50	Rectangular	1.732	1	0.87	0.750	∞
C_C	Current coil Calibration	1.00	normal 2	2.000	1	0.50	0.250	∞
M_{CC}	Mismatch between Coil and Cable	-0.26	U-shaped	1.414	1	-0.19	0.035	∞
	Coil= 0.3		-					
	Cable= 0.1		-					
M_{CA}	Mismatch between Cable and Analyser	-0.18	U-shaped	1.414	1	-0.12	0.015	∞
	Cable= 0.1		-					
	Analyser= 0.2		-					
R_S	Measurement System Repeatability	0.50	normal 1	1.000	1	0.50	0.250	9
R_{EUT}	Repeatability of EUT	0.00	normal 1	1.000	1	0.00	0.000	
$u_c(F_S)$	Combined Standard Uncertainty		normal			1.14	1.300	244
$U(F_S)$	**Expanded Uncertainty**		**normal k=**	**2.05**		**2.3**		244

10/02/2001 EMCTLA Seminar aCЄmark Єurope ltd 47

Here we have the budget for Conducted Induced EM fields when we are applying maximum current based on the U_0/150ohms limit in the specification.

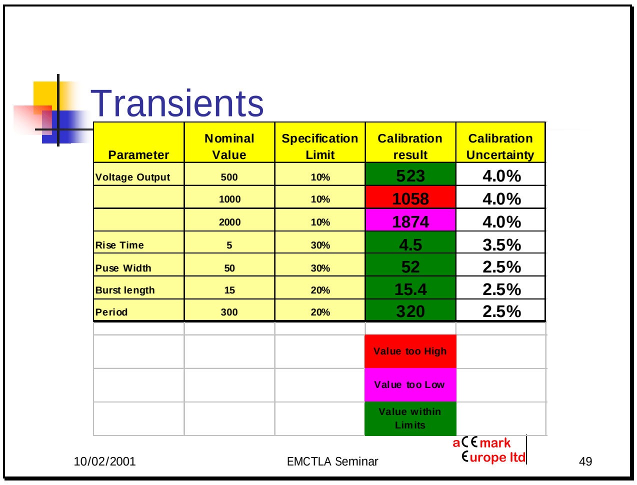
Slide 48

Transients

- ESD
- EFTB
- Surge
- Voltage dips and Interrupts

10/02/2001 EMCTLA Seminar aCЄmark Єurope ltd 48

In the case of our Transient Test Specifications we have a different case, the equipment is defined to meet certain performance characteristics and the methods then requires the tests to be performed using compliant equipment.
We have taken the view that unless otherwise stated these types of tests include the allowable uncertainty in the defined performance criteria.
We should then demonstrate that our equipment meets the requirements through calibration and we can then use the following statement in our test reports:
"The test equipment has been demonstrated by calibration to provide at least a 95% confidence that it complies with the Test specification Requirements"



Transients

Parameter	Nominal Value	Specification Limit	Calibration result	Calibration Uncertainty
Voltage Output	500	10%	523	4.0%
	1000	10%	1058	4.0%
	2000	10%	1874	4.0%
Rise Time	5	30%	4.5	3.5%
Puse Width	50	30%	52	2.5%
Burst length	15	20%	15.4	2.5%
Period	300	20%	320	2.5%

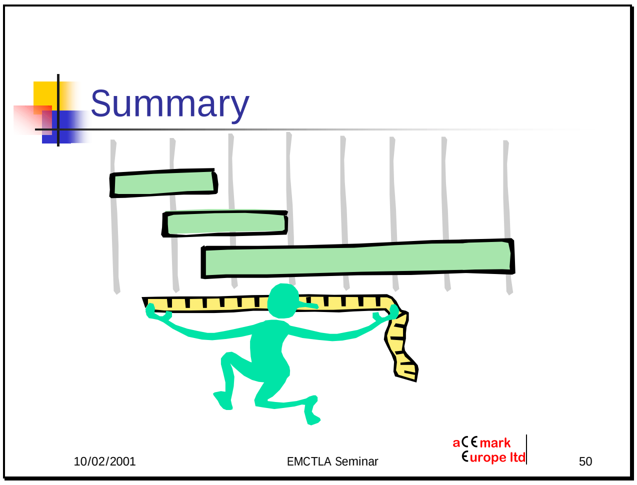
Value too High
Value too Low
Value within Limits

10/02/2001 EMCTLA Seminar aCЄmark Єurope ltd 49

Slide 49

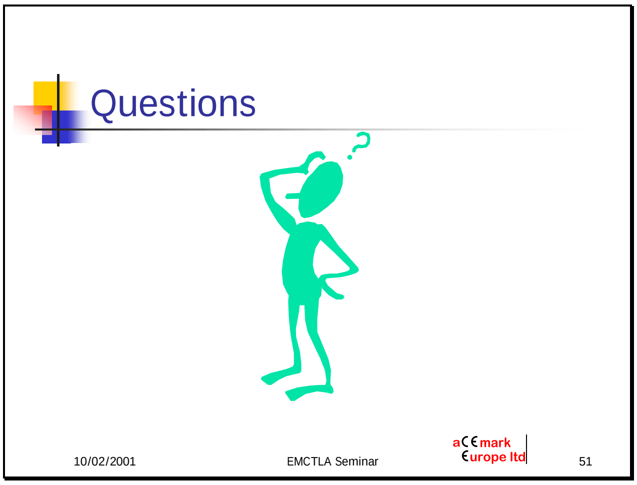
The table shows the use of conditional formatting to indicate results are between the limits higher than the limits or lower than the limits. The specification limits have been inset by the calibration laboratory's uncertainty.
To be complete however, we should ensure through our equipment checks that the waveform continues to perform as expected. This can be achieved by taking data on the equipments return from calibration and periodically after, when sufficient readings have been obtained, a mean and a standard deviation should be calculated and in-service limits to the check results established by applying a + or – 2 standard deviations limit to the check results. Regular checks will confirm our performance and identify any trends etc.
Strictly, we should combine the standard uncertainty from the repeated check results with the original calibration laboratory uncertainty to inset the limits to give us our ongoing 95% confidence.

If we keep the pragmatic approach to our measurement uncertainty we can keep it simple. There are many other complications if we want to include them but the gain is not sufficient to make the effort worthwhile. The very nature of EMC testing gives us quantifiable errors of close to 100%, but that is without counting the un-quantifiable errors that the methods do not account for. In addition to maintaining a strict adherence to our test equipment calibration and set up we must also attempt to be as consistent as possible in our approach to EUT set-up. As the EUT is often the biggest single contribution to the errors. We should ensure we can repeat our measurement as close to the original as possible should the need aver arise.
As a final point, we should consider our measurement as giving us a range in which our result lies instead of having an absolute value! If we think in these terms, we are more likely to properly explain the issues to our customers.



Slide 50

Slide 51



Go ahead make my day