Correlation of Model Simulations and Measurements

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Correlation of Model Simulations and Measurements

Methods of *Quantifying* Data Correlations

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Outline

Definitions

- Variability and population spreads
- Unit-by-unit versus statistical methods
- Measurements
- Feature selective validation (FSV) methods
- Eye closure methods
- Monte-Carlo and other statistical methods
- Errors and uncertainty
- Challenge problems
- Probabilistic design
- Summing up



Validation Versus Verification

- Validation
- Verification
- Accuracy
- Precision
- Deterministic
- Probabilistic



Accuracy and Precision Illustrated



(a) Accurate but not precise (b) Precise but not accurate (c) Accurate and precise



Statistical Design

- Three well known statistical design methods are:
 - Worst Case
 - Monte-Carlo
 - Design-Of-Experiments (DOE)
- Gaussian normal distributions are common
- Accurate Mean and ±3σ is critical information that enables accurate risk assessment statistical design and intelligent design choices
- Accurate Mean and ±3σ is proprietary information that also enables suppliers to set intelligent guard banding, yield, and spec control limits



Process Variation



Process control is important for defining model parameter value ranges, distribution and predictability



Unit-by-unit (classical) Versus Statistical Correlations

Unit-Unit Correlation	Statistical Correlation
Requires a one-to-one correlation between the models and/or units used in the two sets of data.	 Mean Gaussian or "Normal" Standard Deviation, σ
Upside: It is very deterministic and gives a high level of comfort. Not hard with simulation.	Upside: It is very economical to generate via simulation.
Downside: It is VERY tedious, expensive, and painstaking to generate and track physical unit data deterministically.	Downside: Simulation run time and cost of taking lab data on many (sample size) prototypes.

Suggestion: Production test verification data can be used



Switching Measurements

- Here are measurements that can be computed/measured on a population of devices:
 - First switch
 - Final settle
 - Noise margins
 - Propagation and buffer delays
 - Rise and fall times
 - Overshoot and undershoot
 - Crosstalk
 - Jitter and skew
 - Timing margins
- Mean and σ can be computed for these quantities (and others).
- Simulation and measurements can then be compared on a statistically significant basis.





Conditions for Accurate and Precise Waveform Measurements

- Simple waveforms the more ringing and overshoot – the more difficult it is to get repeatable correlations.
- High-speed waveforms are usually anything but simple – witness the discussion being advanced for DDR2 waveform measures



Curve Overlay Metric

The Curve Overlay Metric and Figure of Merit (FOM) applies to cases in which the measured and simulated data (waveforms) should theoretically lie directly on top of each other." page 13, IBIS I/O Buffer Accuracy Handbook.

http://www.vhdl.org/pub/ibis/accurac y/handbook.pdf

A presentation, an example, a test board, and C source code that will compute three FOMs are available at:

http://www.vhdl.org/pub/ibis/accur acy





Feature Selective Validation (FSV) Method

- The FSV method was developed by EMC/EMI engineers interested in comparing frequency spectrum data sets. Here the x-axis is in frequency units and the y-axis is in amplitude, usually db units.
- An IEEE-EMC Society standards committee is developing a specification, P1597, for FSV. A final draft will be going out for comment 1/31/07.
- FSV can equally be applied to time-domain data sets. Here the x-axis is in time units and the y-axis is in amplitude, usually db units.



FSV: ADM, FDM, and GDM

- FSV is similar to FOM except the data is discrete and not necessarily monotonic
- The FSV mathematics separates out 2 sets of data, being compared on a common plot, and quantifies the x and y separations of common features
- Amplitude Difference Measure (ADM)
- Feature (frequency or time) Difference Measure (FDM)
- Global Difference Measure (GDM)



Human (Qualitative) Judgment

The humanlanguage measure was developed from a sixpoint binary rating scale of:

> 1=excellent 2=very good 3=good 4=fair 5=poor 6=very poor





FSV: Quantitative and Qualitative

FSV Quantitative Value	FSV Qualitative Value
Less than 0.1	1=Excellent
Between 0.1 and 0.2	2=Very Good
Between 0.2 and 0.4	3=Good
Between 0.4 and 0.8	4=Fair
Between 0.8 and 1.6	5=Poor
Greater than 1.6	6=Very Poor



FSV-GDM: An Example





GDM Results



Histogram of observer qualitative results from graphs 1 and 6



FSV and Visual Results

Graph 6



Comparison of visual and FSV interpretation of Graph 6





- To make FSV available to any user, a dedicated standalone software interface was developed. The software can be downloaded at: http://ing.univaq.it/uaqemc/
- References:
 - G. Antonini, C. Ciccomancini Scogna, A. Orlandi, C. Ritota and A. Duffy, "Applications of FSV to EMC and SI Data," *IEEE International Symposium on EMC,* Chicago, 2005
 - B. Archambeault, S. Connor and A. Duffy, "Comparing FSV and Human Responses to Data Comparisons," *IEEE International Symposium on EMC*, Chicago, 2005
 - A. Duffy, A. Martin, G. Antonini, A. Orlandi and C. Ritota, "The Feature Selective Validation (FSV) Method," *IEEE International Symposium on EMC*, Chicago, 2005.
 - A. J. M. Martin, A. R. Ruddle, & A. P. Duffy, "Comparison of Measured and Computed Local Electric Field Distributions Due to Vehicle-Mounted Antennas Using 2D Feature Selective Validation," IEEE International Symposium on EMC, Chicago, 2005.



Eye Diagrams



- Eye diagrams are generated with pseudo-random bit sequence (PRBS) digital signals
- Eye diagram measurements: % crossing, eye height, eye width, quality factor, extinction ratio, predominant peaks, and jitter. See also: Bathtub Curves, BER



Bathtubs and BERs

- Bathtub curves of timing errors (BER) are a cumulative density function (CDF) of the jitter probability density function (PDF)
- Bathtub curves come from statistical analysis of a channel with an infinite bit stream
- Bathtub curves are easy to determine after performing step and pulse responses of the channel



Figure 2 - Illustration of relationship between eye diagram, jitter PDF, and bathtub curve. a) Eye diagram indicating data transition threshold. b) Jitter PDF (thick line) with TailFit[™] extrapolation (thin line). c) Bathtub curves found from jitter PDF (thick line) and TailFit[™] extrapolation (thin line).

"Relationship Between Eye Diagrams and Bathtub Curves," Technical Bulletin #13, Wavecrest Corp. 2003



Multiple Monte-Carlo Simulations



- Results of 100 Monte-Carlo simulations of an RF, single stage bandpass amplifier varying circuit element values
- Response surface methods are related to Monte-Carlo but for 3 or more variables



DOE Matrix Examples



Run Order	Turns	Radius	Width	Inductance
1	4.0285	89.5725	10.299	2.17
2	4.236	105	13	2.63
3	5	92.9415	11.3315	3.28
4	5	75	13	2.03
5	3.9558	90.663	8	2.92
6	3	105	10.9155	1.52
7	5	105	8.29125	5.17
8	3	75	8.29125	1.04
9	3.8039	75	11.3315	1.48
10	5	75	8	2.98
11	3	86.46	13	0.95
12	3	105	8	1.91
13	4.0285	89.5725	10.299	2.18
14	5	92.9415	11.3315	3.31
15	3	105	10.9155	1.5
16	3.8039	75	11.3315	1.46
17	3	105	8	1.87

Reference [D]



ANOVA Examples

- ► Fractional factorial DOE experiments save much effort in the numbers of simulation/measurement runs. (1000 → 100 or less).
- But they assume "orthogonality," that is independent, variables.
- ANOVA checks for, and highlights, interaction effects between variables.



Reference [E]



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Error Sources

- Systematic Error:
 - Measurement example: Using an oscilloscope with too low of a bandwidth.
 - Model and simulation example: something left out of the model that is important.
 - After diagnosis systematic errors can be reduced or eliminated by implementing a fix.
- Natural Variability:
 - Use statistical and probabilistic design approaches.
 - Use simulation predictions and measurements with a known range of uncertainty.
- Random Chance:
 - Use sampling distributions and sampling plans.



Predictions and Measurements with a Known Range of Uncertainty



Reference: http://www.micromagazine.com/archive/05/06/yates.html





Measurement Uncertainty Standards

- UKAS Lab 34: The Expression of Uncertainty in EMC Testing
- IEC 61000 Series:
- CISPR 16-4-2: Specification for radio disturbance and immunity measuring apparatus and methods
 Part 4-2: Uncertainties, statistics and limit modeling - Uncertainty in EMC measurements.
- NIST: TN1297: Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results.



Test Board Example II



"Signal Integrity Model Plots," MWS Support CST Studio 2006B ©Sonnet Software Inc., 2005: Used with permission.



S-Parameters for Test Board



"Signal Integrity Model Plots," MWS Support CST Studio 2006B ©Sonnet Software Inc., 2005: Used with permission.



Probabilistic Concepts

Confidence interval	A statistical range with a specified probability that a given parameter lies within the range.
Confidence limits	Either of the two numbers that specify the endpoints of a confidence interval.
Confidence level	The probability value, for example 90%, associated with a confidence interval.

- Probability distribution (PD)
- Cumulative probability distribution (CPD)
- Example: CISPR 22 calls out that we need to show that 80% of a population of equipment will fall below some emission limit, L, with an 80% statistical confidence limit. This is known as the 80-80 rule.



Probability Example

- A system containing ten items that emit at a common frequency. The PD and CPD display a characteristic form. Examples are displayed for the case of common emissions amplitudes, in this case 40 dBmV/m.
- Examination of the figures show that the amplitude, of the combined, system-level emissions, in this case occur between the worst-case limit of (40 dBmV/m + 20 log10{10}) = 60 dBmV/m and a best-case limit of zero.
- The top figure shows that the PD displays a maximum at a system emissions amplitude of ~ 48 dBmV/m. This is some 12 dB below the worst-case value.





Confidence Building Versus Design Assurance

Confidence Building	Design Assurance
►Is about accuracy	►Is risk management
Keep it simple but detailed	Prioritize, but verify everything
Use special purpose boards	Use prototype boards
Investigate the minutia but off-line	Practice conservative, robust design
Tend towards deterministic simulations	Tend towards statistical and probabilistic simulations



Summary

- Remember that methods such as FOM and FSV (excellent as they are) are a comparison of two *single* simulations or a simulation and measurement.
- FOM and FSV must be combined with something like Worst-Case, Monte-Carlo, or DOE to incorporate variability and random chance.
- Calculating the mean and standard deviation of a "population" of measurements and/or simulations is one way of summarizing variability and correlation.
- Confidence-building, high-accuracy correlations should be simple. Design assurance applies to complex, real prototypes, but then don't expect high-accuracy correlations.
- Smart engineers don't design to the limits of model and measurement accuracy and they desensitize their circuits.



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