5 Tips to minimize your Pass/Fail errors

Technical Manager

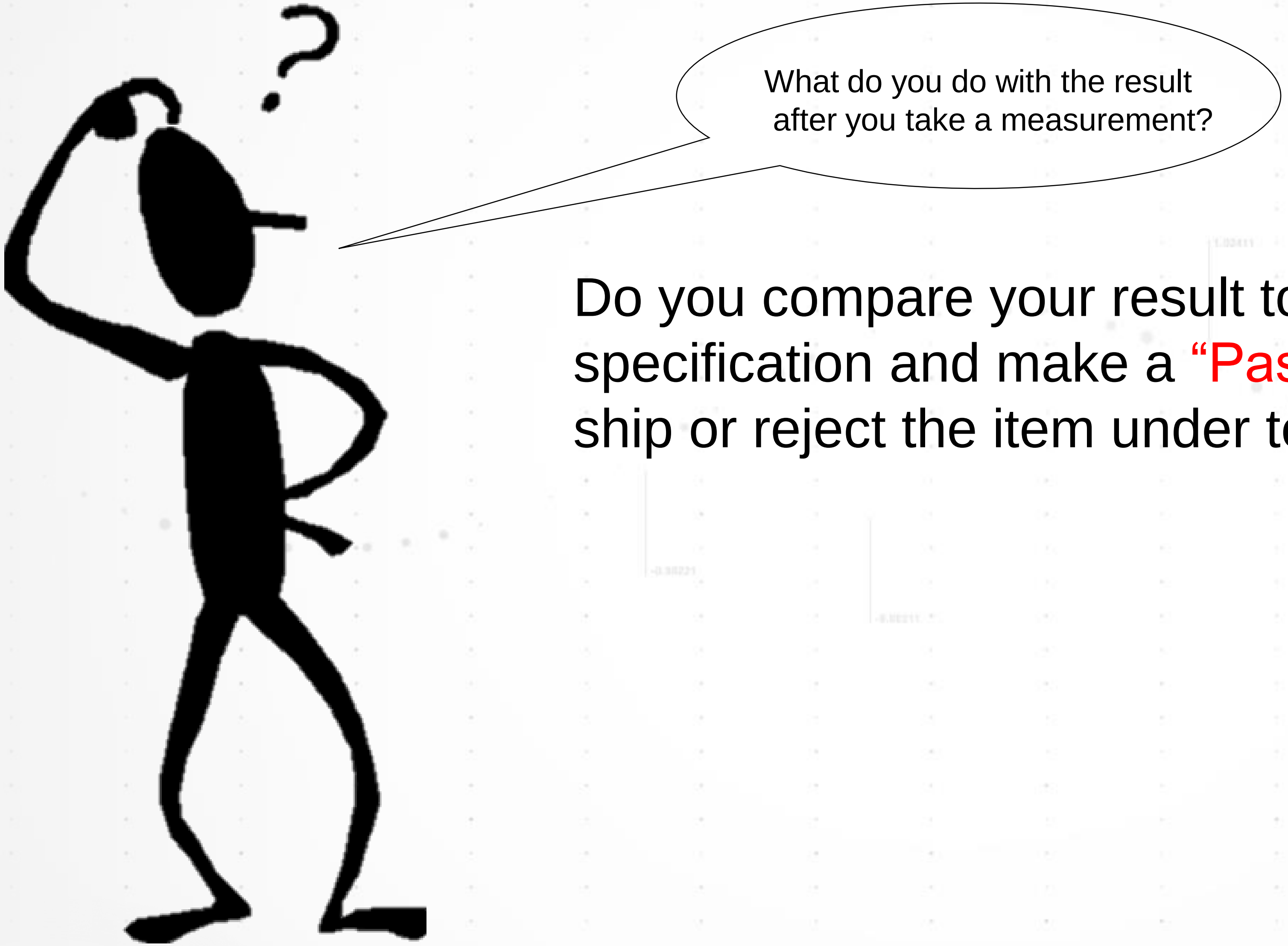
Su Hyoung Park

KEYSIGHT TECHNOLOGIES

Agenda – what's next?

- What is measurement decision risk?

Why do you make measurements?



Do you compare your result to a [customer] specification and make a “Pass” or “Fail” decision to ship or reject the item under test?

Why are decision rules important?

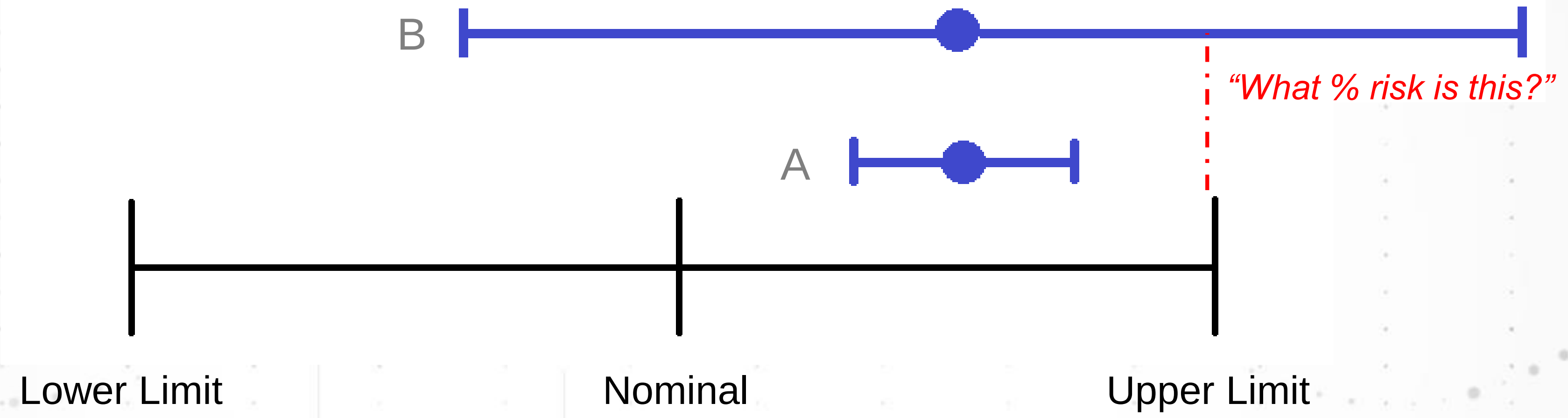
- When performing a measurement and subsequently making a Pass/Fail statement such as in or out-of-tolerance to manufacturer's specifications **there are two possible outcomes**
  - You are right
  - You are wrong

There are no perfect measurements ☹

- Each measurement has an associated uncertainty, and it is that uncertainty that can affect your chance of being right or wrong

Source: Jeff Gust, Chief Corporate Metrologist, Fluke

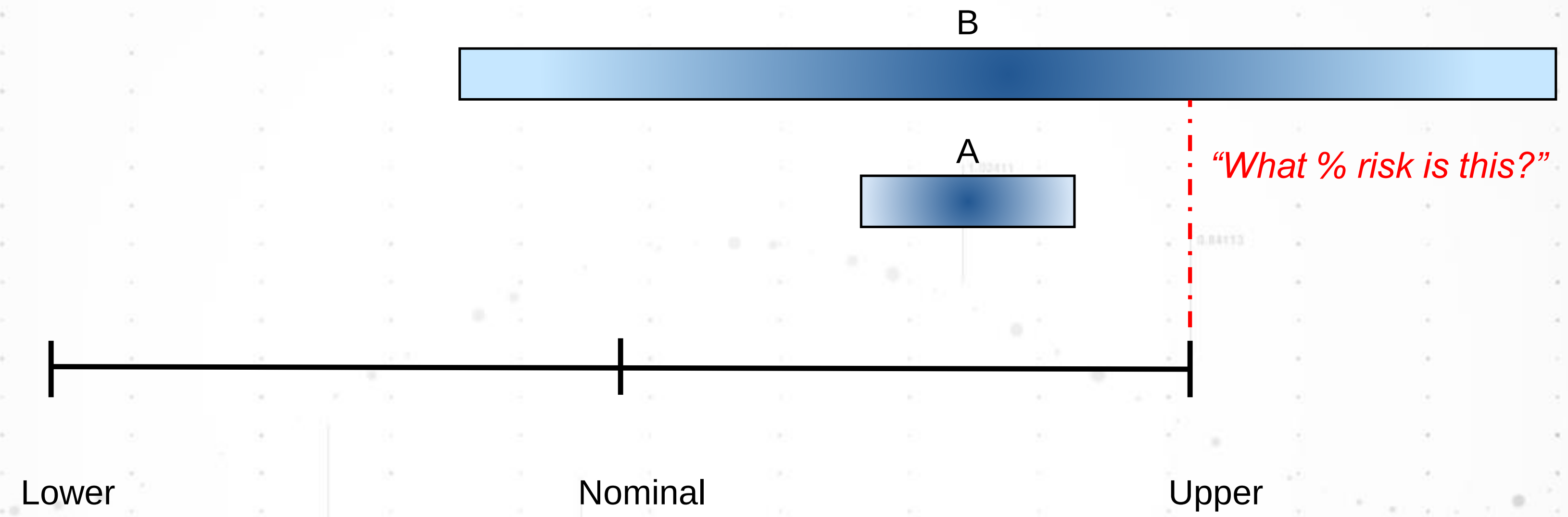
Measurement Decision Risk



- If your uncertainty is large compared to the specified requirement, how confident are you in your declaration of In-Tolerance or Out-of-Tolerance?

Source: Jeff Gust, Chief Corporate Metrologist, Fluke

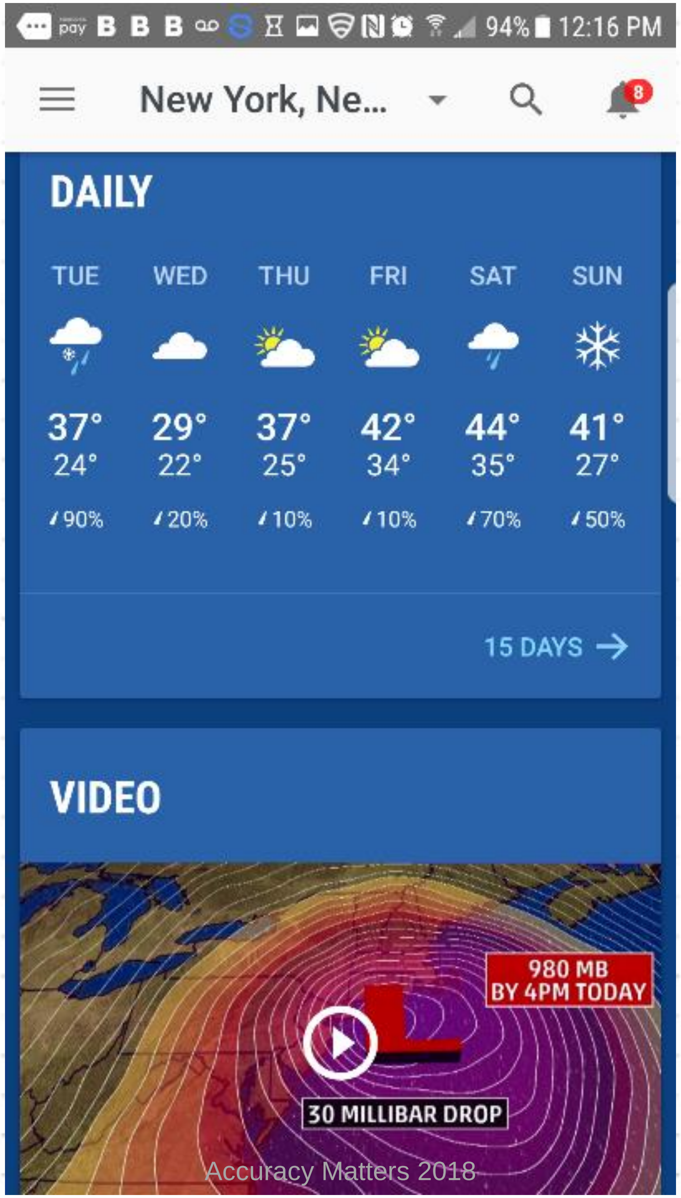
What % Risk is This?



Drawing courtesy of Steve Marschke, Raytheon

People Know How to Make Trade-offs Based on % Risk

What actions will
you take each day?



Agenda – what's next?

- What is measurement decision risk?
- Errors due to measurement decision risk

Measurement Uncertainty Causes Two Types of Test Errors That Increase Testing Costs

True State of Product

Test Outcome	Good	Bad
Pass	✓	Increases return rate & warranty costs
Fail	Increases rework & scrap costs	✓

Agenda – what's next?

- What is measurement decision risk?
- Errors due to measurement decision risk
- Measurement Uncertainty (a.k.a. "test system accuracy")

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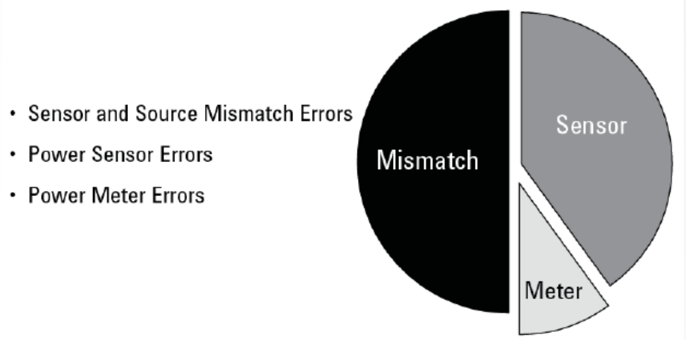
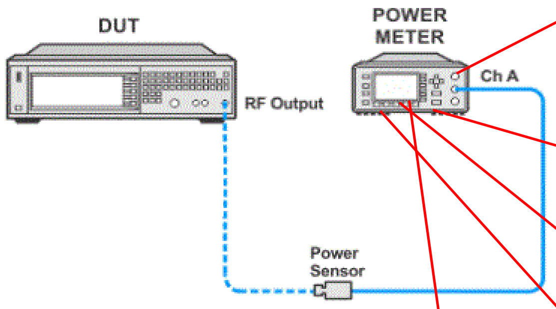
The Expression of Uncertainty and Confidence in Measurement

CONTENTS

Power Measurement Uncertainty





U(Pcal) Calibrator output level uncertainty

U(Zs) Power meter zero set uncertainty

U(Zs) Power meter instrumentation uncertainty

U(D) Power meter drift uncertainty

u(Mu) Mismatch uncertainty, sensor & sig-gen

u(Muc) Mismatch unc., sensor & cal output

u(Kb) Sensor calibration factor uncertainty

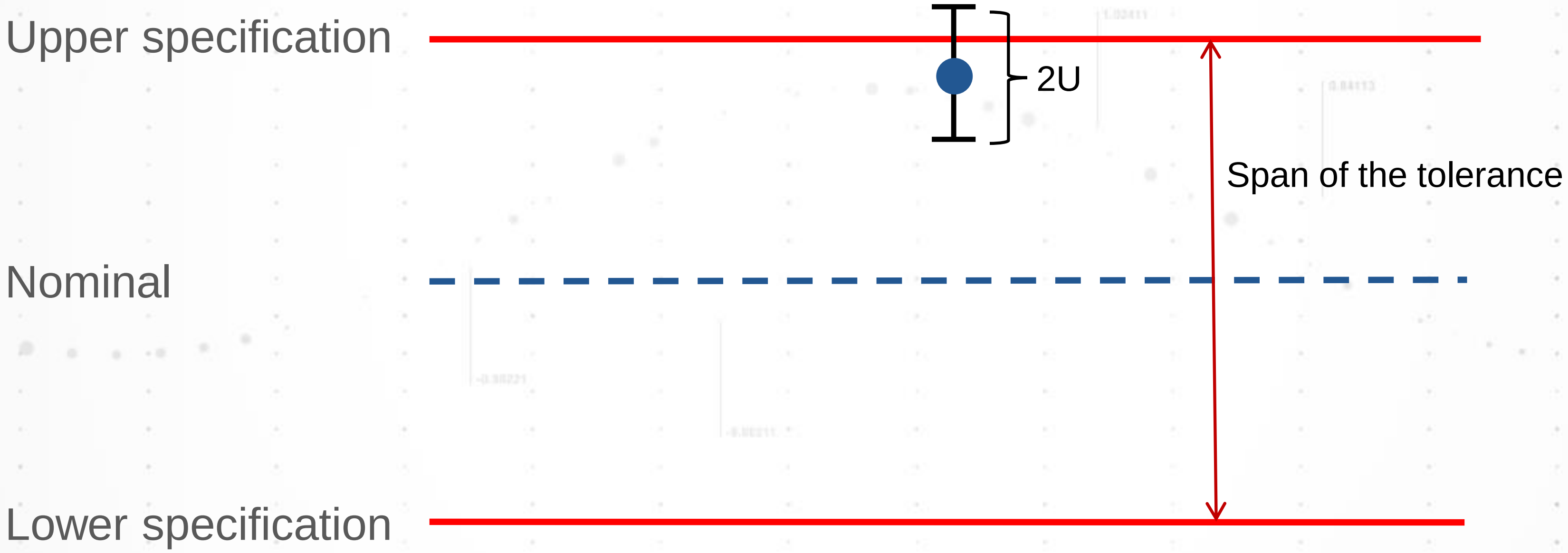
u(N) Sensor and meter noise uncertainty

u(P_l) Sensor linearity uncertainty

http://cp.literature.keysight.com/litweb/pdf/5988-9215EN.pdf

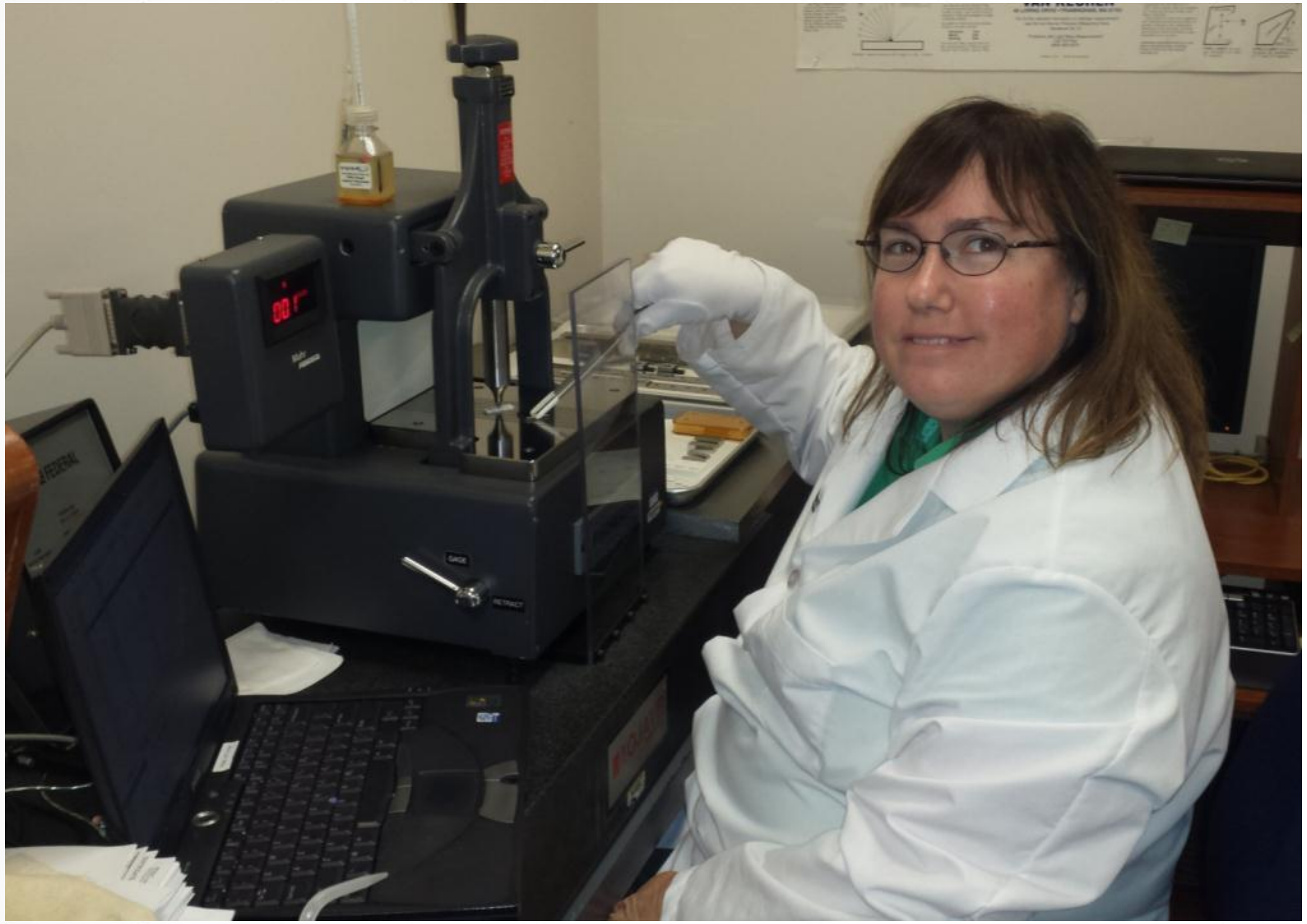
Test Uncertainty Ratio (TUR) Defined

$$TUR = \frac{\text{Span of the tolerance}}{2U}$$



TUR = Test Uncertainty Ratio, paragraph 3.11 ANSI Z540.3

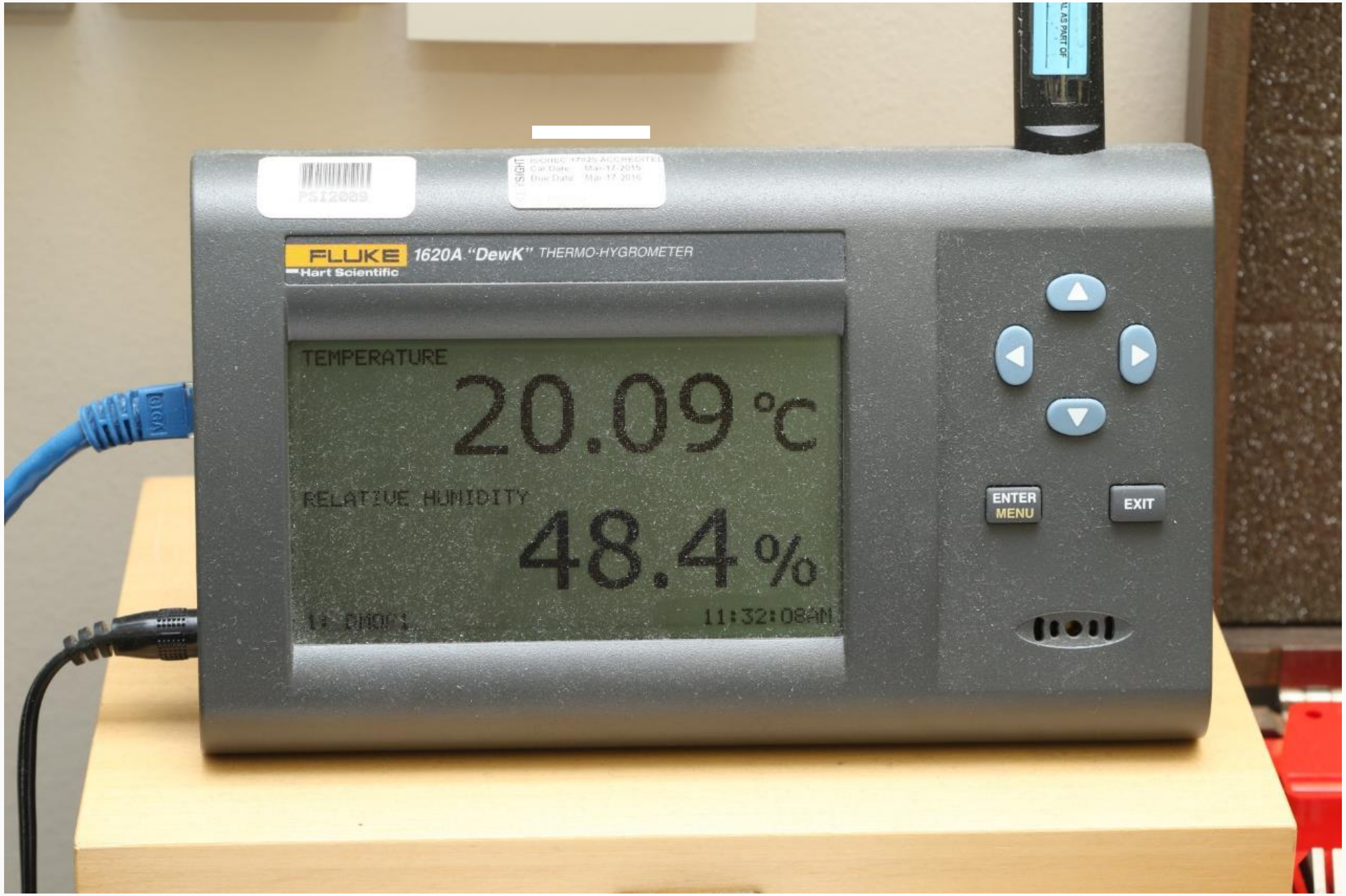
When is TAR[1] acceptable?



Gage block comparator

1. TAR = “Test Accuracy Ratio”, compares Tolerance to a single error type.

Gage Blocks Need 20º ± 0.5º Celsius

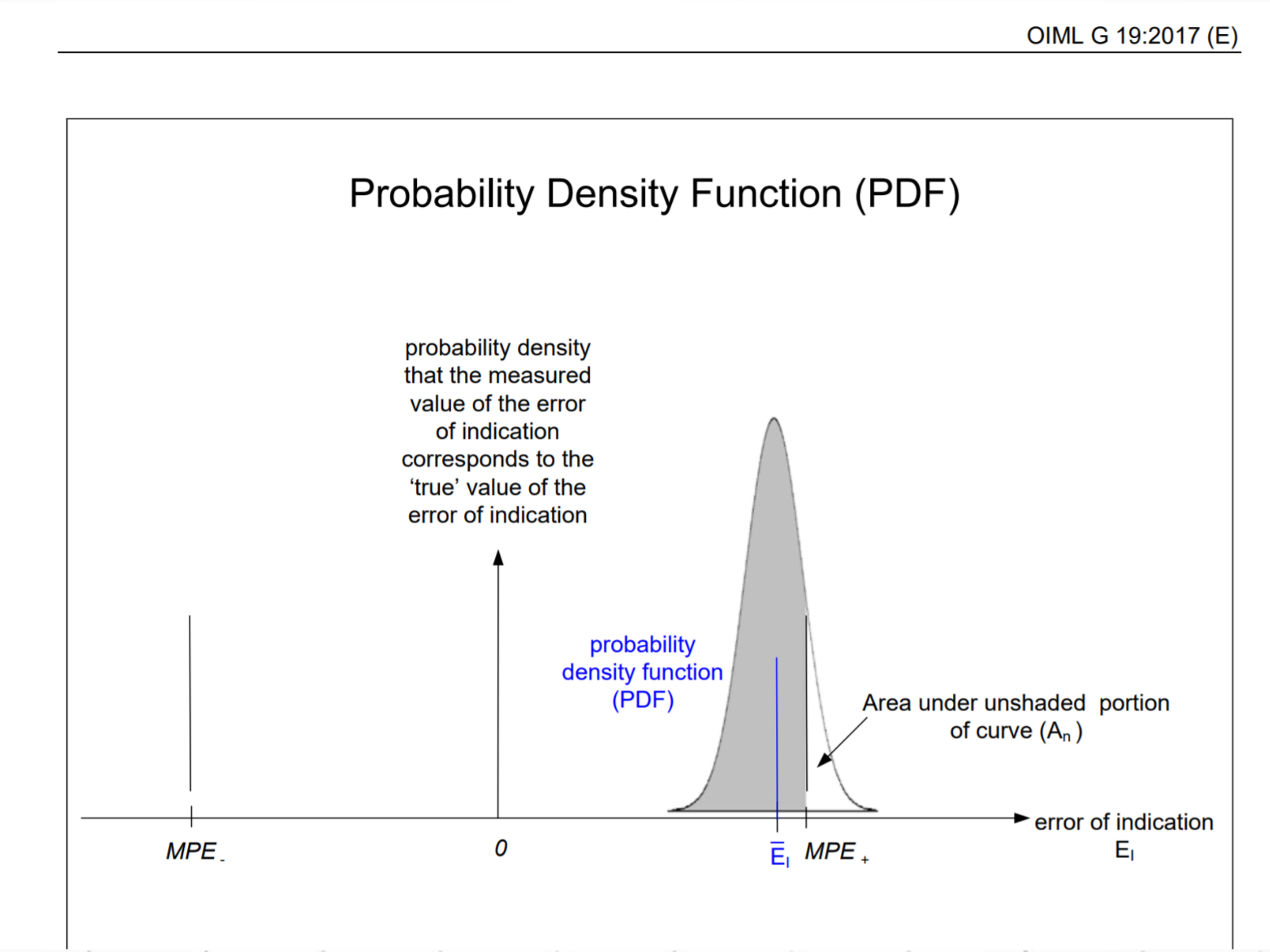



PLEASE DO NOT USE
Starrett
WEBBER GAGE DIV
Mitutoyo CALIBRATION
PSI 1335

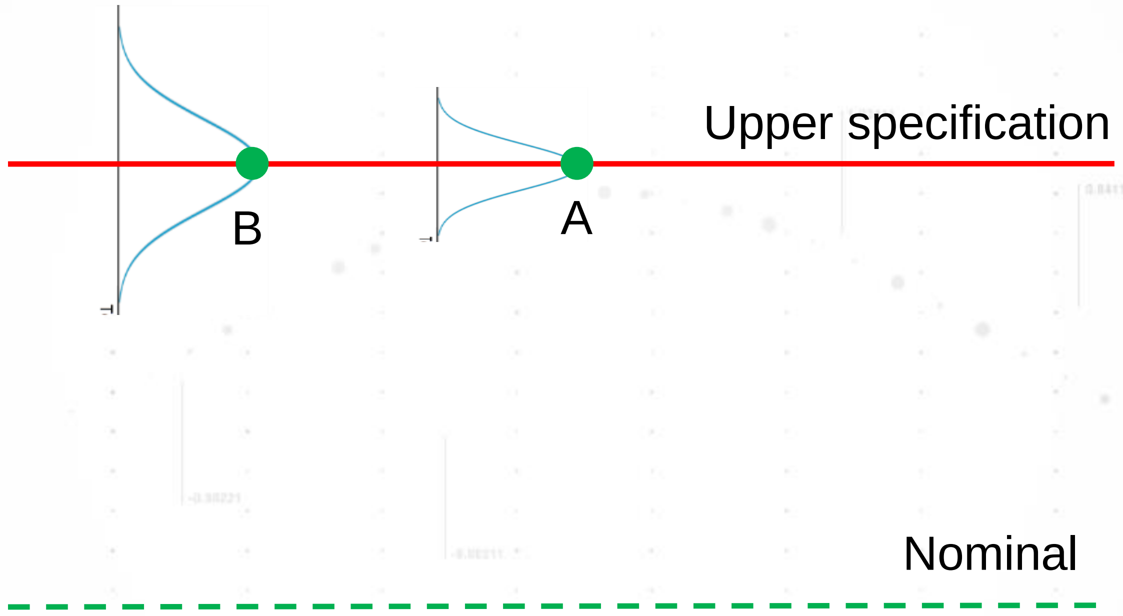
Agenda – what's next?

- What is measurement decision risk?
- Errors due to measurement decision risk
- Measurement Uncertainty (a.k.a system accuracy)
- ➡ Specific risk

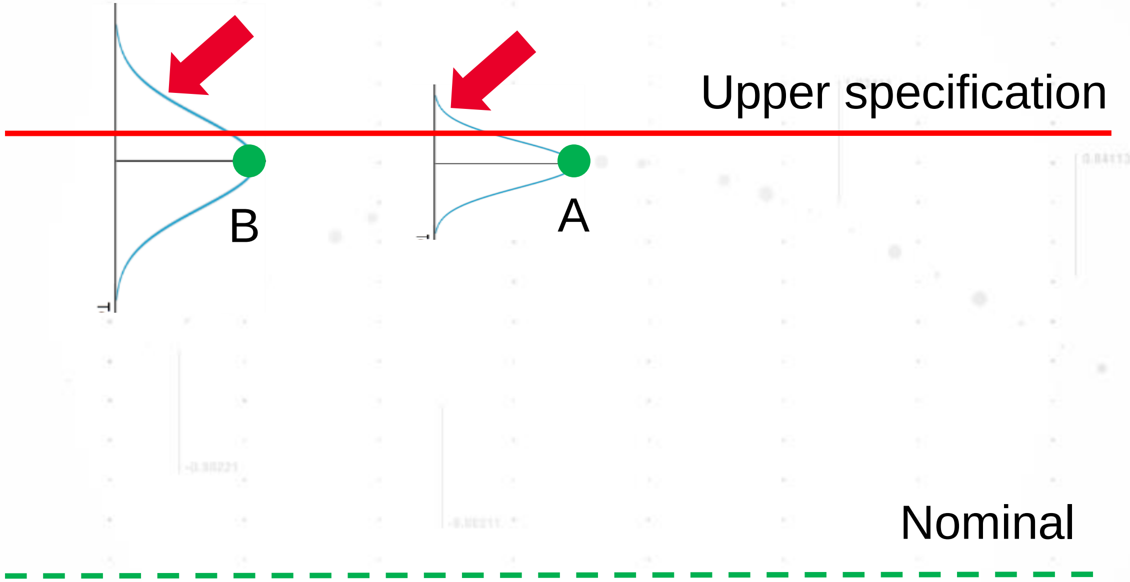
Specific Risk



Zero Guardband Decision Rule – “Shared risk”



A Little Guard Band Goes a Long Way for Higher TURs



Example: Estimating Specific PFA (2)

Standard normal distribution table

The table below contains the area under the standard normal curve from $x = 0$ to a specified value $x = \alpha$.

Area under the Normal Curve from $X = 0$ to $X = \alpha$

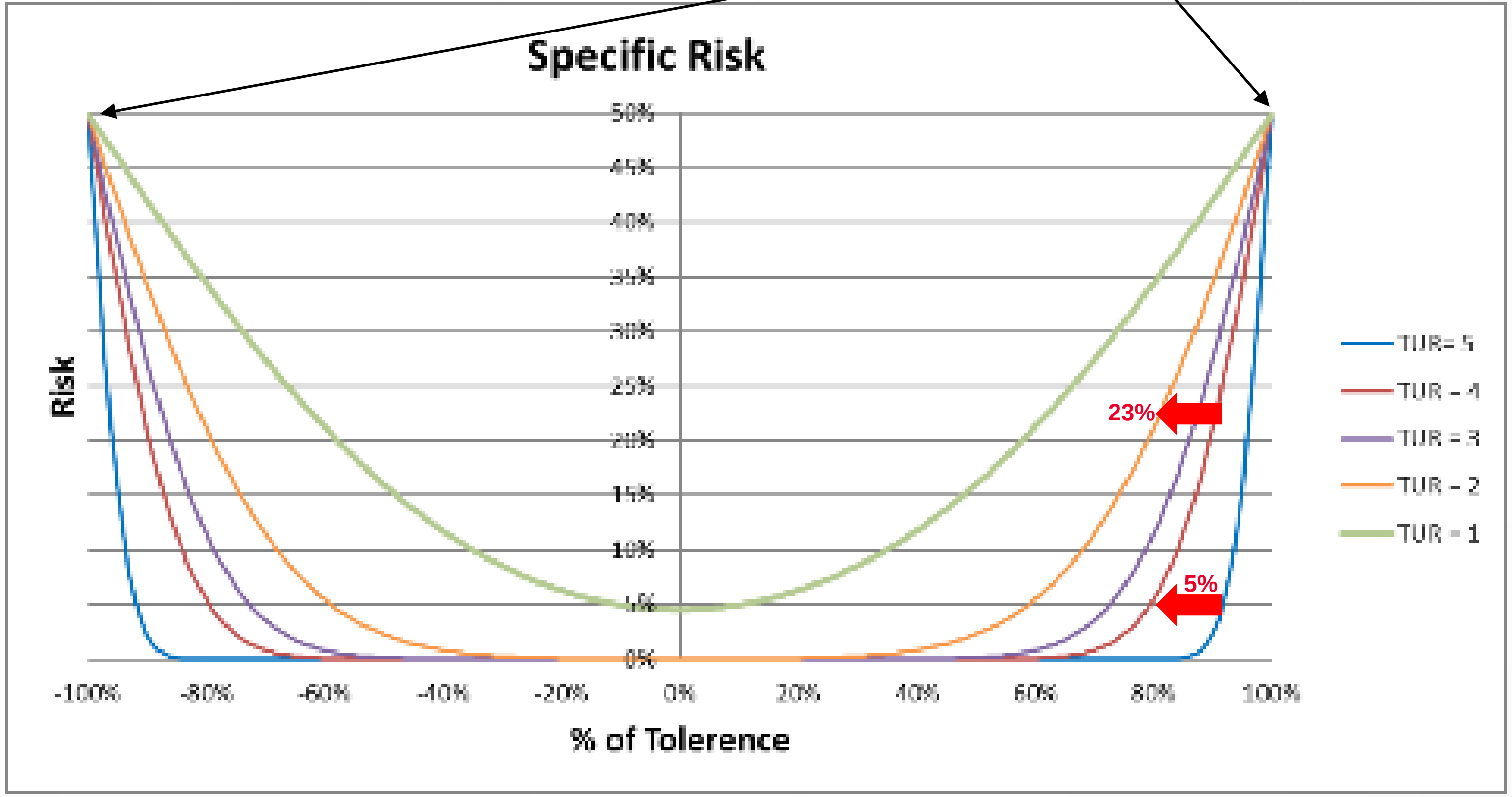
α	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.00000	0.00399	0.00798	0.01197	0.01595	0.01994	0.02392	0.02790	0.03188	0.03586
0.1	0.03983	0.04380	0.04776	0.05172	0.05567	0.05962	0.06356	0.06749	0.07142	0.07535
0.2	0.07926	0.08317	0.08706	0.09095	0.09483	0.09871	0.10257	0.10642	0.11026	0.11409
0.3	0.11791	0.12172	0.12552	0.12930	0.13307	0.13683	0.14058	0.14431	0.14803	0.15173
0.4	0.15542	0.15910	0.16276	0.16640	0.17003	0.17364	0.17724	0.18082	0.18439	0.18793
0.5	0.19146	0.19497	0.19847	0.20194	0.20540	0.20884	0.21226	0.21566	0.21904	0.22240
0.6	0.22575	0.22907	0.23237	0.23565	0.23891	0.24215	0.24537	0.24857	0.25175	0.25490
0.7	0.25804	0.26115	0.26424	0.26730	0.27035	0.27337	0.27637	0.27935	0.28230	0.28524
0.8	0.28814	0.29103	0.29389	0.29673	0.29955	0.30234	0.30511	0.30785	0.31057	0.31327
0.9	0.31594	0.31859	0.32121	0.32381	0.32639	0.32894	0.33147	0.33398	0.33646	0.33891
1.0	0.34134	0.34375	0.34614	0.34849	0.35083	0.35314	0.35543	0.35769	0.35993	0.36214
1.1	0.36433	0.36650	0.36864	0.37076	0.37286	0.37493	0.37698	0.37900	0.38100	0.38298
1.2	0.38493	0.38686	0.38877	0.39065	0.39251	0.39435	0.39617	0.39796	0.39973	0.40147
1.3	0.40320	0.40490	0.40658	0.40824	0.40988	0.41149	0.41308	0.41466	0.41621	0.41774
1.4	0.41924	0.42073	0.42220	0.42364	0.42507	0.42647	0.42785	0.42922	0.43056	0.43189
1.5	0.43319	0.43448	0.43574	0.43699	0.43822	0.43943	0.44062	0.44179	0.44295	0.44408
1.6	0.44520	0.44630	0.44738	0.44845	0.44950	0.45053	0.45154	0.45254	0.45352	0.45449
1.7	0.45543	0.45637	0.45728	0.45818	0.45907	0.45994	0.46080	0.46164	0.46246	0.46327
1.8	0.46407	0.46485	0.46562	0.46638	0.46712	0.46784	0.46856	0.46926	0.46995	0.47062
1.9	0.47128	0.47193	0.47257	0.47320	0.47381	0.47441	0.47500	0.47558	0.47615	0.47670
2.0	0.47725	0.47778	0.47831	0.47882	0.47932	0.47982	0.48030	0.48077	0.48124	0.48169
2.1	0.48214	0.48257	0.48300	0.48341	0.48382	0.48422	0.48461	0.48500	0.48537	0.48574
2.2	0.48610	0.48645	0.48679	0.48713	0.48745	0.48778	0.48809	0.48840	0.48870	0.48899
2.3	0.48928	0.48956	0.48983	0.49010	0.49036	0.49061	0.49086	0.49111	0.49134	0.49158
2.4	0.49180	0.49202	0.49224	0.49245	0.49266	0.49286	0.49305	0.49324	0.49343	0.49361
2.5	0.49379	0.49396	0.49413	0.49430	0.49446	0.49461	0.49477	0.49492	0.49506	0.49520
2.6	0.49534	0.49547	0.49560	0.49573	0.49585	0.49598	0.49609	0.49621	0.49632	0.49643
2.7	0.49653	0.49664	0.49674	0.49683	0.49693	0.49702	0.49711	0.49720	0.49728	0.49736
2.8	0.49744	0.49752	0.49760	0.49767	0.49774	0.49781	0.49788	0.49795	0.49801	0.49807
2.9	0.49813	0.49819	0.49825	0.49831	0.49836	0.49841	0.49846	0.49851	0.49856	0.49861
3.0	0.49865	0.49869	0.49874	0.49878	0.49882	0.49886	0.49889	0.49893	0.49896	0.49900
3.1	0.49903	0.49906	0.49910	0.49913	0.49916	0.49918	0.49921	0.49924	0.49926	0.49929
3.2	0.49931	0.49934	0.49936	0.49938	0.49940	0.49942	0.49944	0.49946	0.49948	0.49950
3.3	0.49952	0.49953	0.49955	0.49957	0.49958	0.49960	0.49961	0.49962	0.49964	0.49965
3.4	0.49966	0.49968	0.49969	0.49970	0.49971	0.49972	0.49973	0.49974	0.49975	0.49976
3.5	0.49977	0.49978	0.49978	0.49979	0.49980	0.49981	0.49981	0.49982	0.49983	0.49983
3.6	0.49984	0.49985	0.49985	0.49986	0.49986	0.49987	0.49987	0.49988	0.49988	0.49989
3.7	0.49989	0.49990	0.49990	0.49990	0.49991	0.49991	0.49992	0.49992	0.49992	0.49992
3.8	0.49993	0.49993	0.49993	0.49994	0.49994	0.49994	0.49994	0.49995	0.49995	0.49995
3.9	0.49995	0.49995	0.49996	0.49996	0.49996	0.49996	0.49996	0.49996	0.49997	0.49997

Source:
OIML G 19 Annex B; an adaptation from the
NIST/SEMATECH e-Handbook of Statistical Methods
http://www.itl.nist.gov/div898/handbook/eda/section3/eda3671.htm

Estimating Specific Measurement Decision Risk

IS A FUNCTION OF TOLERANCE, UNCERTAINTY, AND MEASURED VALUE

Max Risk 50%



Source: Harben & Stern, NCSLI paper 2017

Example: Speed Limit Enforcement

Example : Speed Limit Enforcement

If the Doppler radar gun uncertainty = 2%, what speed must he measure to ensure a car is travelling > 100 km/hr (60 mph) with 99.9% probability?

One-sided specific risk

p_c	$\overline{p}_c$	z
0.80	0.20	0.84
0.90	0.10	1.28
0.95	0.05	1.64
0.99	0.01	2.33
0.999	0.001	3.09

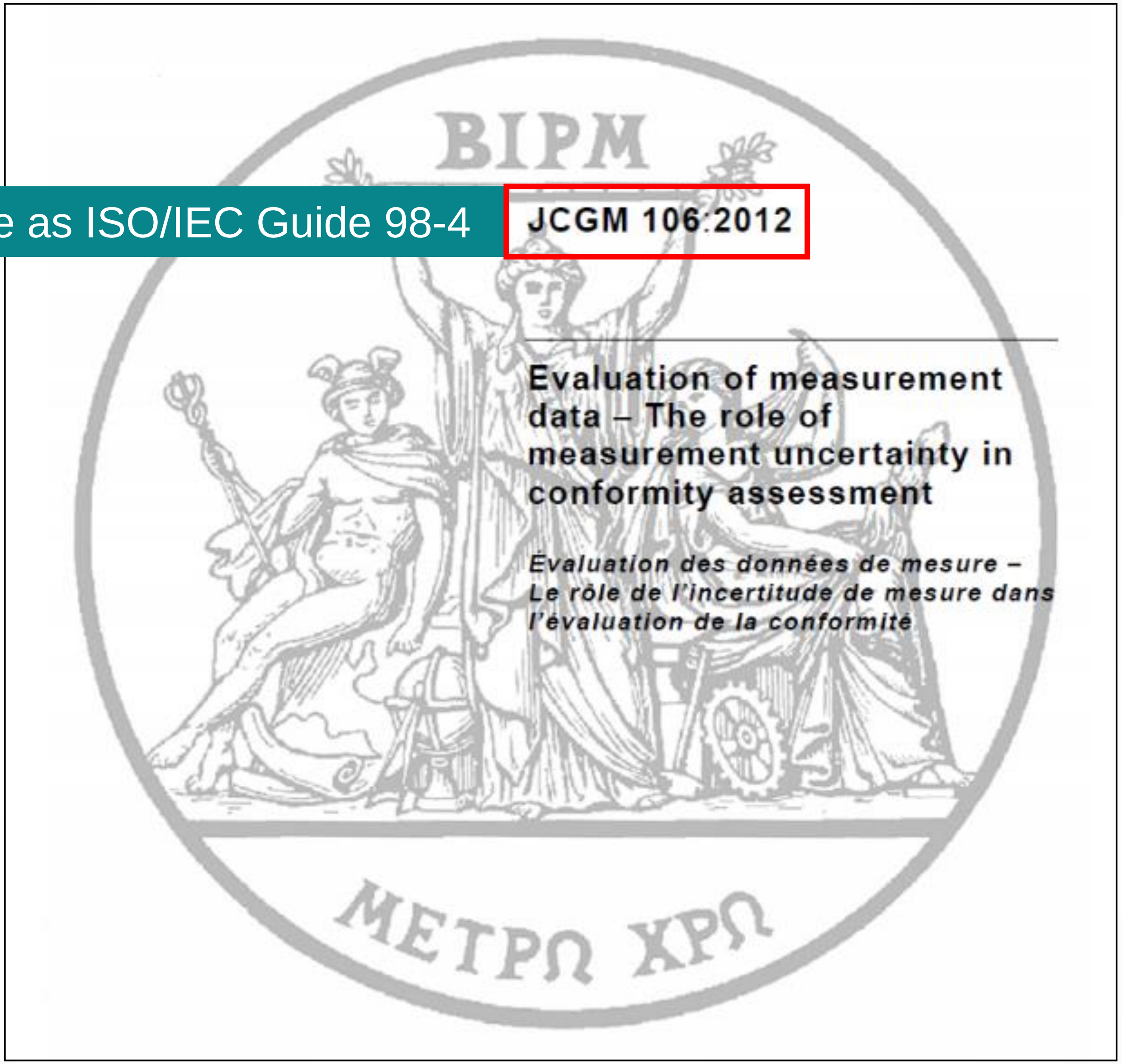
$$v_{\max} = \frac{v_0}{1 - 0.02z} = \frac{100}{1 - 0.02 \times 3.09} \text{ km/h} \approx 107 \text{ km/h}.$$

Meas. 85.3 mph to prove 80 mph @ 99.9%

Agenda – what's next?

- What is measurement decision risk?
- Errors due to measurement decision risk
- Measurement Uncertainty (a.k.a system accuracy)
- Specific risk
- Average risk

Same as ISO/IEC Guide 98-4



BIPM

JCGM 106:2012

Evaluation of measurement data – The role of measurement uncertainty in conformity assessment

Évaluation des données de mesure – Le rôle de l'incertitude de mesure dans l'évaluation de la conformité

ΜΕΤΡΩ ΧΡΩ

Understanding Measurement Risk

By: Michael Dobbert

2007 NCSL International Workshop and Symposium

Understanding Measurement Risk

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1 Abstract

One key reason for performing a calibration is to assess a device as either in- or out-of-tolerance. Common calibration test scenarios compare a device parameter against that of a measurement standard by way of a measurement process. If the difference between the device parameter and the measurement standard is greater than the specified tolerance, the device is deemed out-of-tolerance. However, errors in the measurement process bring about the possibility of an incorrect assessment. An incorrect assessment may result in devices incorrectly declared as in-tolerance (false-accept) or incorrectly declared as out-of-tolerance (false-reject).

The risk of making an incorrect in- or out-of-tolerance assessment can be determined b[y] evaluating probability density functions that incorporate a device's parameter population and t[he] measurement error. This paper provides an intuitive explanation of these probability dens[ity] functions drawing on Monte Carlo simulation to demonstrate the relationship between a devic[e] true value and the corresponding measured value.

2 Introduction

In manufacturing facilities throughout the world, test engineers design measurement procedures for manufacturing purposes. It is common for test engineers to rely on the specifications of

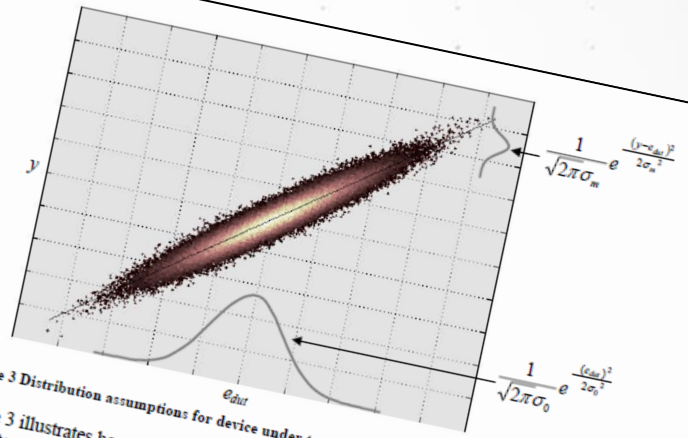


Figure 3 Distribution assumptions for device under test error and measurement error.

Figure 3 illustrates how the device population distribution and the measurement error distribution relate to our Monte Carlo simulation. (It is necessary, however, to imagine the measurement error distribution sliding diagonally across the plot for various values of e_{dut}.) Given the Gaussian assumptions, most points occur near the center of the plot as indicated by the point coloring. The point coloring indicates density with the light coloring representing high point density; dark coloring, low point density[2].

The product of equations (5) and (6) is the joint probability density function, which defines probability density over a two-dimensional surface area.

$$p(e_{dut}, y) = p_0(e_{dut})p_m(y - e_{dut}) = \frac{1}{\sqrt{2\pi}\sigma_0} e^{-\frac{(e_{dut})^2}{2\sigma_0^2}} \cdot \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{(y-e_{dut})^2}{2\sigma_m^2}} \quad \text{Eq. (7)}$$

The total probability for a given two-dimensional rectangular area or region is found by integrating the joint probability density function over the region. That is, the probability for a given region is,

$$P_R = \iint_R p_0(e_{dut})p_m(y - e_{dut})dA$$

http://literature.cdn.keysight.com/litweb/pdf/5991-1265EN.pdf?id=2254266

Joint Probability Density Function

$$p_0(e_{dut})p_m(y - e_{dut}) = \frac{1}{\sqrt{2\pi\sigma_0}} e^{\frac{-(e_{dut})^2}{2\sigma_0{}^2}} \; x \; \frac{1}{\sqrt{2\pi\sigma_m}} e^{\frac{-(y-e_{dut})^2}{2\sigma_m{}^2}}$$

Device Population Error

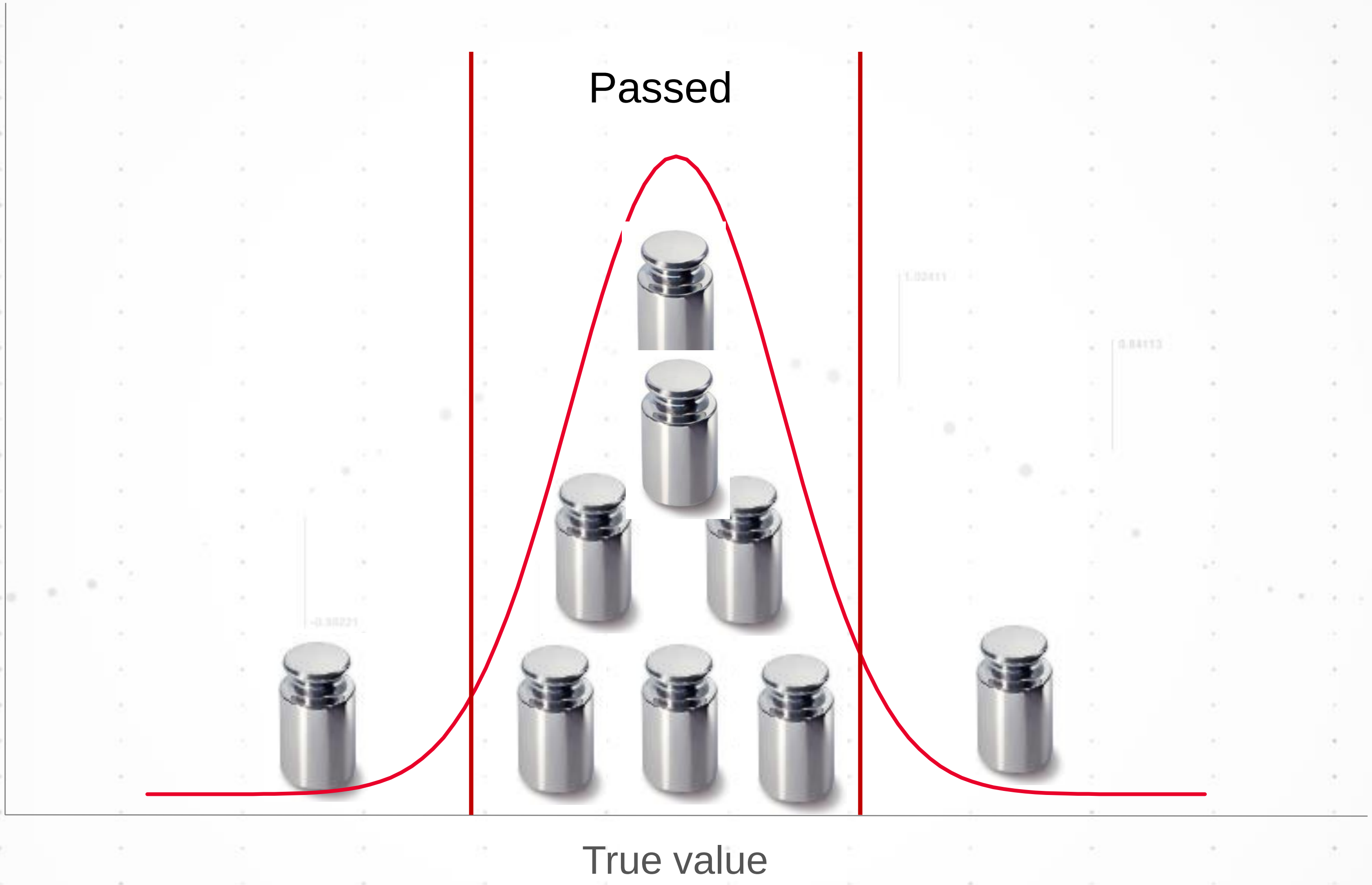
Measurement Process Uncertainty

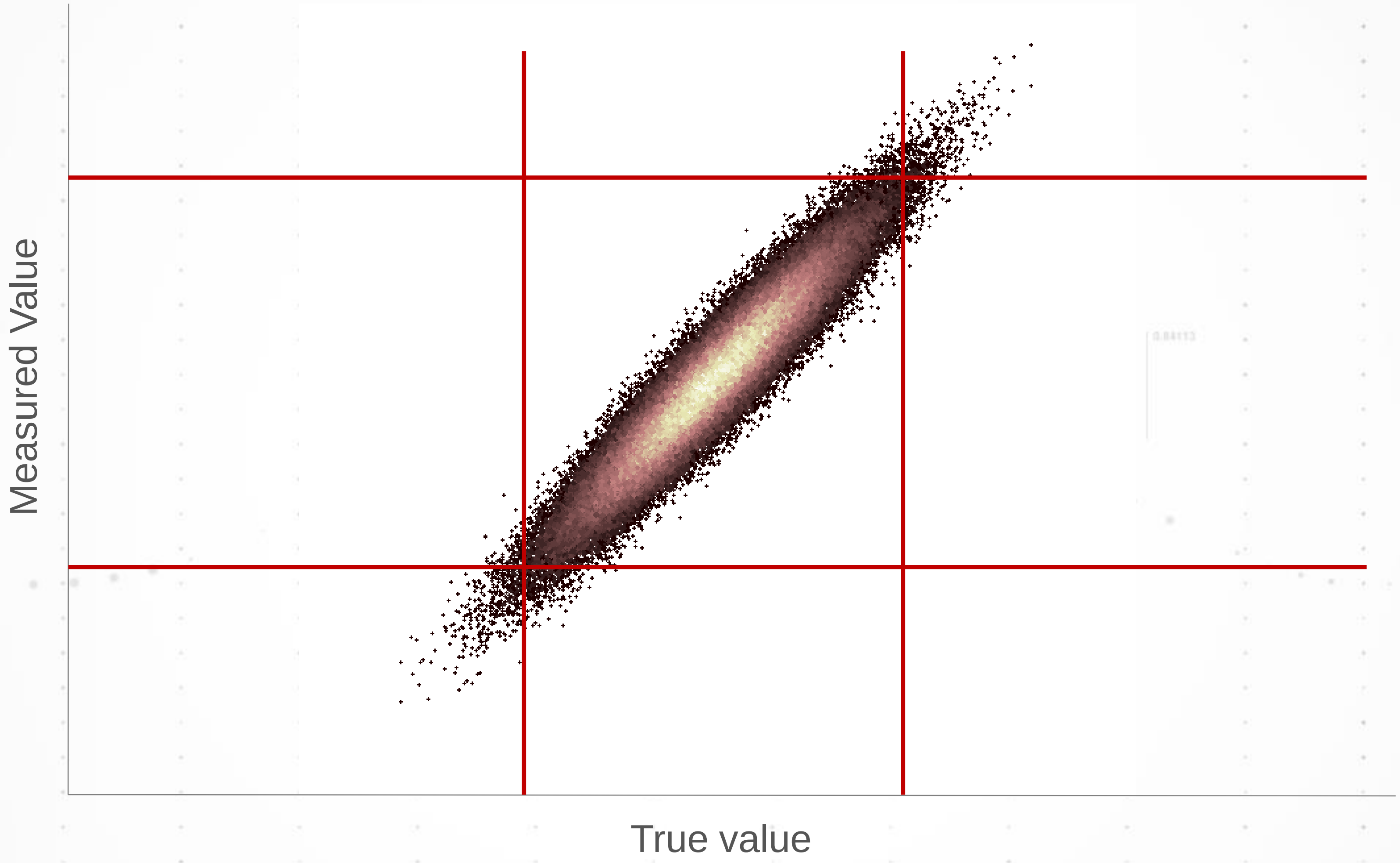
Global risk per clause 9.5, JCGM 106:2012

$$P_R = \iint_R p_0\,(e_{dut})p_m(y - e_{dut})dA$$

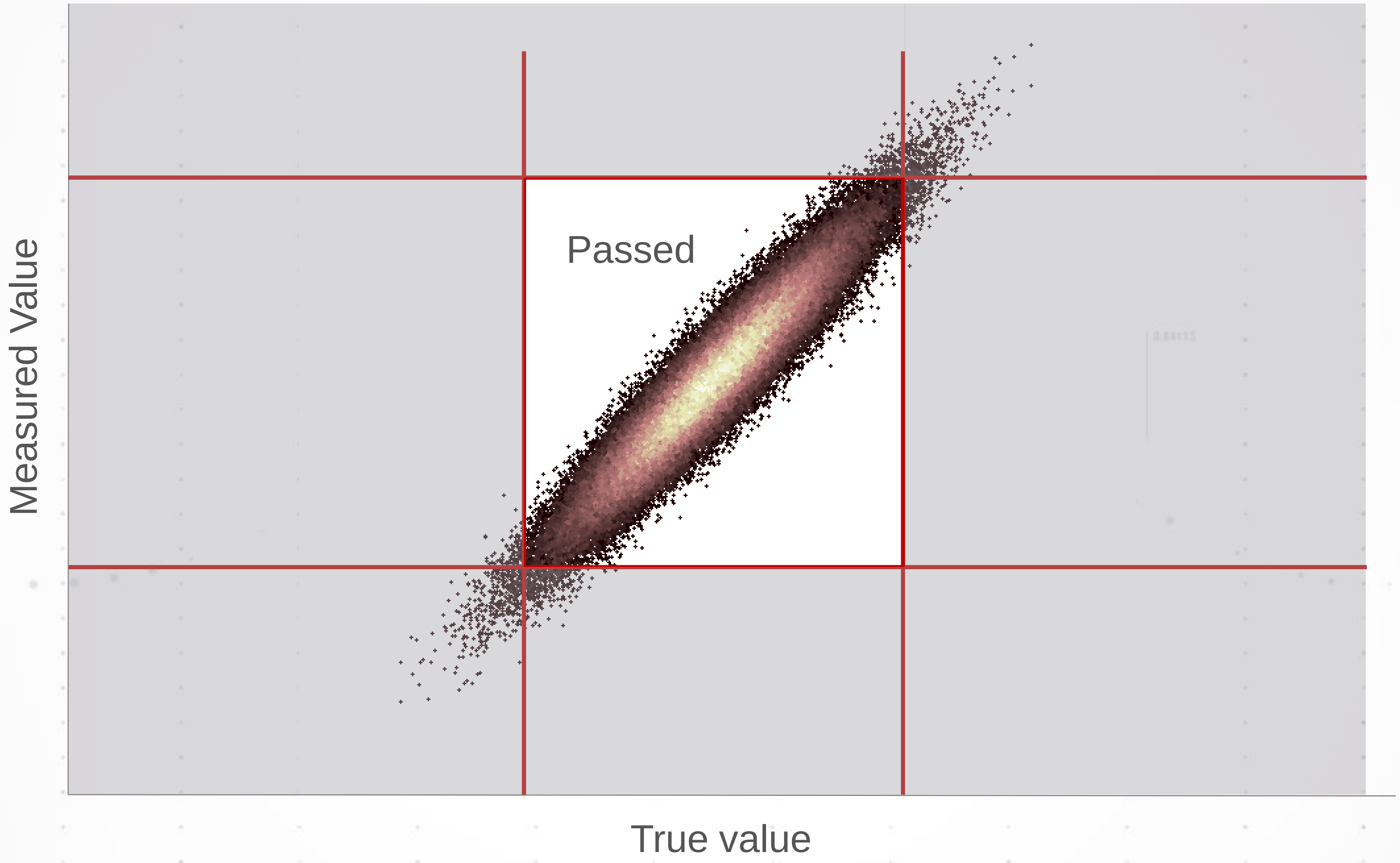
Error = Measured Value - True Value

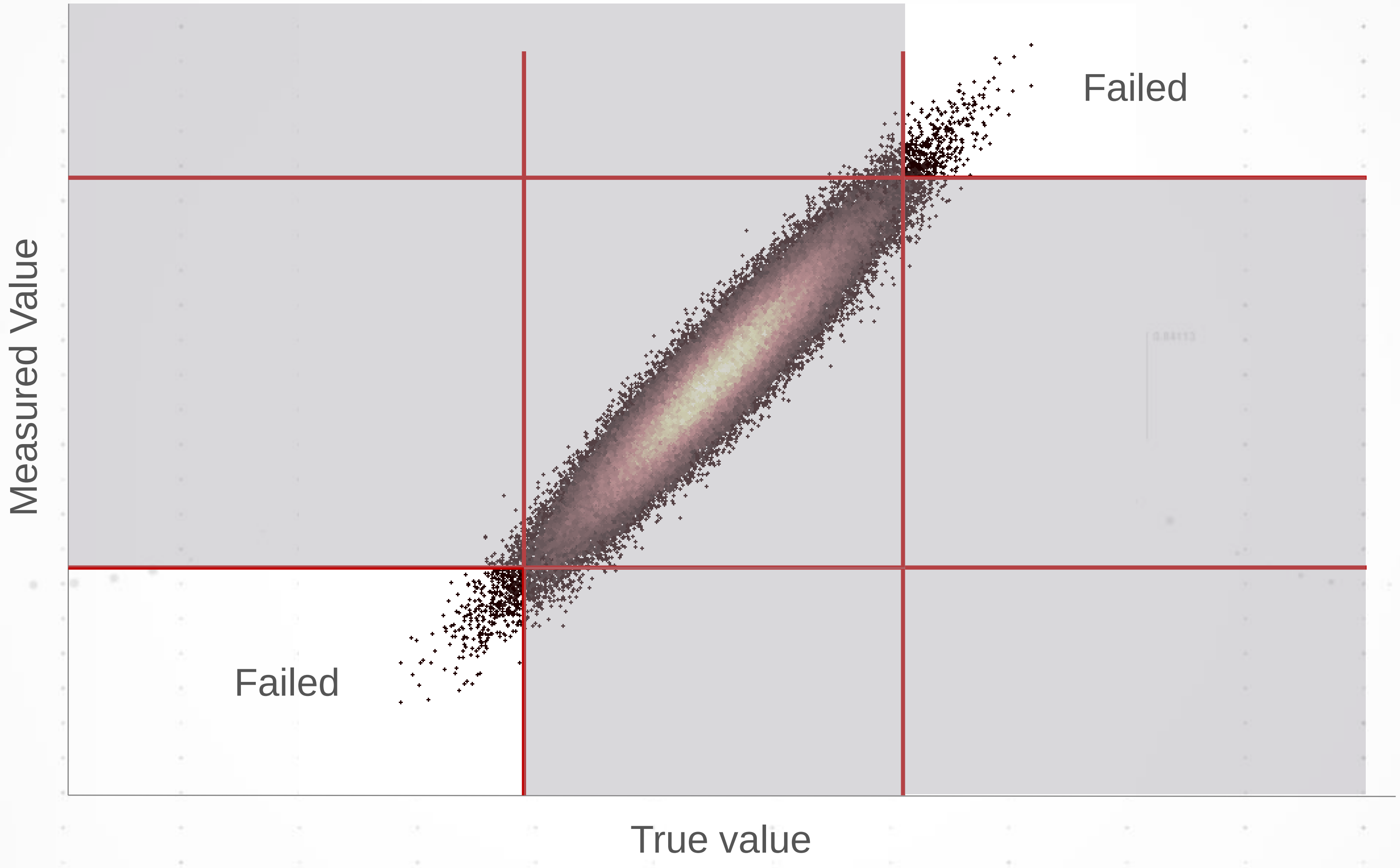
Any Manufactured Item Has a Distribution of True Values

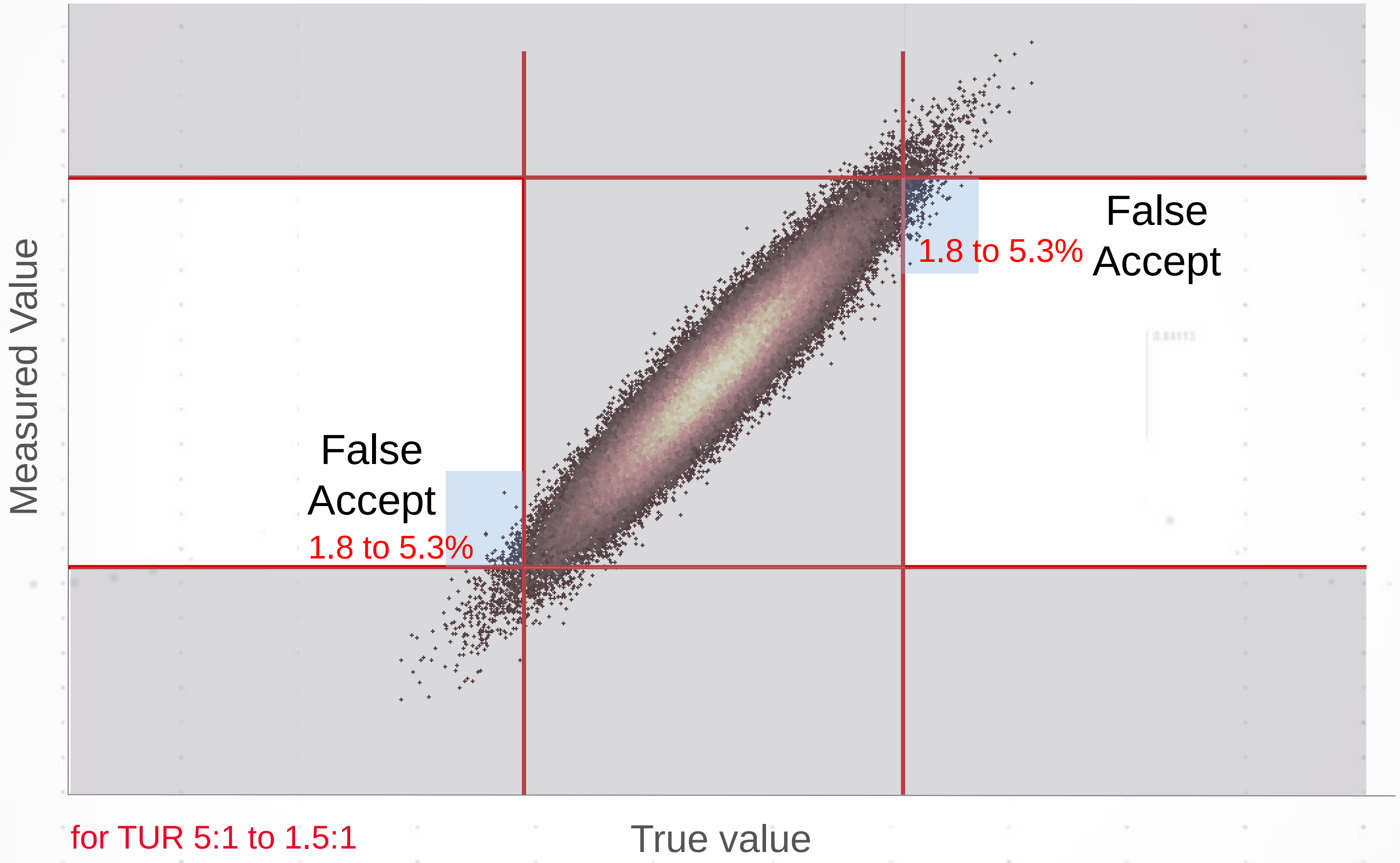




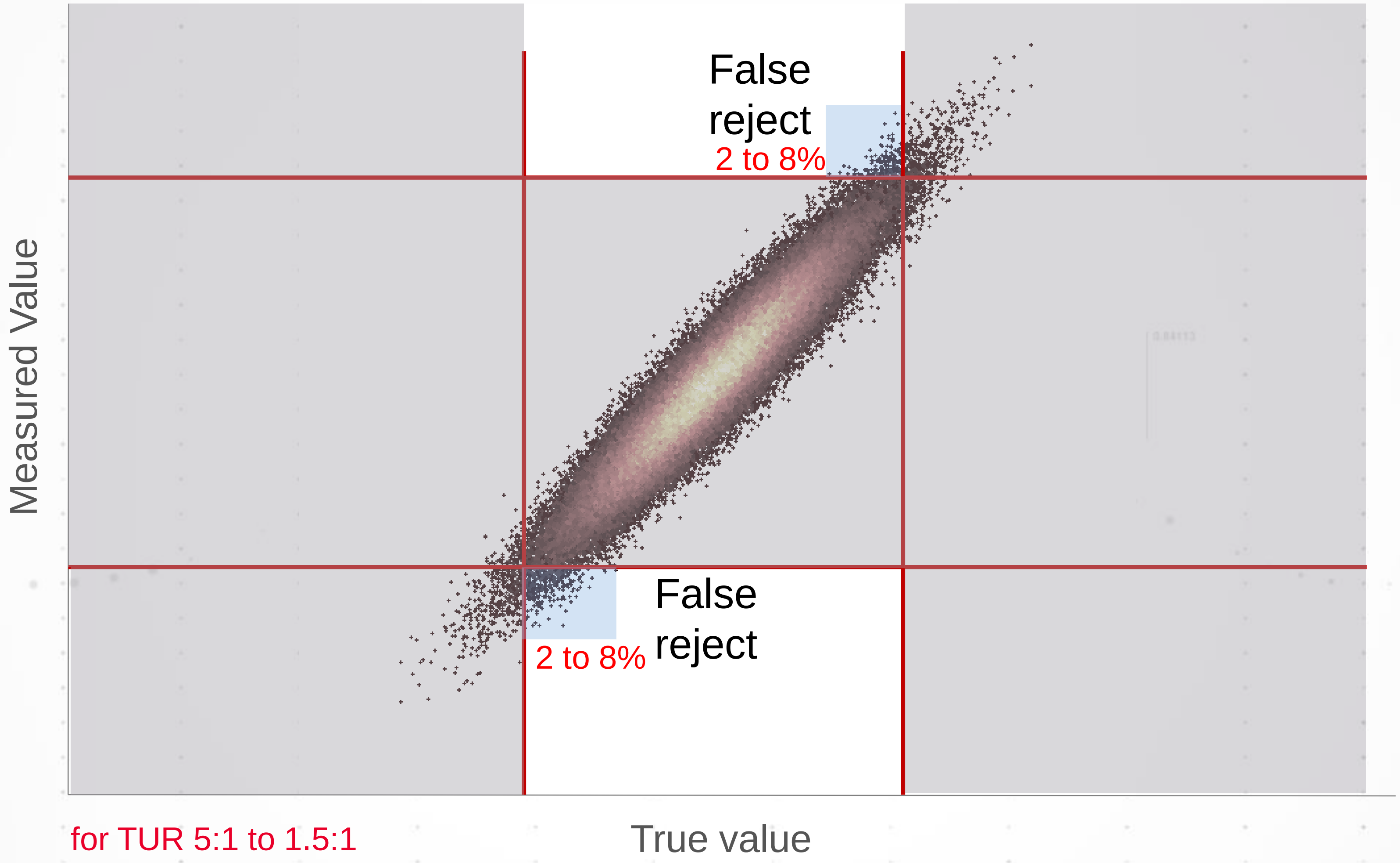
Monte Carlo simulation : https://en.wikipedia.org/wiki/Monte_Carlo_method


Passed
Measured Value
True value


Failed
Measured Value
Failed
True value

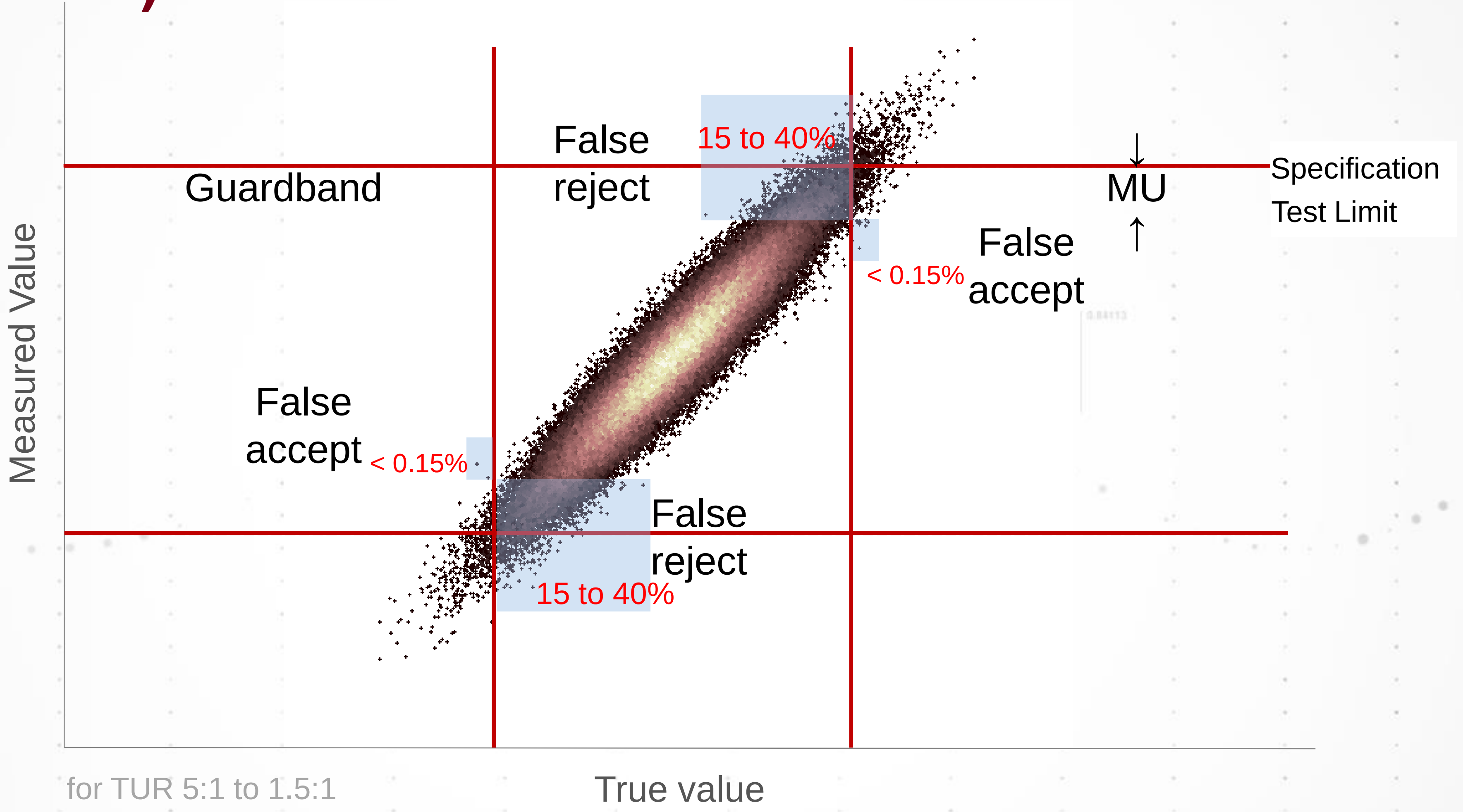


Source: Jon Harben, Senior Metrologist, Keysight Technologies



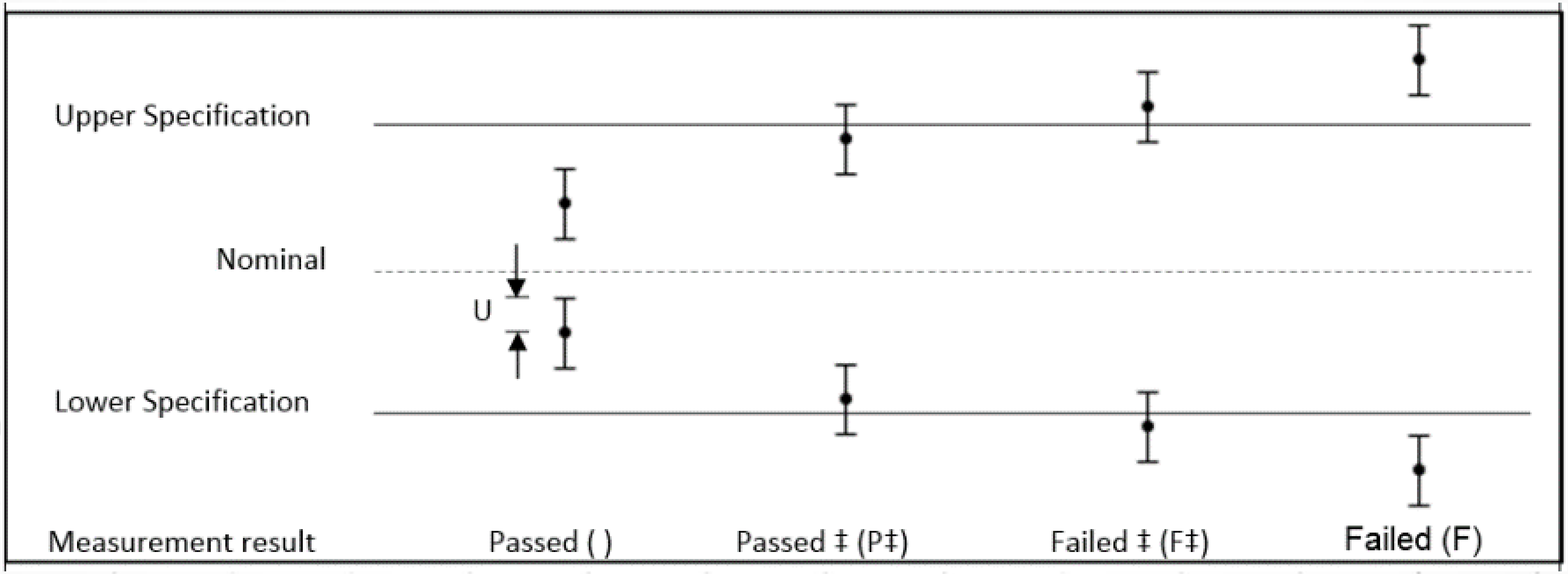
Source: Jon Harben, Senior Metrologist, Keysight Technologies

2 Sigma (95%) Guard Band

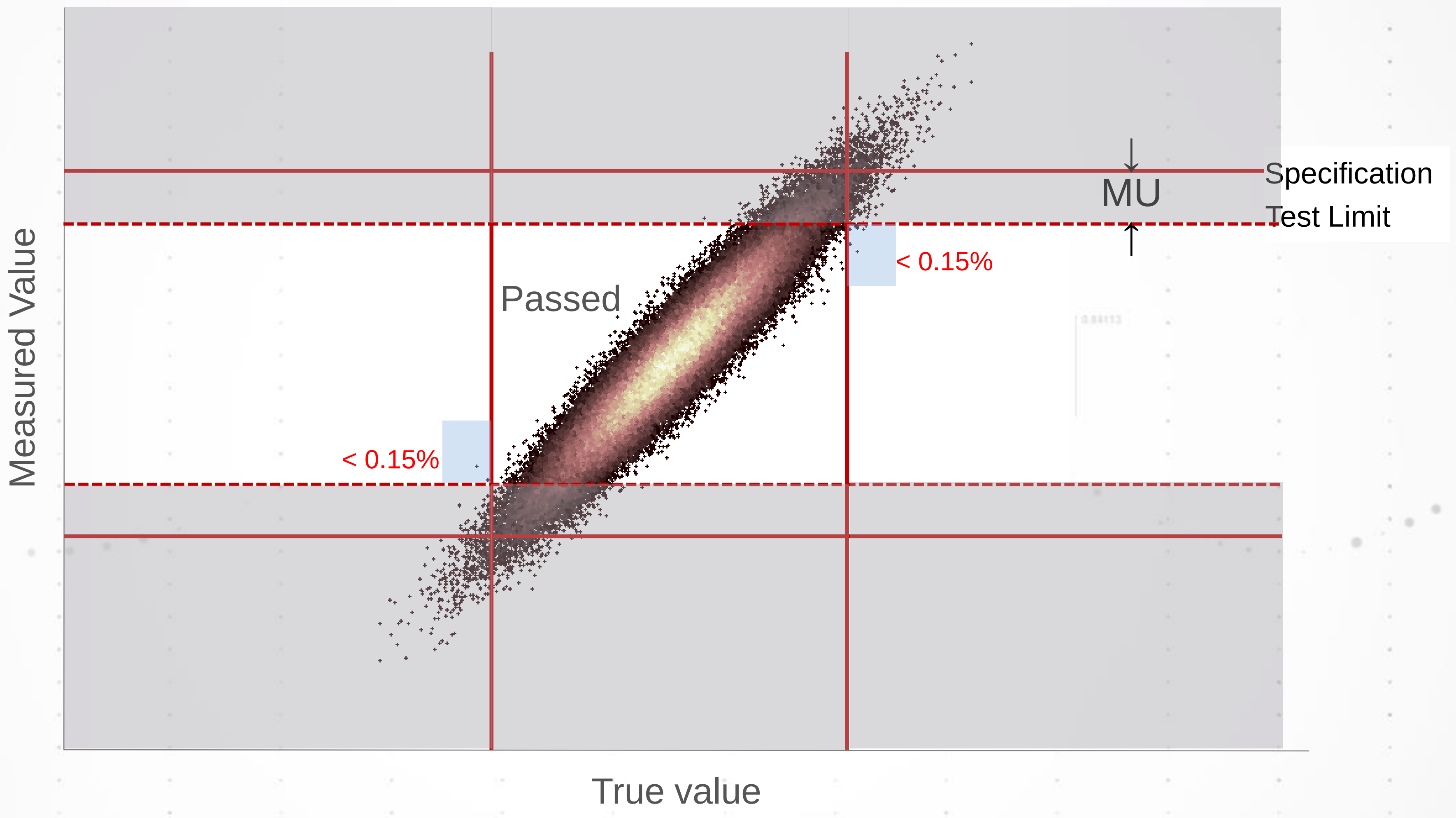


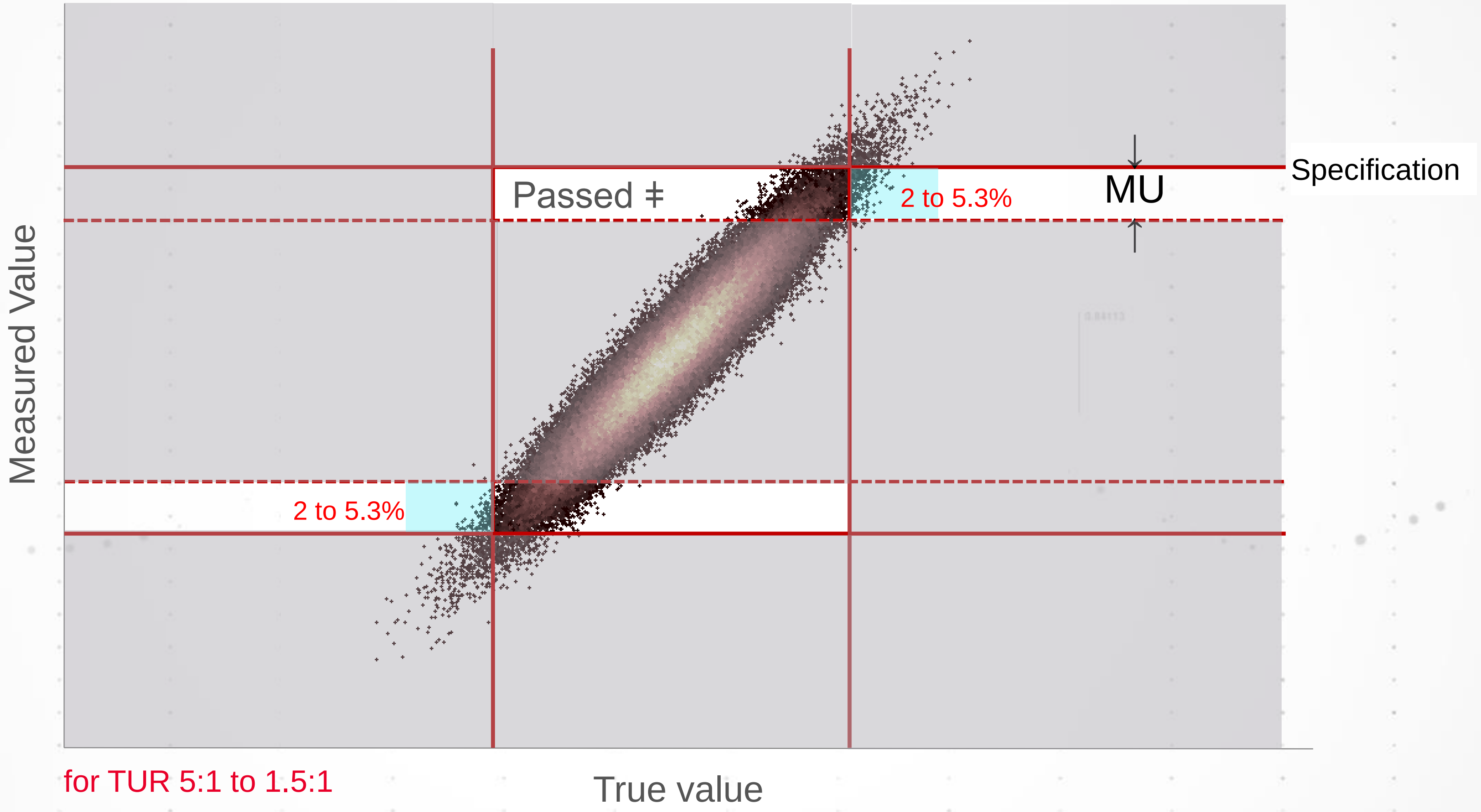
Source: Jon Harben, Senior Metrologist, Keysight Technologies

Alternative Pass/Fail labels



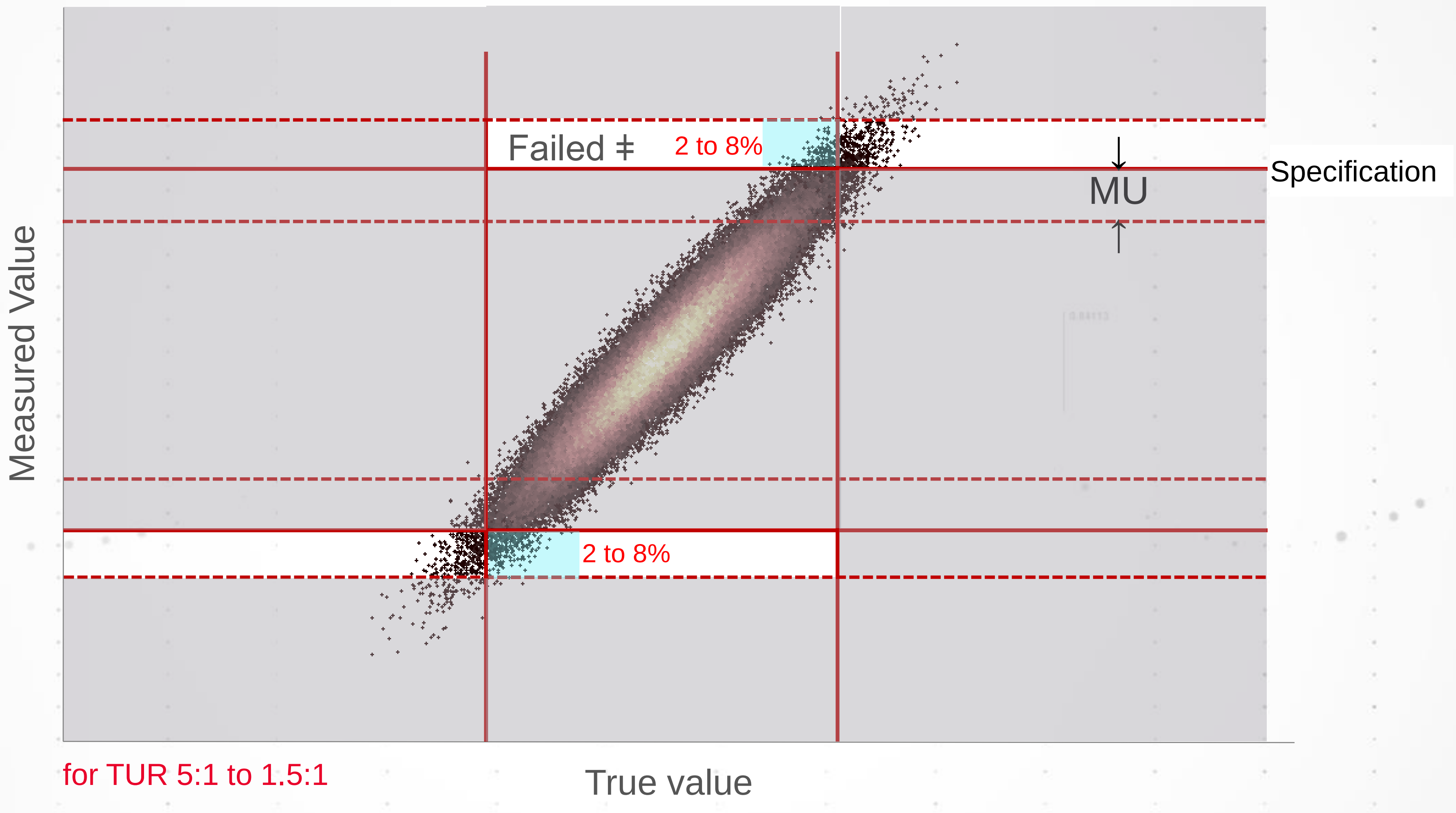
< 0.15% PFA | 2 to 5.3% PFA | 2 to 8% PFR | < 0.15% PFR


Specification
Test Limit
MU
< 0.15%
Passed
< 0.15%
Measured Value
True value



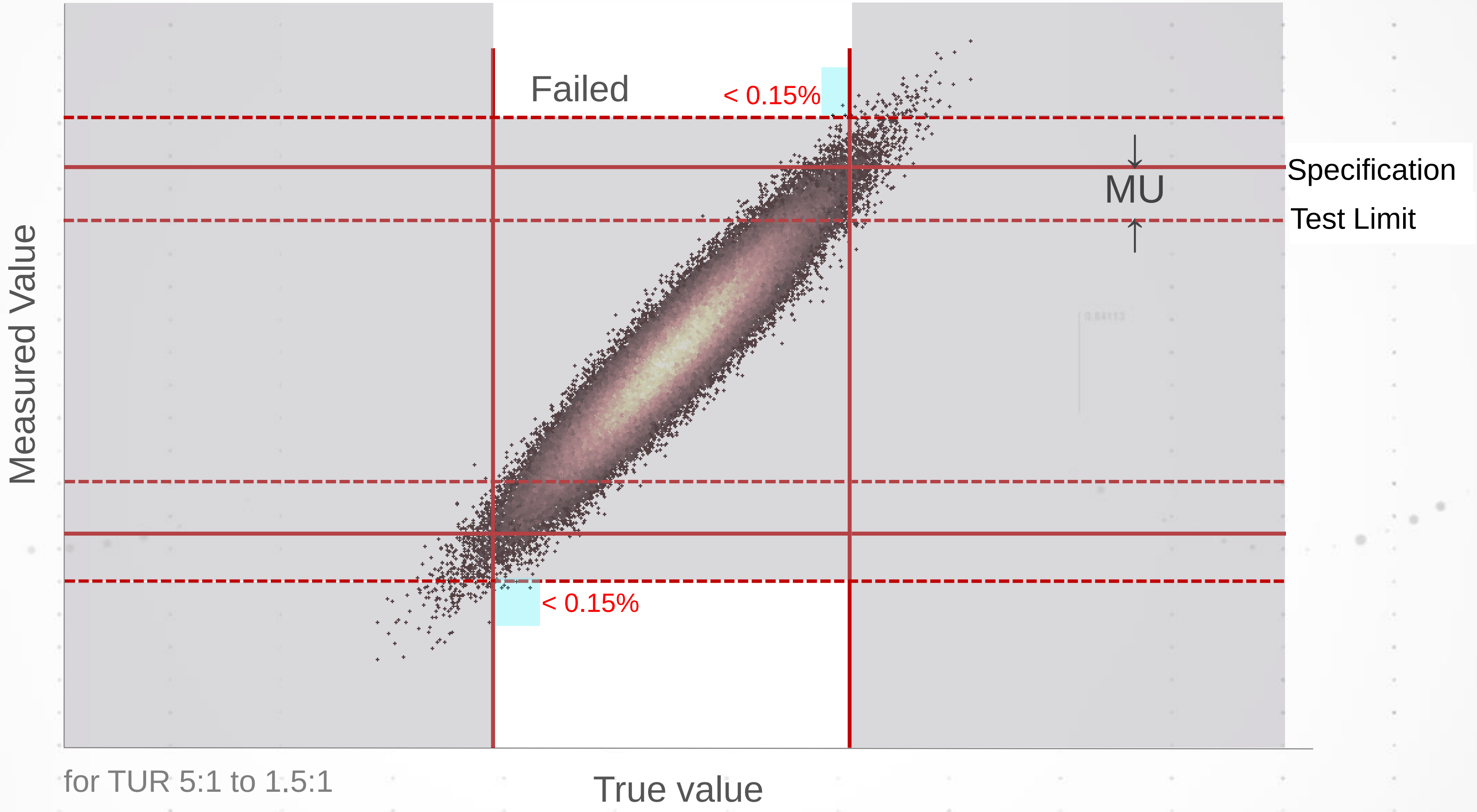
for TUR 5:1 to 1.5:1

Source: Jon Harben, Senior Metrologist, Keysight Technologies



for TUR 5:1 to 1.5:1

Source: Jon Harben, Senior Metrologist, Keysight Technologies



for TUR 5:1 to 1.5:1

Source: Jon Harben, Senior Metrologist, Keysight Technologies

Tool to estimate Average risk

Maximum Global Risk		
TUR[1]	Passed ‡ PFA	Failed ‡ PFR
1	7.50%	13.80%
1.25	6.10%	10.30%
1.5	5.30%	8.10%
1.75	4.60%	6.70%
2	4.10%	5.70%
2.25	3.70%	5.00%
2.5	3.40%	4.40%
2.75	3.10%	4.00%
3	2.90%	3.60%
3.25	2.70%	3.30%
3.5	2.50%	3.00%
3.75	2.40%	2.80%
4	2.20%	2.60%
4.25	2.10%	2.40%
4.5	2.00%	2.30%
4.75	1.90%	2.20%
5	1.80%	2.10%

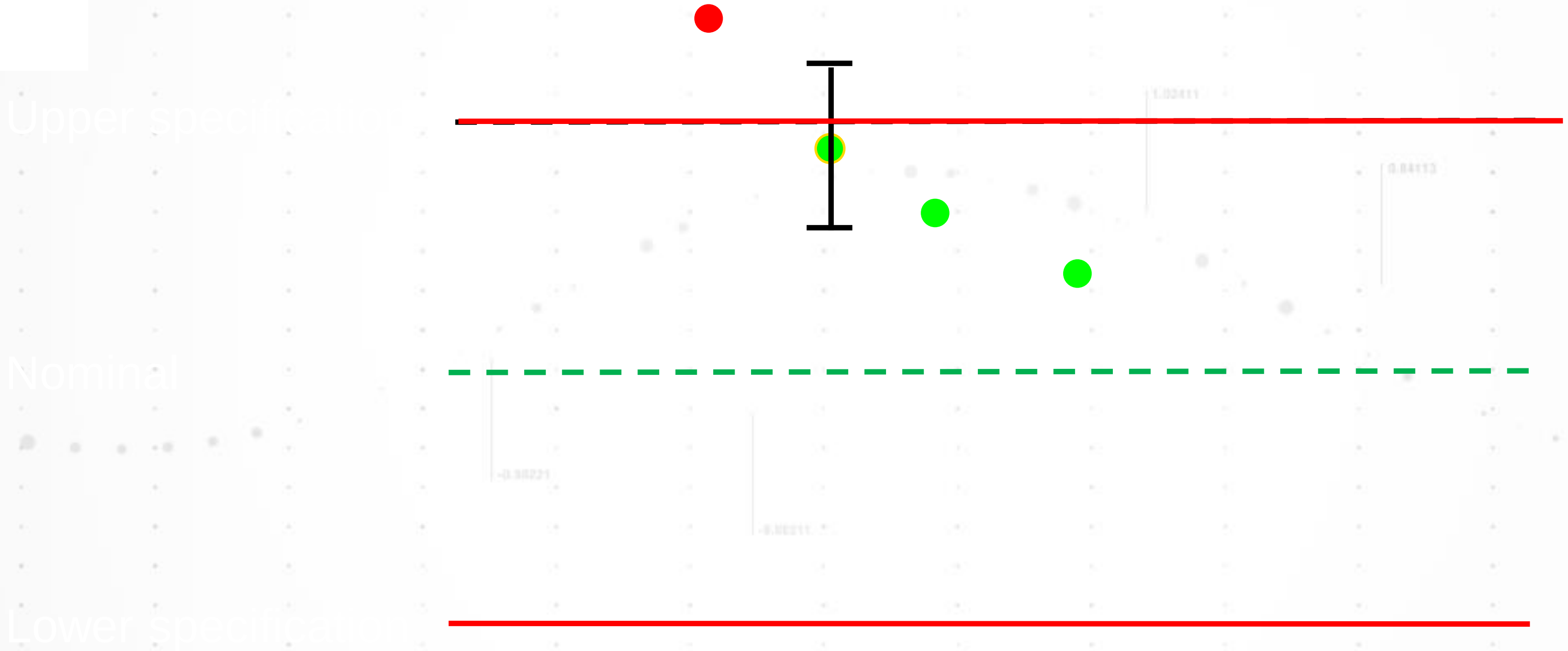
1. TUR is Tolerance (specification) divided by measurement uncertainty.

Source: Stern & Harben, NCSLI paper 2017

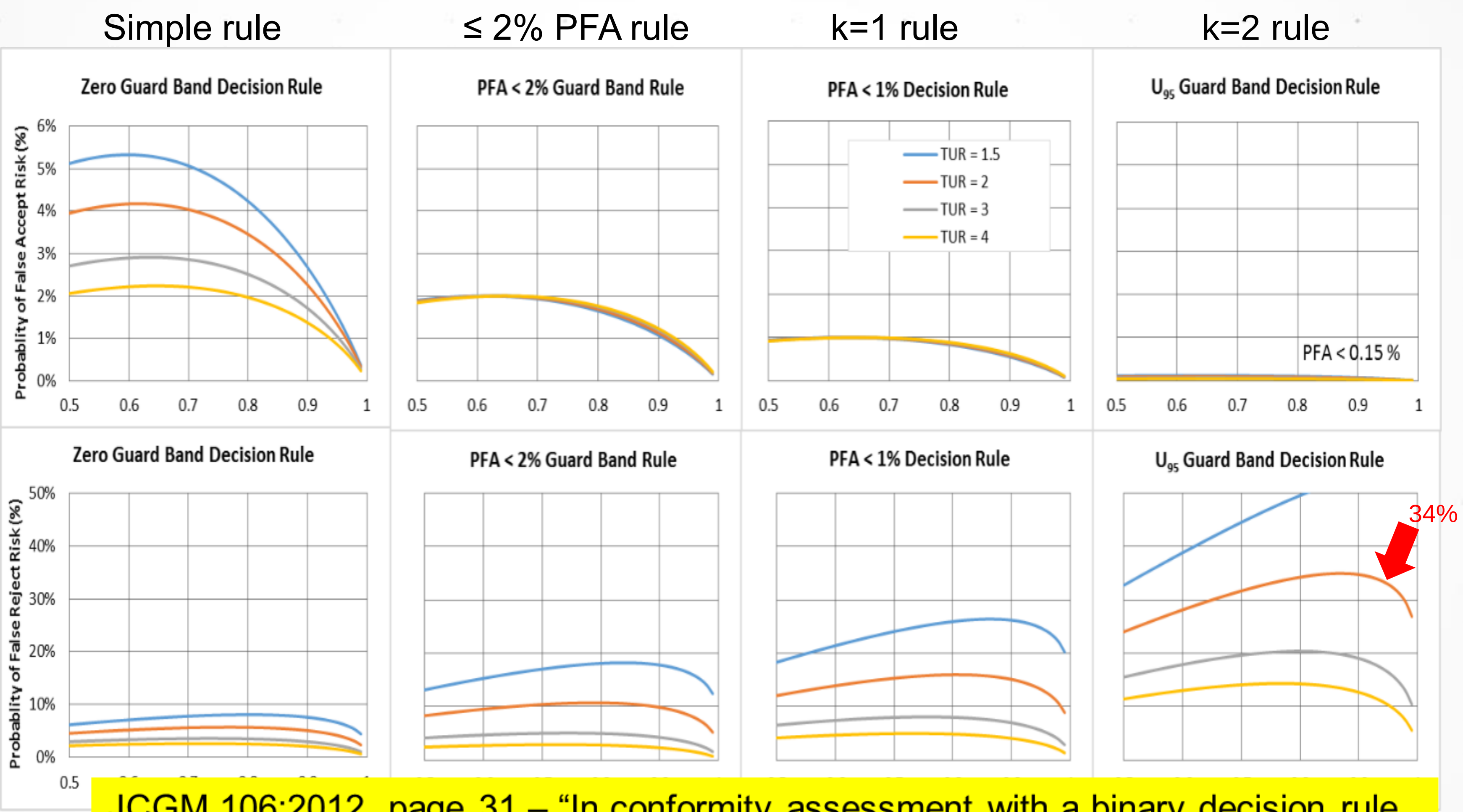
Agenda – what's next?

- What is measurement decision risk?
- Errors due to measurement decision risk
- Measurement Uncertainty (a.k.a system accuracy)
- Specific risk
- Average risk
- ➡ Optimizing challenge: false accept vs. false reject risk.

Guard Band Drives Both False Accept & False Rejects.



Average risk comparison - 4 decision rules



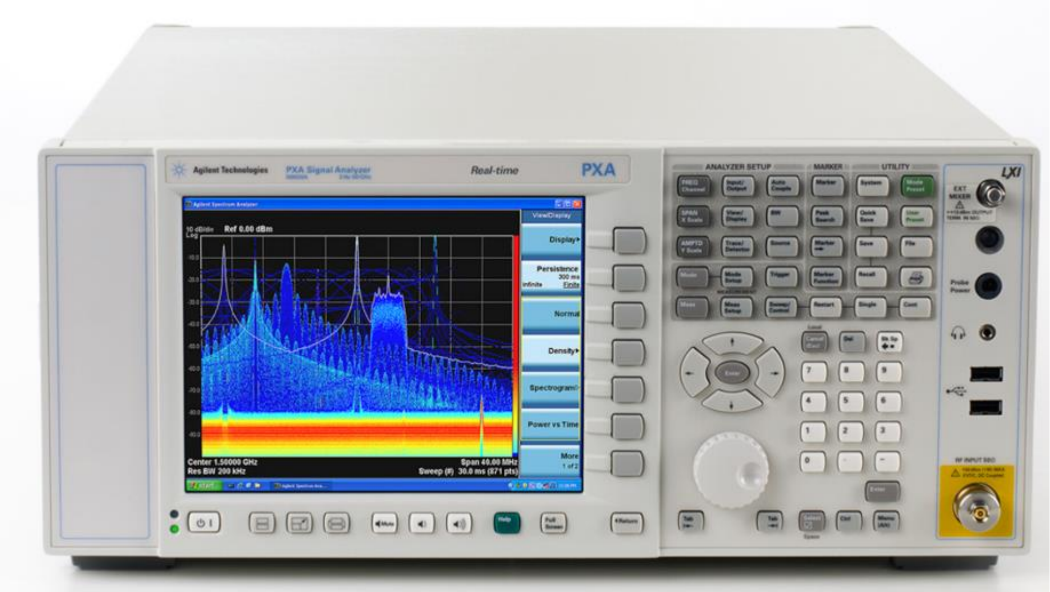
JCGM 106:2012, page 31 – “In conformity assessment with a binary decision rule, acting to reduce the consumer’s risk will always increase the producer’s risk.”

Agenda – what’s next?

- What is measurement decision risk?
- Errors due to measurement decision risk
- Measurement Uncertainty (a.k.a system accuracy)
- Specific risk
- Average risk
- Optimizing challenge: false accept vs. false reject risk
-  *“Is there any way to improve both false accept & false reject at the same time?”*

Question

WANT TO LOWER YOUR MEASUREMENT PROCESS UNCERTAINTY?

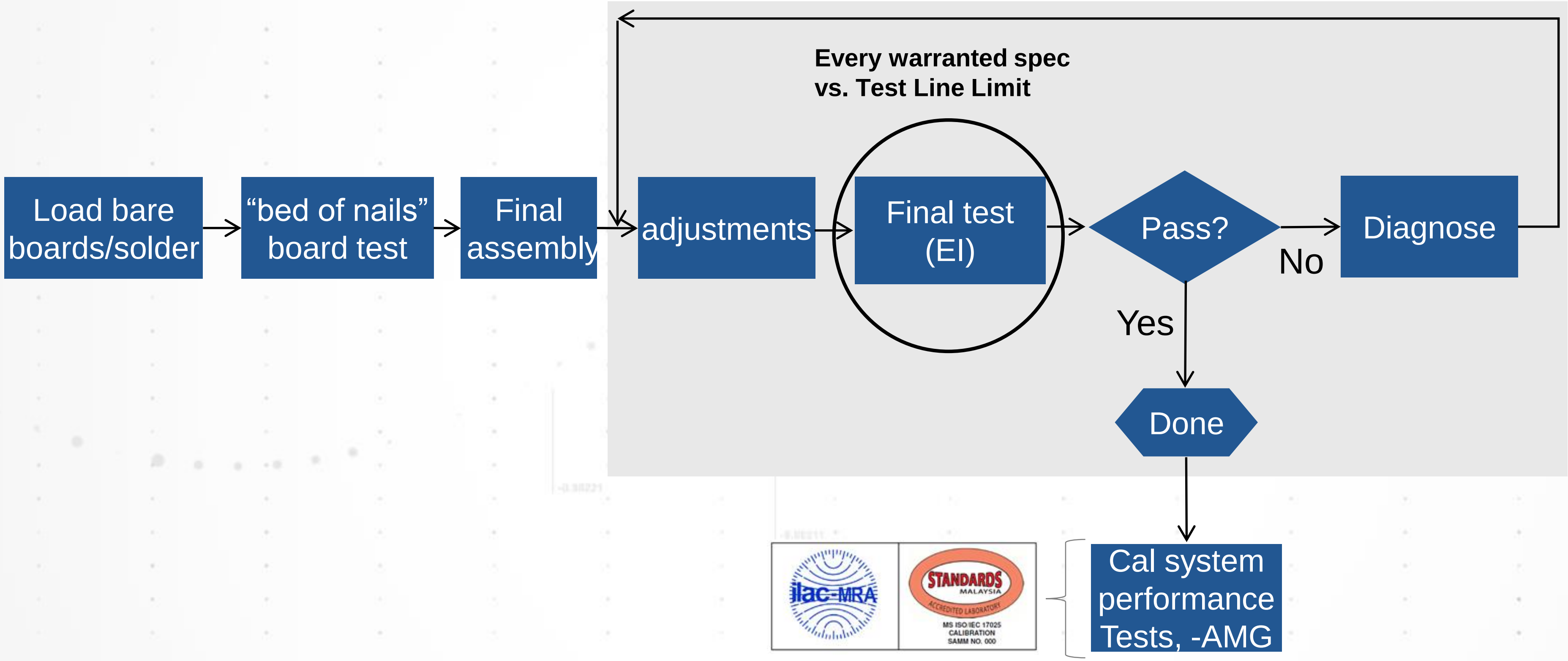


Instrument

Calibration

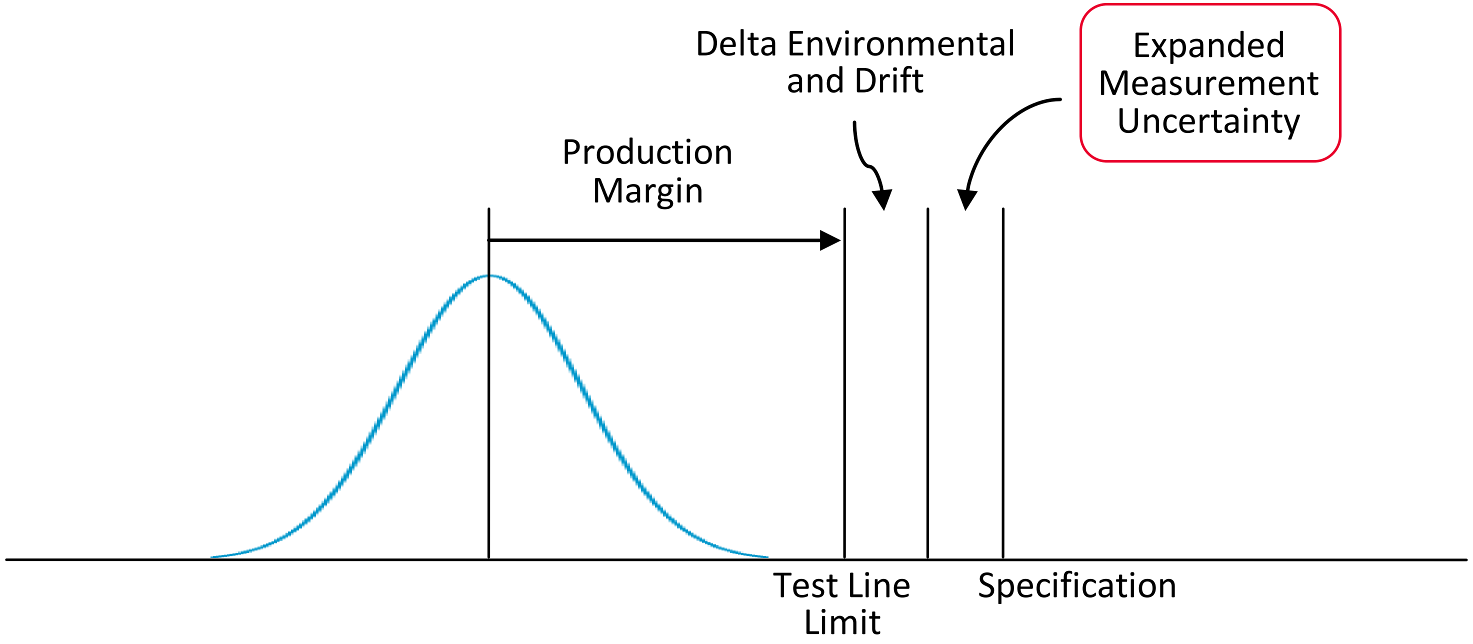
Let Keysight help you reduce your measurement uncertainty

Factory Instrument Production Process Flow & Calibration



Courtesy of Ed Dempsey, Santa Rosa. "EI" is electronic inspection

Meeting Specifications - Keysight Technologies



New instruments from the factory comply with ISO/IEC 17025, ILAC-G8, and ANSI/NCSL Z540.3-2006

Source: Setting and Using Specifications, Michael Dobbert, Sept 2010 issue, Measure Magazine

Why Test Phase Noise During Calibration?

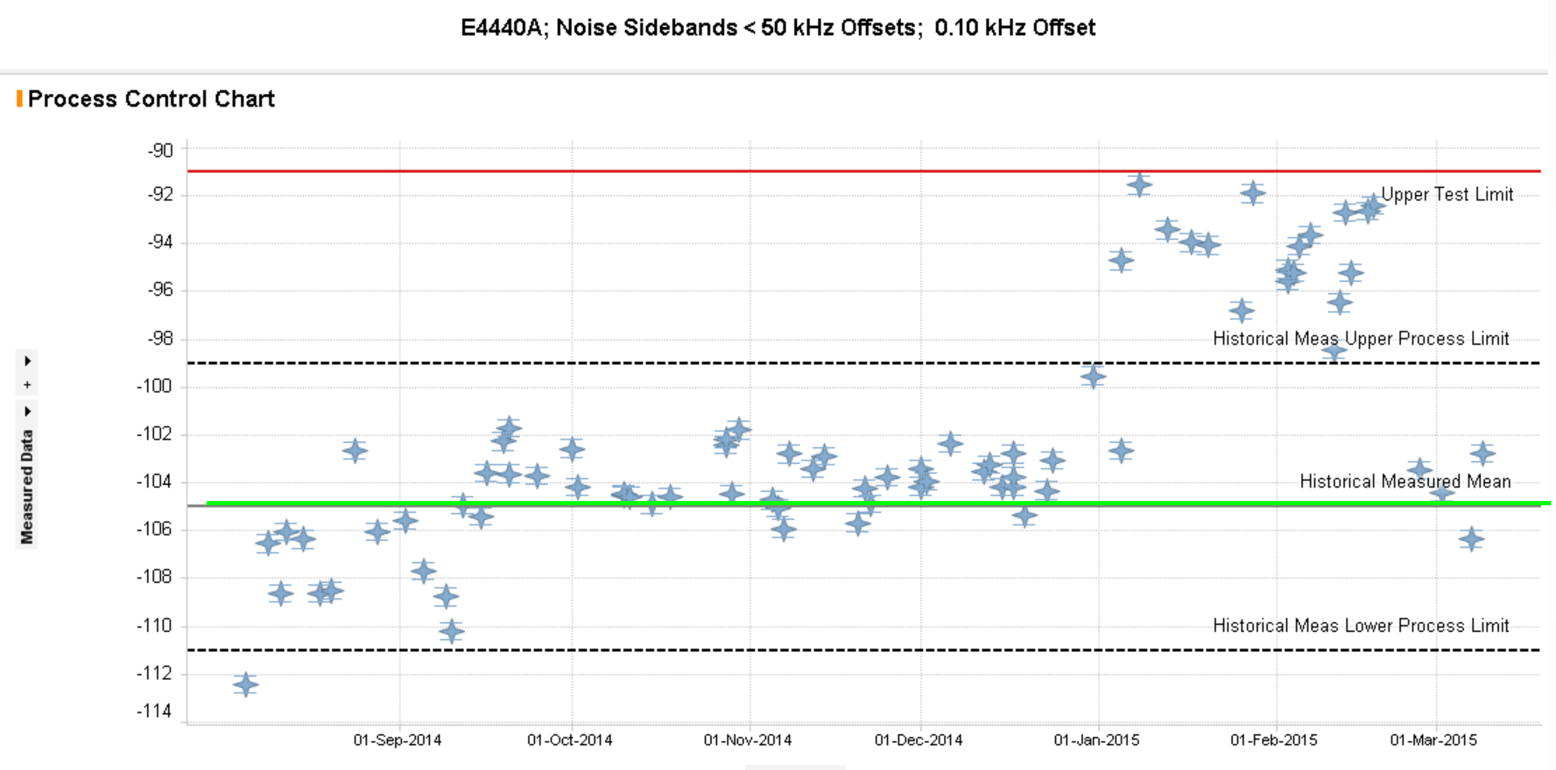
Does it really matter to test phase noise during calibration every time? My TPM tells me that *"phase noise doesn't drift; it is part of the design."*

Yes it matters!

"*Like many instrument characteristics, it doesn't change . . . until it does!*"

Instruments Don't Change . . . Until They Do!

Sudden phase noise measurement shift on a Spectrum Analyzer test station



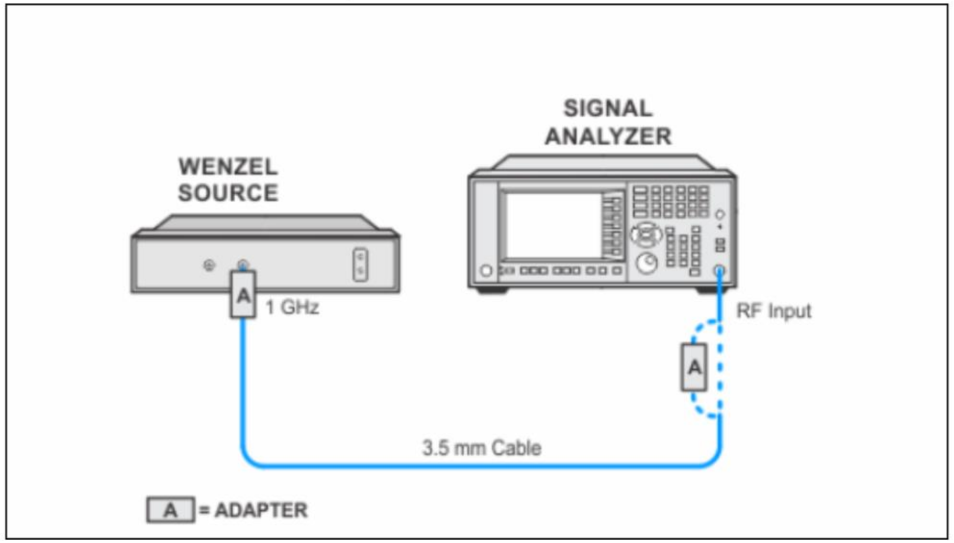
Source: Roseville, Keysight Cal Monitoring system

11 dB shift!! → the microwave signal generator that changed was in a rack, was not moved, and not power cycled.

PXA (N9030B)/UXA (N9040B)

HOW PHASE NOISE IS CHECKED

Phase Noise Wenzel Test Setup



Required Test Equipment

Test Equipment	Model Number
Synthesized Signal Source	**Recommended model:** Wenzel model 500-13438 Rev D **Alternate model for all X-Series analyzers EXCEPT UXA:**[1] Wenzel model 500-13438 Rev C

PXA (N9030B) Cal Report Excerpt: Phase Noise

Report Number
1-7889090347-1-22RW

Phase Noise

Model N9030B **Serial** MY55520177 **Test Date** 31-May-2016 **Test Result** Passed

Environmental Conditions

Temperature 23.00 **Celsius** **Humidity** 35.00 **%** **Line Frequency** 60.00 **Hz**

Test Standards and Required Equipment

Model	Description	Equipment ID	Trace Number	Cal Due
500-13438D	Ultra Low Phase Noise Source	7243-1449	500-1343831449	14-Dec-2016
909D	50 Ohm Terminator	NONE		Cal Not Required

CW Frequency = 1.00 GHz

Phase Noise Offset (kHz)	Measured Phase Noise (dBc/Hz)	Specification (dBc/Hz)	Status
0.10	-105.10	-94.00	
0.99	-126.89	-121.00	
10.00	-136.24	-129.00	
30.00	-138.35	-130.00	
100.00	-142.44	-129.00	
1,000.00	-148.19	-145.00	
9,900.00	-156.41	-155.00	

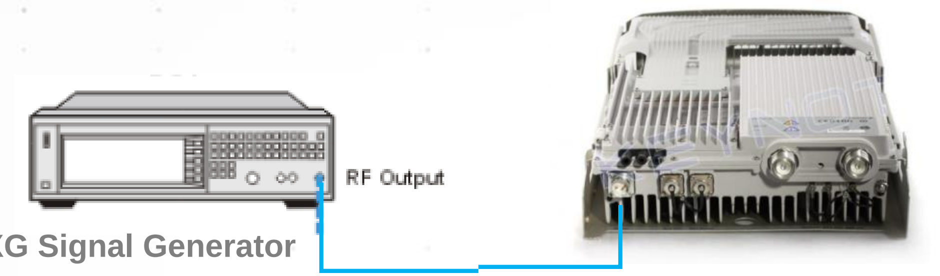
Note: The UXA (N9040B) also has great phase noise and requires a test during calibration.

Agenda – what's next?

- What is measurement decision risk?
- Errors due to measurement decision risk
- Measurement Uncertainty (a.k.a system accuracy)
- Specific risk
- Average risk
- Optimizing challenge: false accept vs. false reject risk
- *"Is there any way to improve both false accept and false reject?"*
- Importance of verifying (Low level) Power Level Accuracy of signal generators

Receiver Sensitivity Test Example

Receiver under test



MXG Signal Generator

<u>How measured:</u>

Find the minimum RF signal level needed to produce minimum intelligible communication [target (S+N)/N or BER]. [Iterative process]

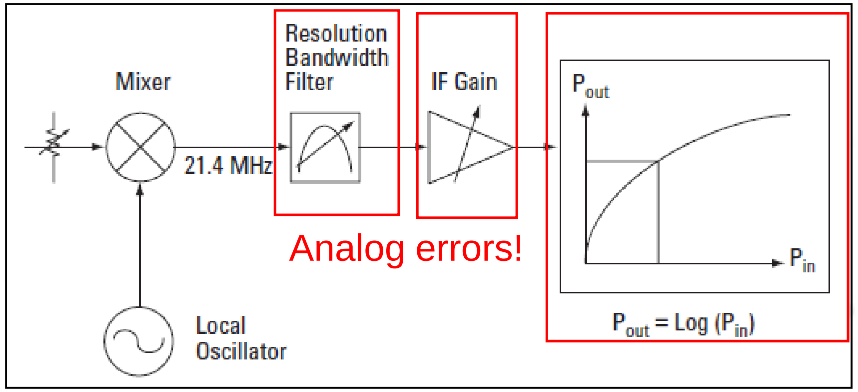
<u>Test Conditions:</u>

- 107 dBm (1.0 µV) Customer spec.
-
- >±1.5 dB MU   Case 1: MXG calibrated w/8563E (3rd party)
- ±0.2 dB MU   Case 2: MXG calibrated w/E4448A (Keysight)

Key Test Standards

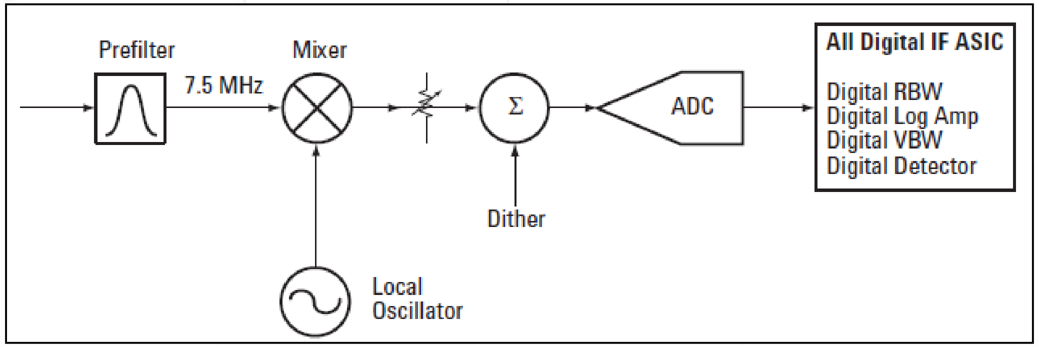
SIGNAL GENERATOR LOW LEVEL POWER ACCURACY TEST

>± 1.5 db error at -107 dBm



Traditional analog IF Section, i.e. **8563E**

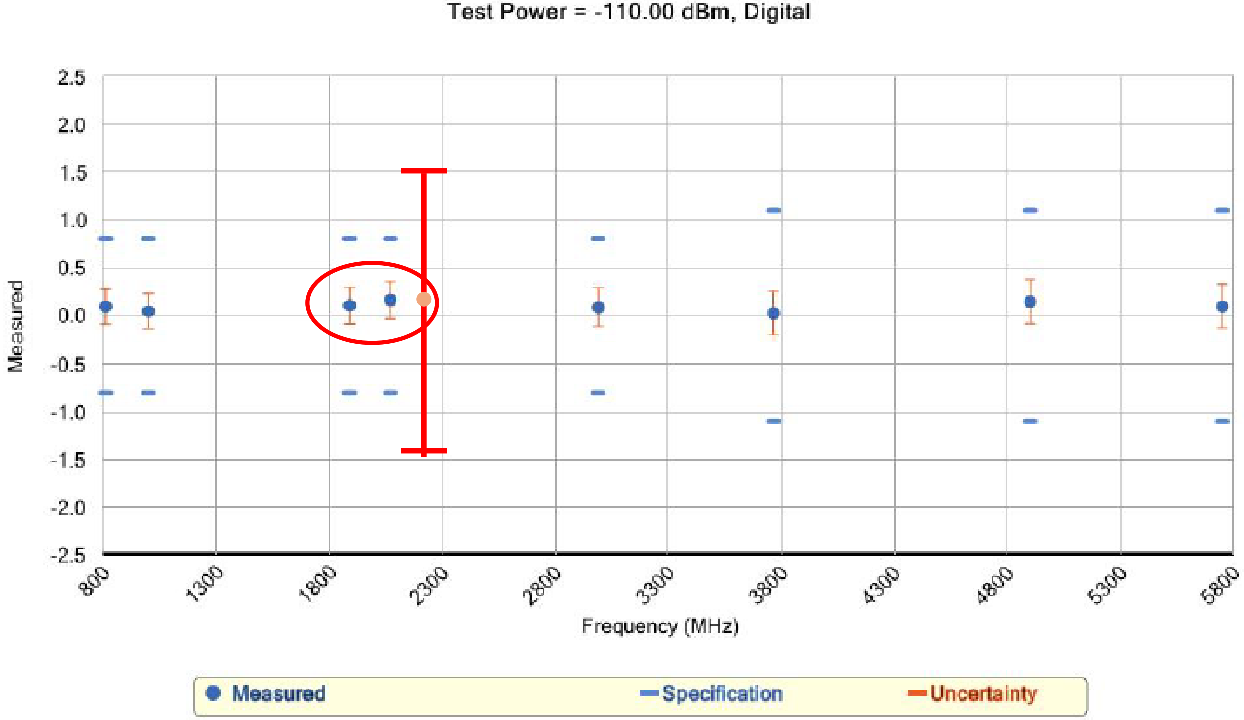
<± 0.2 db error at -107 dBm



All-digital IF Section **E444xA**

Typical MXG Cal Result at -110 dBm

Power Level Accuracy (cont.)



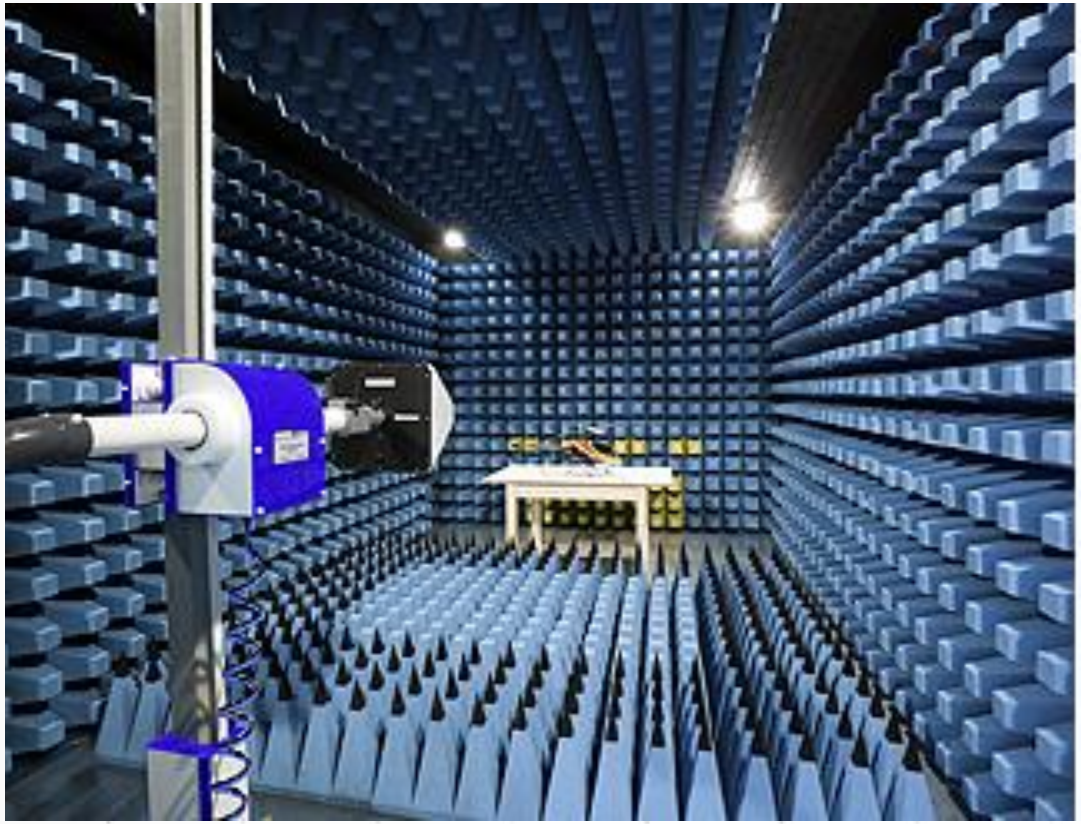
Test Power = -110.00 dBm, Digital

Frequency	Minimum	Measured	Maximum	Uncertainty	Status
810.001 MHz	–0.8 dB	0.09 dB	0.8 dB	0.18 dB	
999.001 MHz	–0.8 dB	0.04 dB	0.8 dB	0.19 dB	
1890.001 MHz	–0.8 dB	0.10 dB	0.8 dB	0.19 dB	
2070.001 MHz	–0.8 dB	0.16 dB	0.8 dB	0.19 dB	

Decision Rule Examples

Example 2: New Prototype Sent to a Test Lab for Assessing Compliance to CISPR 16

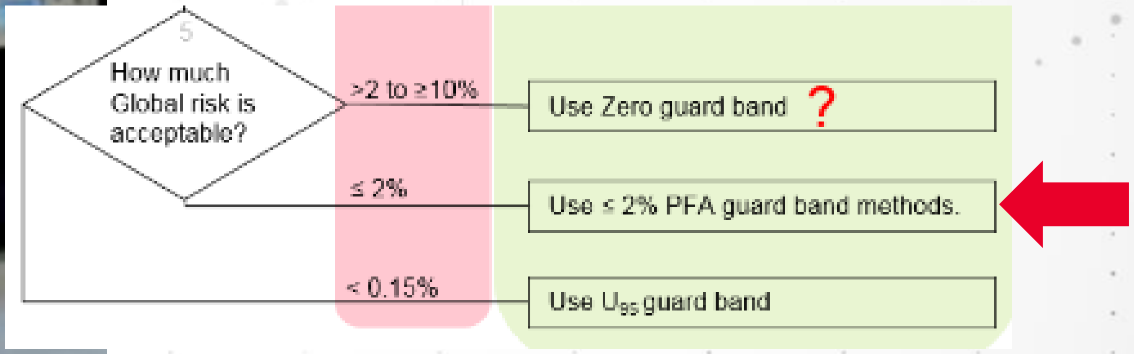
Which Decision Rule/amount of guard band is most appropriate??



No population exists, so recommend guard band of U_{95} (Specific risk)

Example 3: Production Instrument Submitted for Periodic Calibration

End customer wants a [binary] Pass or Fail statement of conformance to specification.



Conclusions/Call-to-Action

1. All measurements contain errors 

2. Estimate your system accuracy (measurement uncertainty)

3. Determine the maximum % False pass/False reject risks you can tolerate.

4. Select a decision rule with suitable guard band to achieve your % risk tolerance.

5. Minimize instrument [drift] error contributions with regular [accurate] calibration.

YouTube Videos for More Information

- What calibration is supposed to do
- What service deliverables you should receive
- How to get measurement uncertainties for your instrument's current performance

https://www.youtube.com/playlist?list=PLvQ5Bzr3tM50No0sfwYr40jA50rsIQyD-