Case Study on the "4:1 Rule" Applied to Conformity Assessment for Signal Generator Calibration based on ASME NQA-1 Requirement 12, Section 302

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Keywords : ASME NQA-1, Reference Standard, the 4:1 Rule, Conformity Assessment of M&TE

1. Introduction

The "4:1 Rule" is a heuristic established in the 1950s for the conformity assessment of calibrated measurement and test equipment (M&TE). It was initially incorporated into the Section 302 Reference Standards of Requirement 12 in ASME NQA-1-2008. While conformity assessment for calibrated M&TE is not mandatory for ISO/IEC 17025 accredited laboratories unless requested by the customer, the ILAC Guideline provides decision rules for such assessments [1]. Drawing upon the ILAC Guideline and the original intent of the "4:1 Rule," practical guidelines have been developed [2, 3]. This paper examines the applicability of these guidelines using a calibration certificate for a Rohde & Schwarz SMB100B signal generator.

2. The Guideline of the "4:1 Rule" under ISO/IEC 17025 framework

The proposed guideline outlines the following steps [3]:

Step 1: Define M&TE Accuracy Requirements.

1. Check the required accuracy of the M&TE.
2. Select **the Tolerance Limit (T. L.)** based on the following priority:
   - Manufacturer's specification.
   - Regulation or Regulatory Standards.
   - Instrument accuracy of range on IECEE OD-5014 [19] if it is less than or equal to the required accuracy.
   - If necessary, define a T. L. stricter than the required accuracy following ISO/IEC 10012

Step 2: Select the Decision Rule.

1. If Test Uncertainty Ratio (TUR) calculation is possible:
   - Priority 1: Use guard band producing ≤ 2% Probability of False Acceptance (PFA 2% decision rule)
   - Priority 2: Use Zero guard band and TUR ≥ 4:1 (TUR 4:1 decision rule)
2. If TUR calculation is NOT possible:
   - Use w = U guard band

Step 3: Calculate the Acceptance Limit (A. L.) (Guard Banding).

1. If TUR calculation is possible:
   - PFA calculation is practical: PFA 2% decision rule (U: 95% expanded uncertainty of calibration process)
     (1) The Dobbert's method (applicable only when 1 < TUR < 15)

$$A.L. = T.L. - U \times (1.04 - e^{(0.38\log(TUR)-0.54)})$$

$$* A.L. = T.L. \text{ (if TUR} \geq 4)$$

     (2) The Root-Sum-Square method

$$A.L. = \sqrt{T.L.^2 - U^2}$$

   - PFA calculation is NOT practical: TUR ≥ 4:1 decision rule

$$A.L. = T.L.$$

2. If TUR calculation is NOT possible: (U: 95% expanded uncertainty of calibration process)
   - $A.L. = T.L. + U$, if the measured value should be more than tolerance limit.
   - $A.L. = T.L. - U$, if the measured value should be less than tolerance limit.

Step 4: Determine As-Left Error only if TUR calculation is Possible.

- As-Left Error = | the measured value – the reference value |

Step 5: Conformity Assessment: Compare the As-Left Error with the Acceptance Limit.

- If TUR calculation is possible and the As-Left Error is less than the Acceptance Limit, then "Pass" for the Conformity Assessment.
- If TUR calculation is NOT possible.
  - ■ If the measured value should be more than the Tolerance Limit and the measured value is more than the Acceptance Limit, then "Pass" for the Conformity Assessment.
  - ■ If the measured value should be less than the Tolerance Limit and the measured value is less than the Acceptance Limit, the "Pass" for the Conformity Assessment..

In accordance with JCGM guidelines, measurement errors are assumed to follow a normal distribution. The JCGM stipulates that a normal distribution may be assumed when the underlying distribution is unknown [4].

3. Case Study

Signal Generators are essential for Electromagnetic Compatibility (EMC) testing. The U.S. Regulatory Guide 1.180 (Rev.2, 2019) provides guidelines for evaluating electromagnetic and radio-frequency interference in safety-related instrumentation and control systems, endorsing MIL-STD-461G, parts of the IEC 61000 series standards [5]. Unlike EMI test receivers, which adhere to CISPR 16-1-1 accuracy requirements, signal generators lack mandatory manufacturing regulatory standards. Consequently, the manufacturer's specification limits are used as the tolerance limits for calibration.

This study utilizes a calibration certificate for a Rohde & Schwarz SMB100B. The specification limits are < 0.5 dB (Level > -90 dBm, 200 kHz < frequency ≤ 3 GHz) and < 0.7 dB (Level > -90 dBm, frequency > 3 GHz) according to its specification sheet.

Application of the Guideline:

Step 1: Manufacturer specifications were adopted as the tolerance limit (T.L.), assuming a normal distribution.

Step 2: Since the tolerance interval is defined, TUR calculation is feasible. The PFA 2% rule with guard band was selected.

Step 3: Dobber's method was used to calculate the Acceptance Limit (A.L.) as the TUR fell between 1 and 15.

Step 4&5: As-Left Errors were calculated and compared against the A.L. (See Table I).

Table I. The Example of the Conformity Assessment for SMB100B

Freq. (GHz)	T.L. (dB)	Refe-rence Value (dBm)	Mea-sured Value (dBm)	TUR	A.L. (dB)	Pass/ Fail
0.03	0.5	5	4.99	2	0.43	Pass
3.0	0.5	5	5.11	1.9	0.42	Pass
3.8	0.7	5	5.09	2.7	0.65	Pass

(The 95% expanded uncertainty of the calibration process is 0.25 dB)

(Decision Rule: PFA ≤ 2% with the Dobbert's method)

3. Conclusions

The "4:1 Rule" guideline was successfully applied to the conformity assessment of the Rohde & Schwarz SMB100B signal generator. Future research should examine the applicability of this guideline to other types of M&TE.

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