

# Calibration Process Innovation Using Non-Required Guard Banded Testing

## White Paper

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**Abstract**— *Calibration services vary as to how to set the acceptance limits compared to the required tolerance (i.e., specification). Using a guard band to reduce the acceptance limit will increase the confidence in the calibration. The larger the guard band, the lower the probability of a false acceptance. Unfortunately, this also raises the cost of ownership for the unit.*

*But there are other advantages to be gained by setting more restrictive test limits, internal to the calibration organization, than the prescribed acceptance limit from the end user (customer). This paper recaps the method and results of a project that used such a strategy. It explores some of the benefits gained through a calibration process for a targeted tolerance that has very little measurement margin. By collecting and analyzing measurement data from instances where a unit met the acceptance limit but failed the more restrictive internal limit, much insight into the health of the process was obtained. The new process identified both systemic issues and margin failures that were affecting the overall quality of the calibration process. Addressing these issues provided process improvements that would reduce future apparent out-of-tolerance situations. It also allowed suspected instrument failures to be correctly identified as a faulty calibration process.*

*The intent of this paper is to help calibration laboratory managers to make informed decisions related to managing their internal processes. Judicious use of guard banding can improve a calibration process. Calibration is performed to bound process margins and control risk to the organization. The process change discussed in this paper can contribute to both. This paper should prepare you to evaluate whether a similar process change would enhance your calibration service or not.*



## Introduction

The specific project being reported on here was focused on a single instrument family. While the typical calibration (i.e., verification) time for this family of instruments was 6 hours, there were numerous units that experienced over 30 hours of work. The project was launched to examine and identify what factors were causing the extensive amount of time. The author of this report was not a participant in the project but is simply sharing the lessons learned for the benefit of others.

Some examination of data was needed to identify what was causing the additional test time. To find a pattern in the performance it was deemed necessary to look at more than the few instruments requiring excessive time. Due to the relative high volume of instruments being calibrated, a filter was needed to select those instruments that would receive additional scrutiny. Most of the calibrations performed included a determination of conformance without any guard band. That is, the test limits applied were equal to the tolerance or specifications of the instrument. The failure rate for the instruments was relative low.

Applying a guard band would increase the apparent failure rate by classifying marginal instruments as failures. It was anticipated that the units requiring excessive time would ultimately be either a bona fide failure or fall into this marginal category. Therefore the project instigated the use of a guard band equal to the expanded uncertainty as an internal test or filter for additional examination. There was no change to the definition of the service as provided to customers. That is, the determination of conformance for the calibration continued (on these units) to be without a guard band.

## 2. Guard Band Practices

The term “*guard band*” dates to the 1940s when radio communication was taking on new significance. It is the term that was used to refer to the space of unused spectrum between communication channels. The purpose was to decrease interference between the channels. Literally, it was a band of frequencies dedicated to guard the communication signals from harm.

In metrology a guard band has a similar purpose, in that it is an offset designed to guard against a false decision. In most cases the guard band is employed to guard against a false acceptance decision, thus tightening the test limits to be more restrictive than the tolerance. There are cases where this guard band is used to protect against a false rejection decision leading to unnecessary out-of-tolerance (OOT) action. The final affect of employing a guard band is to adjust the ratio between the supplier and consumer risks. It does not alter the measurement, but does alter the probabilities of a specific decision for a specific parameter quantity.

Very often in the commercial calibration business the test limits used for making a determination of conformance are the same as the tolerance or specification. In essence the guard band used is zero. Most reputable manufacturers establish specifications with some degree of conservatism making allowance for unknowns such as environmental effects and measurement uncertainties in their processes. Thus the general performance of the instrument is often noticeably better than the specification. If the distribution of actual performance is not wide compared to the specification limits then the consumer risk is relatively low.

Some calibration services do include a non-zero guard band, or set the test limit tighter than the tolerance. Again the purpose is to manipulate the relative risks between the producer and the consumer. Increasingly the guard band used is set equal to the expanded measurement uncertainty. This provides for a very low probability of false acceptance, and in some economies, it is required for accredited calibrations <sup>1</sup>.

There are two different approaches to the calculation of GUM <sup>2</sup>-compliant measurement uncertainties. In one scenario the metrologist uses the specified performance of the laboratory standards in calculating the uncertainty. This technique allows for the applicability of the calculation to multiple instances of the testing environment. It also provides a simpler measurement approach because this quantity remains static. In another scenario the metrologist applies either the characterized performance of the specific laboratory standards in use, or makes system measurements at the time of calibration to affect certain terms in the uncertainty calculation. This results in a dynamic measurement uncertainty.

It is worth mentioning that at one time it was common practice to use some fixed percentage of the tolerance as a guard band. Typical numbers often would range from 10% to 25% of the tolerance limit. The author is not aware of this as a common practice at this time.

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1. *Some people are surprised that this in fact is inconsistent around the world. The differences are derived from local interpretations of ISO/IEC 17025 paragraph 5.10.4.2 in reference to taking uncertainties “into account.” While this is currently the case, it is not the focus of this paper.*
  2. *ISO/IEC Guide 98-3:2008*

Recently the adoption of ANS Z540.3-2006 led to new approaches for choosing a guard band. With that standard the calibration process target is a specific maximum probability of false acceptance (i.e., 2%). The choice of guard band to achieve this target is dependent upon a number of factors. The first dynamic guard band process developed to achieve that goal was developed by Mike Dobbert of Agilent Technologies <sup>3</sup>.

### 3. Process Used

The project being reported on was originally conceived to address the issue of long periods of time for certain units in calibration. The family of microwave sources typical requires 6 hours for a full calibration. Yet it was not uncommon for a unit to log over 30 hours of work by the laboratory staff. Clearly a portion of these in fact were not in compliance as revealed by the first attempted calibration. These units would undergo corrective action and then a re-calibration to ensure conformance before being returned to the customer. Yet some units did not have confirmed problems, yet still required considerable time.

The project to expose the process issues needed to minimize any adverse affects on customers. In many cases the unit was already experiencing extra time out-of-service. The criteria for making a determination of conformity could not be different than normally required for these commercial calibrations. To change that would impact the probability of triggering the customer's quality processes that deal with OOT calibrations.

But it was possible to use a guard band to identify units that would trigger internal processes within the laboratory. This is the approach that was followed, and an internal guard band equal to the expanded uncertainty was chosen. Units that failed this more restrictive test limit would be examined more closely. These units would have data points that either "failed" or were "indeterminate" under ILAC G8:1996.

In the first phase of the project a baseline for station variation was established. In general there was very good consistency between the stations, as shown in Figure 1.

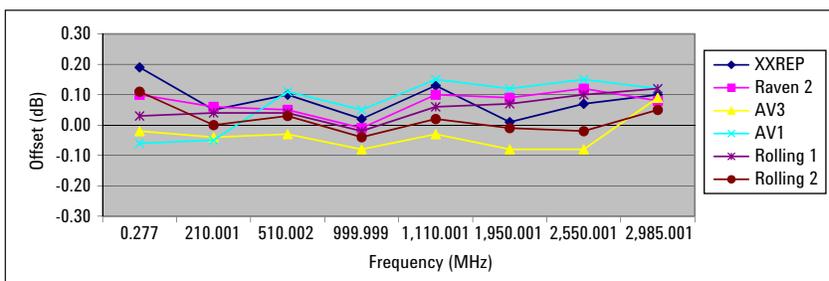
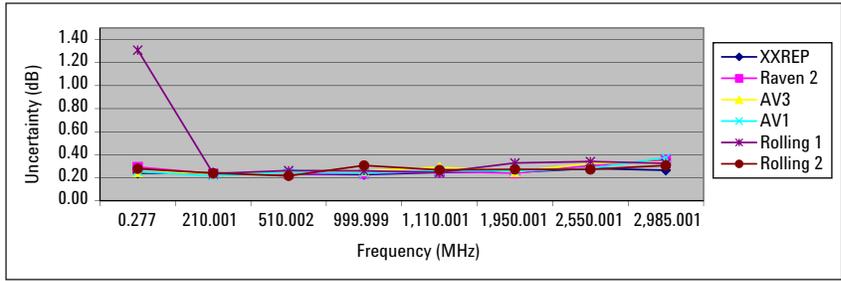


Figure 1. Performance data from 5 separate stations.

Additional analysis was done on the dynamic measurement uncertainty calculated for each measurement point. The uncertainties for each point at each station are shown in Figure 2. Note that the data clearly indicates an issue with one station at the low end of the frequency range. This was identified as a station issue and resolved.

3. Presented at the 2008 NCSLI Conference – [http://metrologyforum.tm.agilent.com/ncsli2008\\_dobbert.shtml](http://metrologyforum.tm.agilent.com/ncsli2008_dobbert.shtml).

Figure 2. Measurement uncertainties for each point.



Since the measurement uncertainty is calculated dynamically, it is influenced by various parameters in the station calibration. Common factors include excess noise on a spectrum analyzer, or a spurious signal on the analyzer, a bad cable, or even a loose connection external or internal to the unit under test. These events may or may not directly affect the measured value. But these items do reduce the noise margin or other factors about the measurement that increase the measurement uncertainty.

When the measurement uncertainty is simply reported to the customer but not used to affect the test limit, an unusual increase in the uncertainty can go unnoticed. By applying the uncertainty as a guard band these incidences trigger the technician to apply additional scrutiny.

The team had access to historical calibration data which included the dynamic measurement uncertainty for each point. This allowed for careful analysis to identify how often the uncertainty was unusually large and for correlation to troubled units. It also permitted identifying the correlation between test stations where this happened and where instruments realized troubled calibrations. The historical mapping of the uncertainty is shown in Figure 3. Note that while the uncertainty is generally well behaved, there are a few cases that suggest a definite problem existed on that calibration.

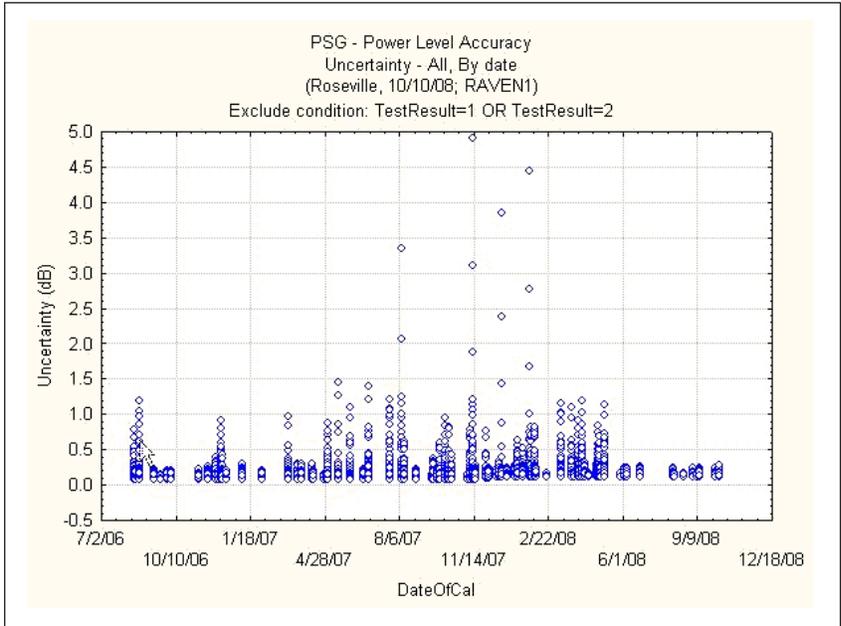


Figure 3. Historical view of uncertainty on one test station.

Note that by applying the measurement uncertainty as a guard band what is often detected is one of two items:

First is a case where the uncertainty has expanded beyond what the process normally produces. Additional work is required on each case to identify the cause of the anomaly. Depending on the parameter the expanded uncertainty may point to missing calibration data for a laboratory standard, connection problems, or other such items. It could also be a function of the unit under test. Further investigation typically would begin with a manual measurement of the significant data point where the technician can look at the intermediate results (i.e., look inside the measurement at intermediate values).

The second area that is often captured by this process is where there is a bias to the measured values. See Figures 4 and 5 for typical examples <sup>4</sup>.

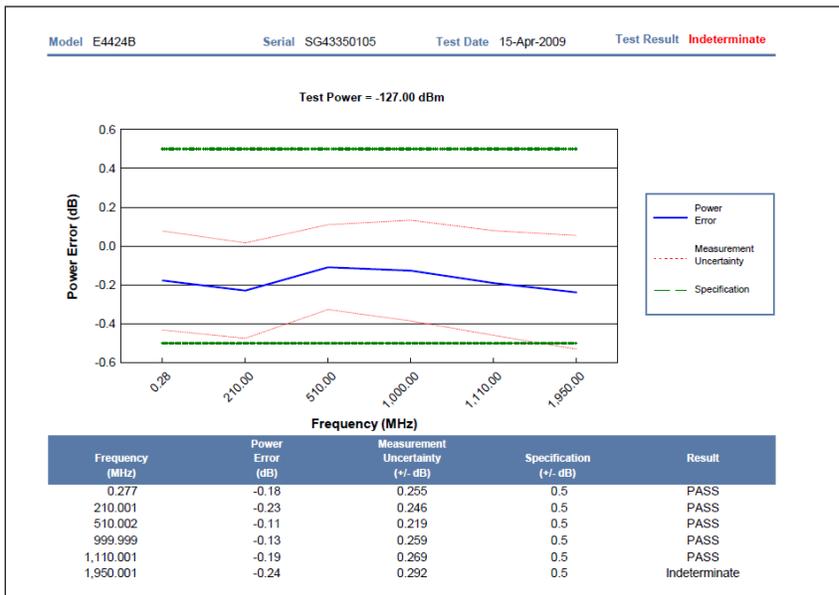


Figure 4. Offset or bias results in reduced margin at the highest frequency.

Note that in neither of the cases shown does the unit fail to meet the specified tolerance. But in both cases the operating margin is reduced. This condition could potentially lead to an unneeded OOT situation before the end of the next calibration interval. It could also potentially lead to operation outside the specified tolerance under certain environmental conditions. It is not possible to predict the impact this will have on the reliability of the instrument.

Once defined the process was implemented for 30 failures or indeterminate results. Analysis of those units and what was found is shown in Figure 6. Note that for the 30 units flagged for additional analysis, 14 of those had bona fide problems with the instrument.

4. Note that while in the strict sense a guard band is an offset from the tolerance, the software tools used indicate a range around the measured value reflecting a 95% measurement uncertainty. Where this range exceeds the tolerance the result is deemed indeterminate. Mathematically this is the same effect as guard banding the tolerance by the 95% measurement uncertainty.

## 4. Results

The first area of satisfying results was the identification of systemic errors in the production process. Of the 16 units where the problem was not related to the instrument being calibrated, 5 were station issues and 3 more were specifically problems with cables. The process identified technician issues (i.e., cleaning, training) that could be addressed to benefit all units.

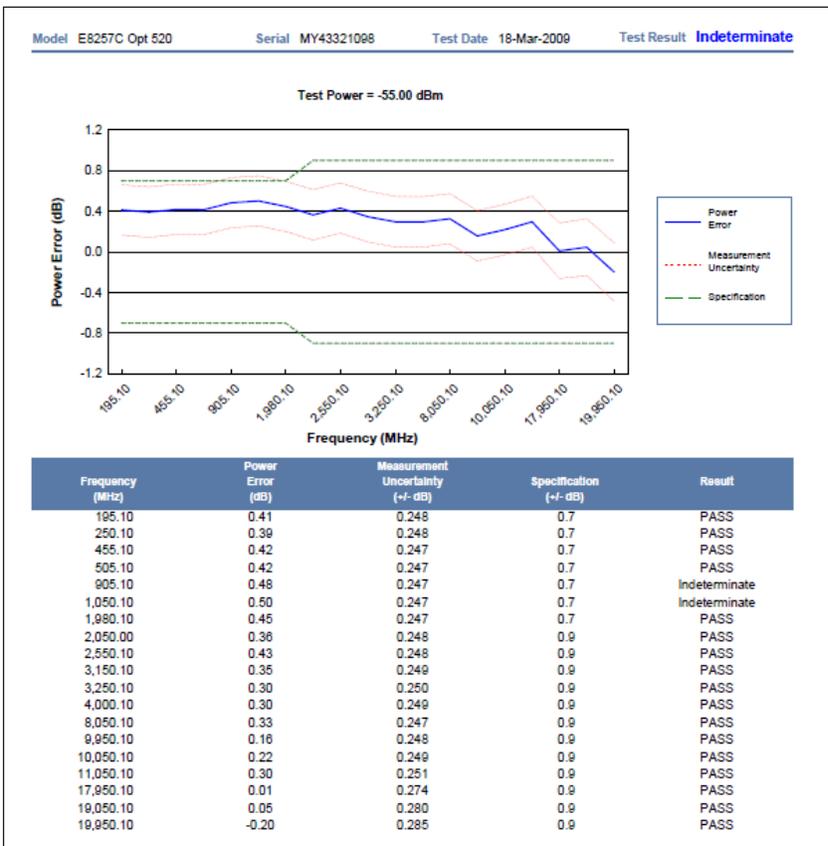


Figure 5. Offset or bias results in reduced margin around 1 GHz.

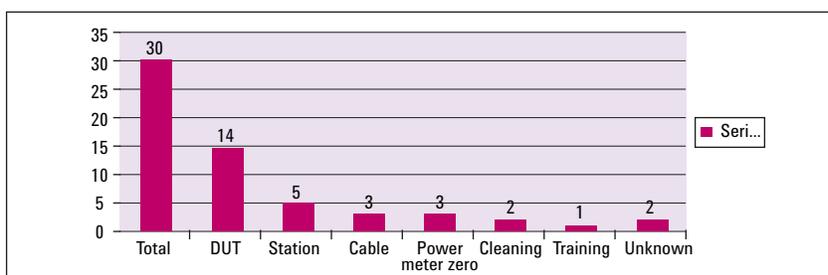


Figure 6. Results of 30 test cases used to validate process.

Another benefit was to identify patterns of suspected instrument failures and what the actual cause was. Some of the problems first appear to be a problem with the instrument under test but the team has now learned to identify certain symptoms and look for test process issues instead. This was particularly rewarding when a customer, who performs their own calibrations, submitted an instrument for repair. Based on the reported failure data the team was able to identify a familiar calibration process problem as the cause. They then helped the customer to avoid the cost of repair on this unit and future occurrences.

Naturally with these positive results this process change has been adopted as standard at this Service Center. A sample of data from a later month showed 26 suspected units (“*failed*” or “*indeterminate*”) and of those units 17 were instrument issues and the other 9 were station issues. The 17 units received corrective action such as optimization to enhance the usefulness of the instrument and improve its in-use reliability. It is noteworthy that such an experiment for a limited length of time is not sufficient to eradicate all process issues. Continued use of the process continues to detect station degeneration before instrument calibrations are significantly impacted.

## 5. Conclusions

Not only has this process become standard for this family of products at the first Service Center, but the process is now being evaluated for replication for other instrument families and at other Service Centers.

The process provides only positive impact to customers. Any additional time spent on analyzing flagged units is offset by time spent trying to troubleshoot instruments that do not have failures.

The process identifies units that could meet the acceptance criteria during calibration only to fail those criteria for the user. Yet it does not impose restrictive limits that result from cascading guard bands.

The process provides good monitoring of the calibration test stations and the opportunity to expose systemic issues before they negatively impact customer deliverables to any significant amount.

These benefits can be accomplished without rigorous resource-consuming analysis of large amounts of calibration data. This winnowing process allows the team to focus on units most likely to expose issues that need to be addressed. It also permits patterns to be seen to guide the team away from specific unit problems and toward systemic problems.



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