





A software-centric platform that accelerates the development and increases the productivity of test, measurement, and control systems.

Improve Measurement Accuracy in Your Application

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Why Characterize a Measurement System?

- Inadequate uncertainty
- More accurate system not available
- Difficult to deploy or operate

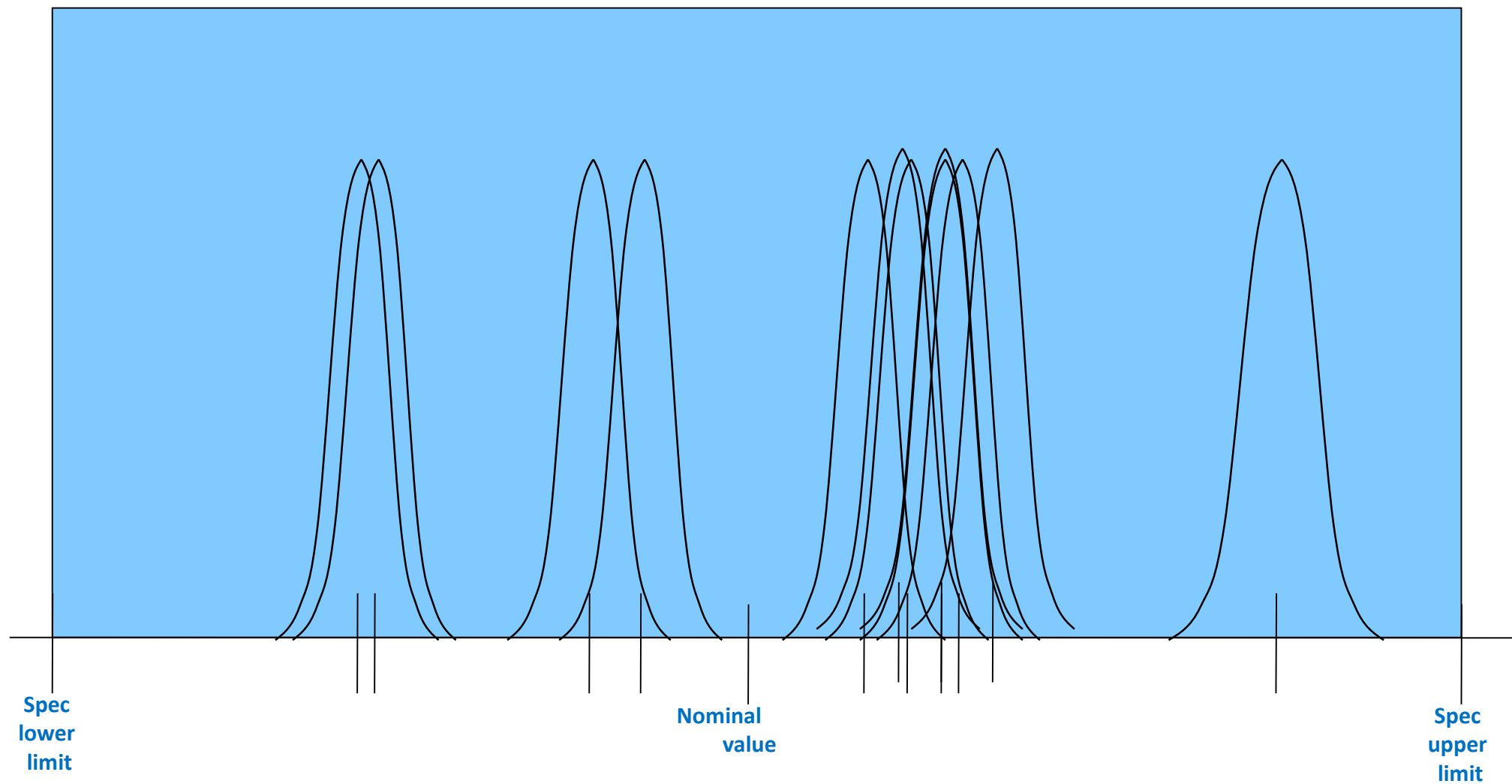
Solution

- Characterization of calibration system:
 - Using more accurate standards
 - Improved measurement method
- Characterization provides the system:
 - Traceability to SI units
 - Better Measurement Uncertainty
 - Nominal value corrected to a more accurate value

Why it Works

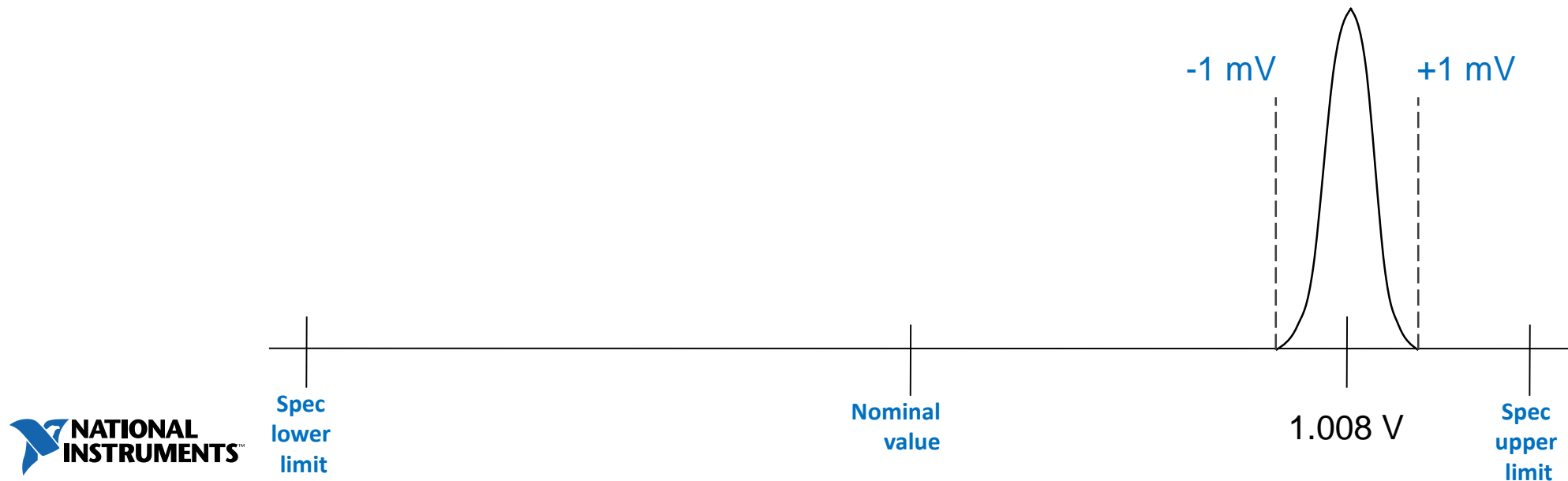
- Individual instruments perform better than the published specifications
- Systems are used in environmental conditions that vary much less than the normal instrument operating ranges
-
- Time related Performance drift is minimized
- System external calibration uncertainty and traceability errors become negligible
- Range errors are removed by characterization of all points of interest
- Relies on short term stability of the system

Warranted Specification

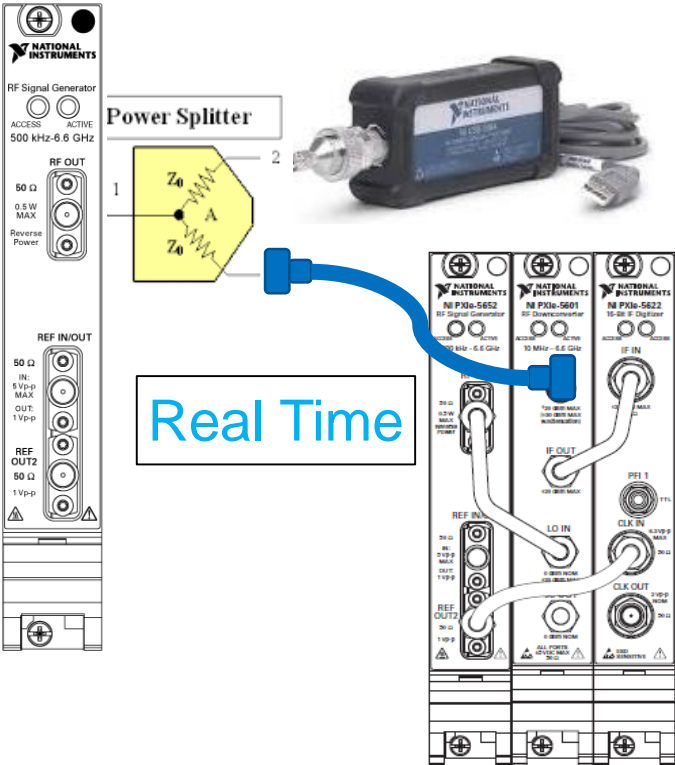
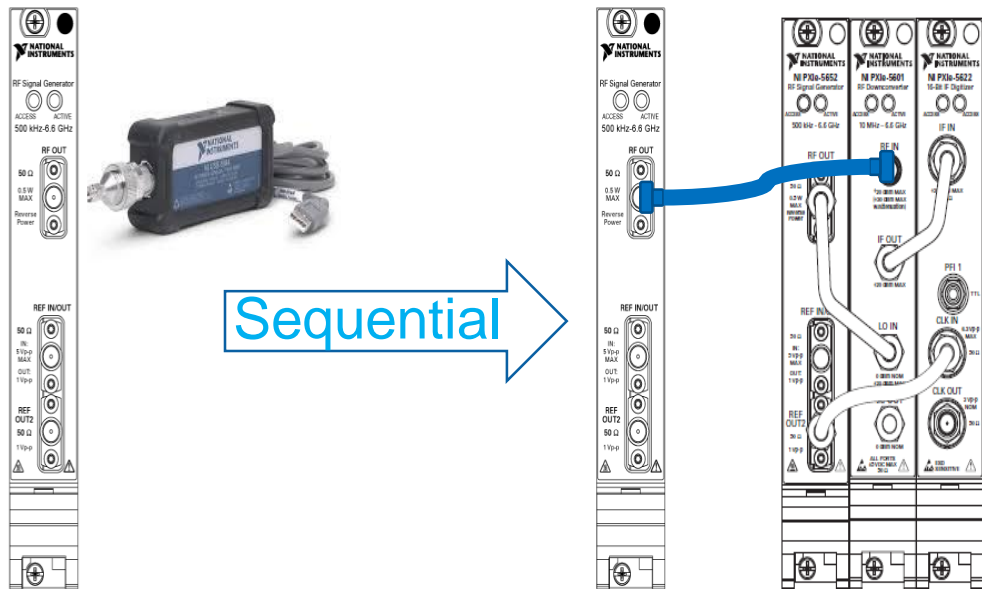


How it Works

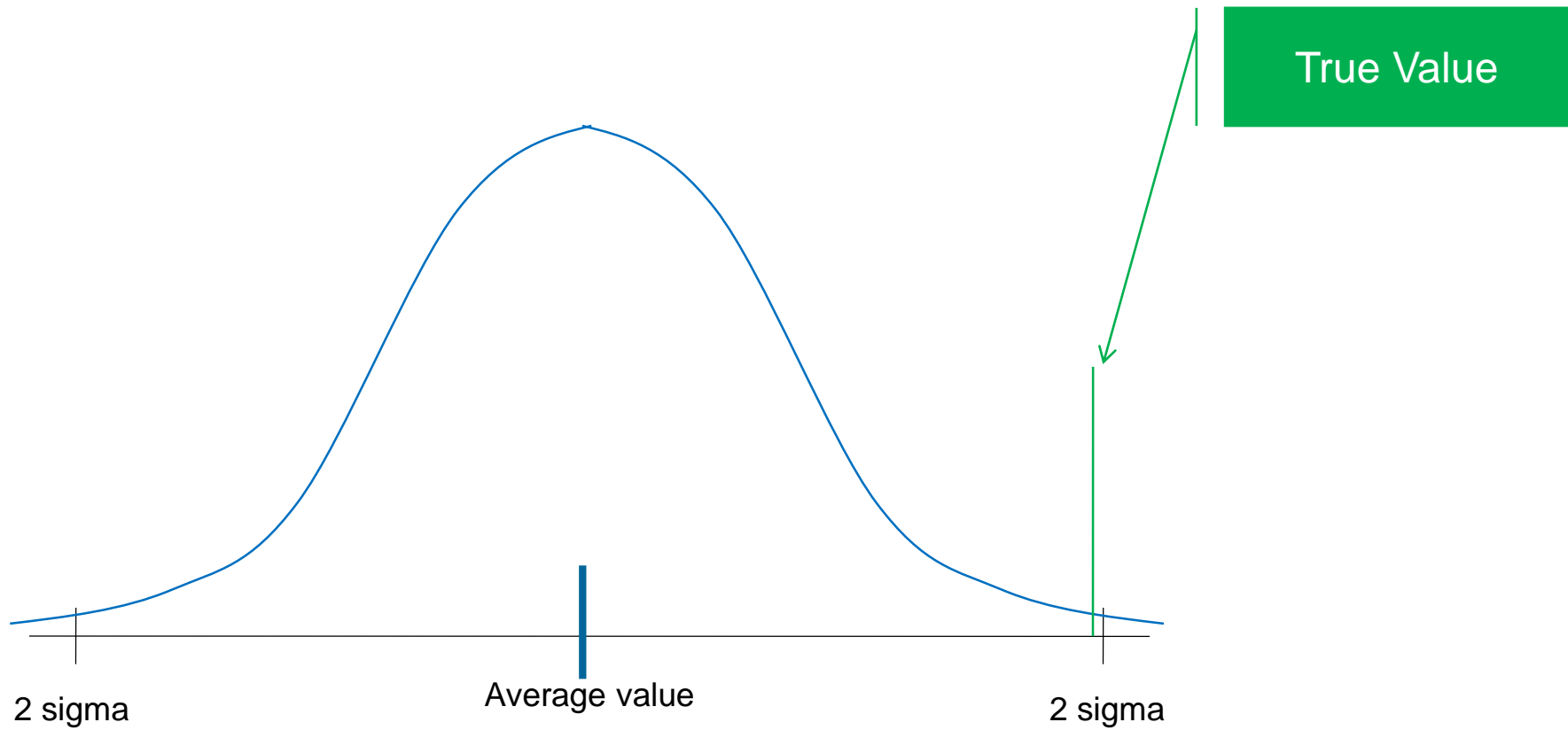
Nominal Value	Mfg. Specification	Characterized Value	Characterization Uncertainty
1.000 V	± 10 mV	1.008 V	± 1 mV



Types of Characterization



Measurement Uncertainty



Most Common Uncertainty Components

- Standards specification
- Standards calibration uncertainty
- Standards Time stability
- Environmental conditions Common mode errors
- Instrument resolution
- Repeatability
- Retrace error
- SW errors (e.g. rounding)
- Equipment and connections layout
- Thermoelectric Voltages
- Loading and cable impedance
- Mismatch errors
- Directivity Test Port Match on VRC
- RF connector repeatability

Is Your Uncertainty Good Enough?

$$\text{TUR} = \frac{\text{Accuracy of Device Under Test}}{\text{Uncertainty of the measurement process}}$$

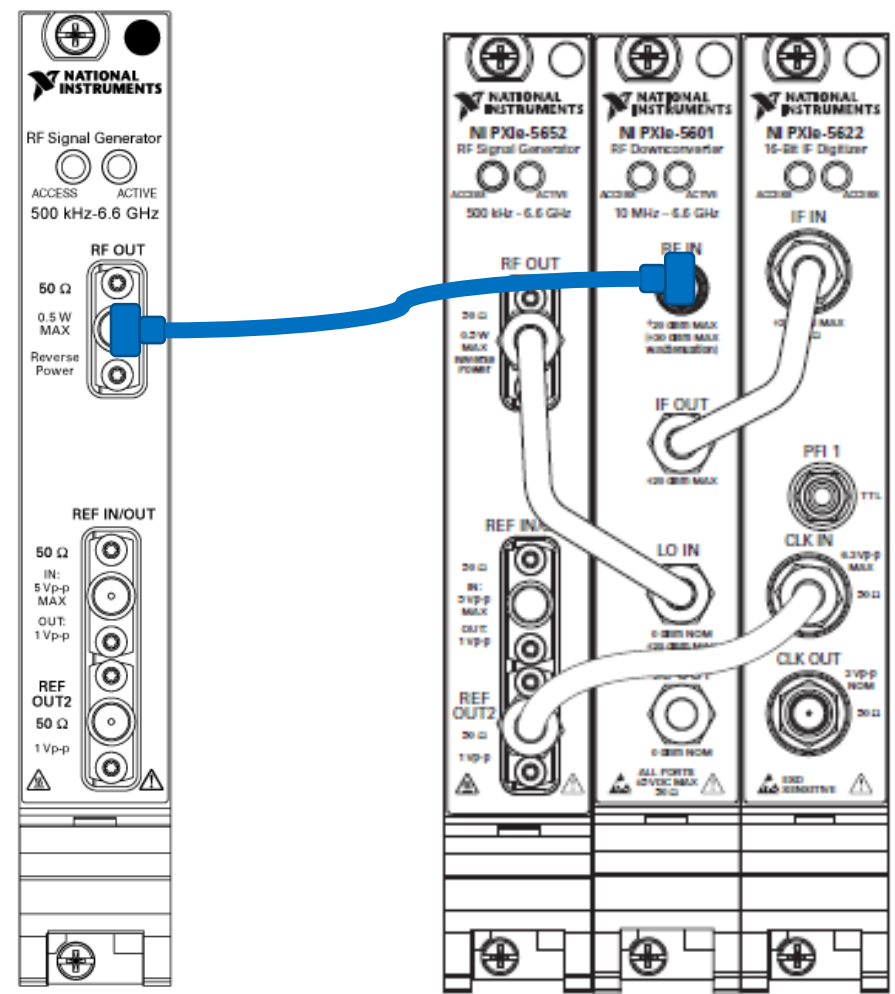
- Rule of thumb:
 - $\text{TUR} \geq 4:1 \Rightarrow$ We are done
 - $\text{TUR} < 4:1 \Rightarrow$ Review the characterization process

What If Your Uncertainty is Not Good Enough?

- Use a better characterization method
- Better characterization standards
- Eliminate the noise source
- Reduce standards uncertainty

Example Without Characterization

Stand Alone Source



Calibrate DUT Amplitude accuracy at 0 dBm @ 4 GHz

Standard specifications		DUT
Amplitude accuracy	± 1.0 dB	± 1.6 dB
VSWR	1.8:1	2.0:1

Example Without Characterization Uncertainty Analysis (UA)

Stand Alone Source

Uncertainty component	Value	
Generator Amplitude Accuracy	$\pm 25.9\%$	$\approx \pm 1.0$ dB
Mismatch Generator-DUT	$\pm 19.0\%$	$\approx \pm 0.76$ dB
Measurement repeatability	$\pm 1.0\%$	$\approx \pm 0.09$ dB
Measurement uncertainty	$\pm 40\%$	$\approx +1.5$ dB ≈ -2.2 dB

DUT Accuracy $\pm 44.5\%$ (1.6 dB)

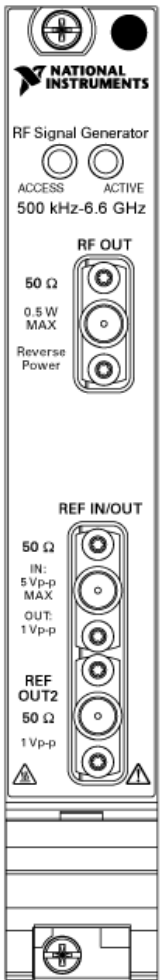
Measurement Uncertainty $\pm 40\%$

TUR= 1.1 << 4.0 Unacceptable

Example Characterization UA

Stand Alone Source + Power Sensor

First Step



Characterize Generator Amplitude accuracy at 0 dBm @ 4 GHz		
Power Sensor specifications		Generator
Amplitude accuracy	± 0.13 dB	To be characterized
VSWR	1.22:1	2.0:1

Example Characterization UA

Stand alone source + power sensor

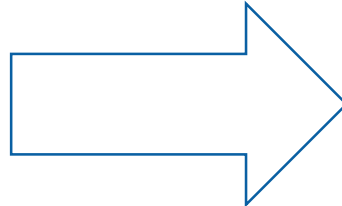
Uncertainty component	Value	
Power sensor absolute accuracy	$\pm 3.0\%$	$\approx \pm 0.13 \text{ dB}$
Mismatch Generator - Pw Sensor	$\pm 6.6\%$	$\approx \pm 0.28 \text{ dB}$
Measurement repeatability	$\pm 0.5\%$	$\approx \pm 0.04 \text{ dB}$
Characterization Measurement uncertainty	$\pm 10\%$	$\approx +0.4 \text{ dB}$ $\approx -0.5 \text{ dB}$

Save the Power Sensor average Measurements as the characterized output of the generator

For example = $+0.124 \text{ dBm} \pm 10\% @ 4 \text{ GHz}$

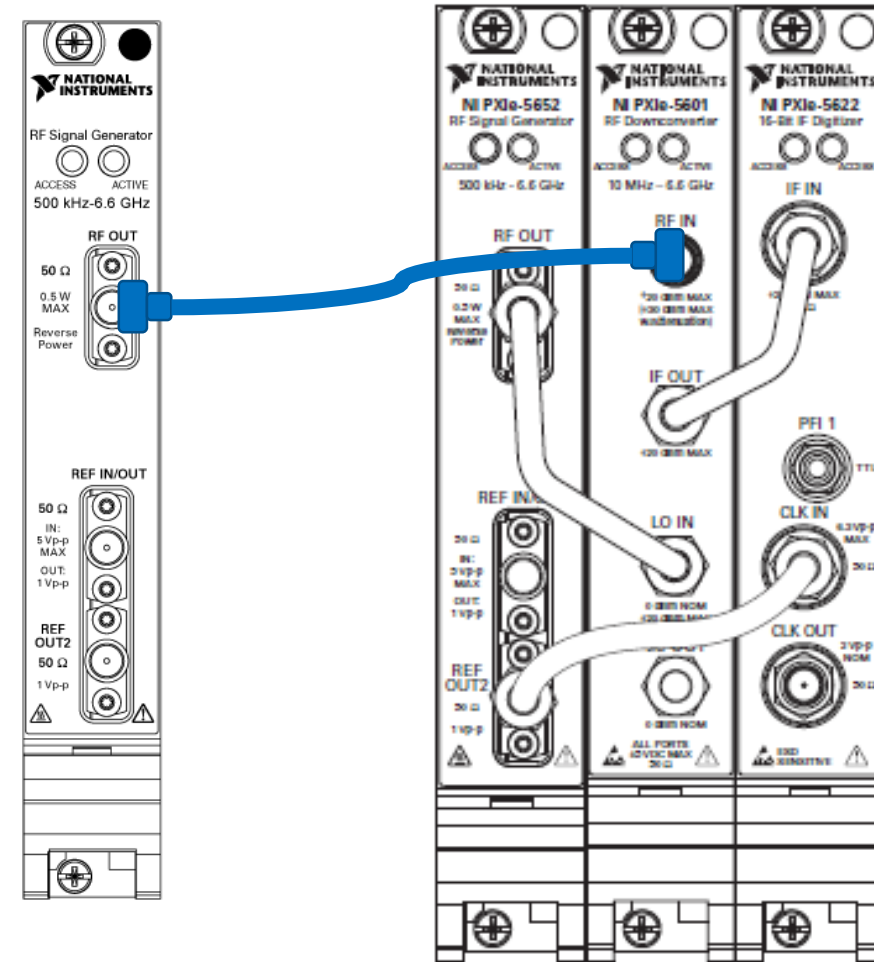
Example Characterization UA

Stand Alone Source + Power Sensor



Second Step

Calibrate DUT with Characterized Source



Example With Characterization UA

Stand Alone Source + Power Sensor

Uncertainty component	Value	
Characterization uncertainty	$\pm 10\%$	
Mismatch Generator-DUT	$\pm 6.6\%$	$\approx \pm 0.28$ dB
Generator retrace error	$\pm 5.0\%$	$\approx \pm 0.20$ dB
Measurement repeatability	$\pm 0.5\%$	$\approx \pm 0.04$ dB
Measurement uncertainty	$\pm 14.9\%$	$\approx +0.6$ dB ≈ -0.7 dB

Characterized output of the generator [0 dBm] = **+0.124 dBm $\pm 15\%$ @ 4 GHz**

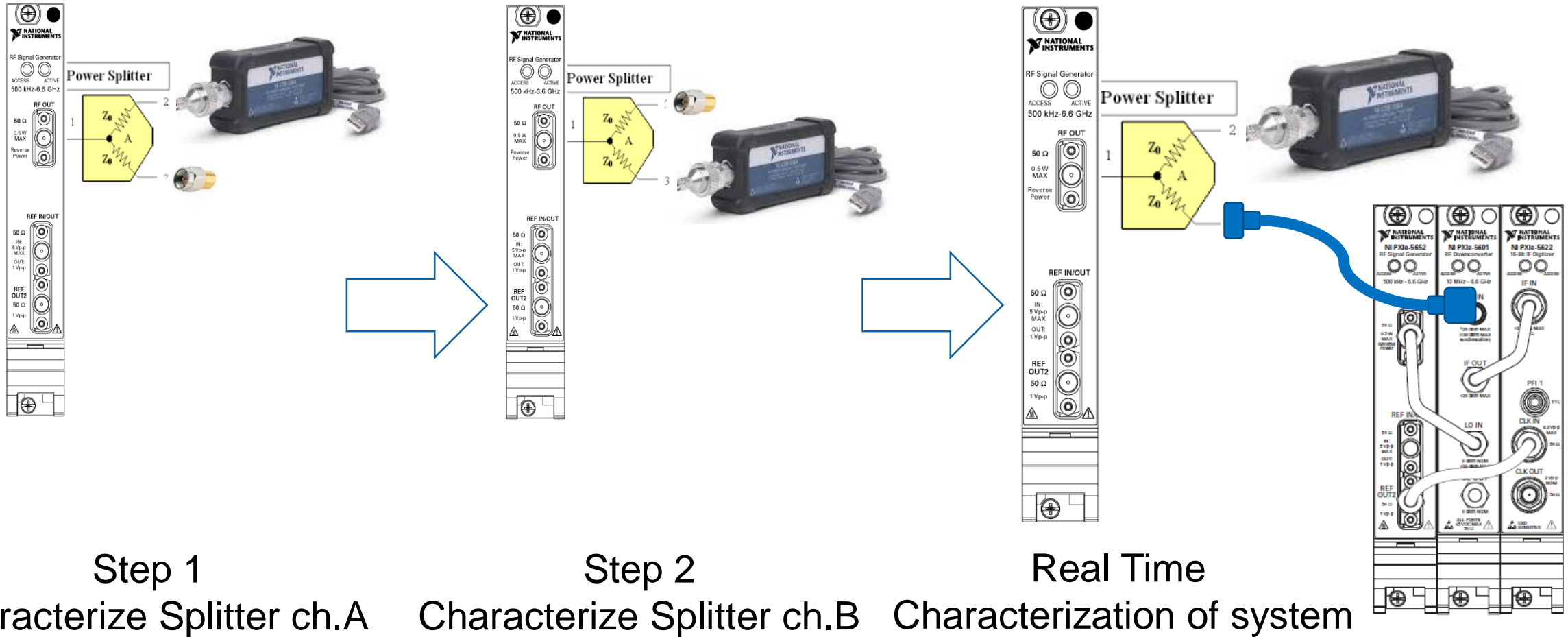
DUT Accuracy $\pm 44.54\%$ (1.6 dB)

Measurement Uncertainty $\pm 14.9\%$

TUR= 3.0 << 4.0 Unacceptable but better

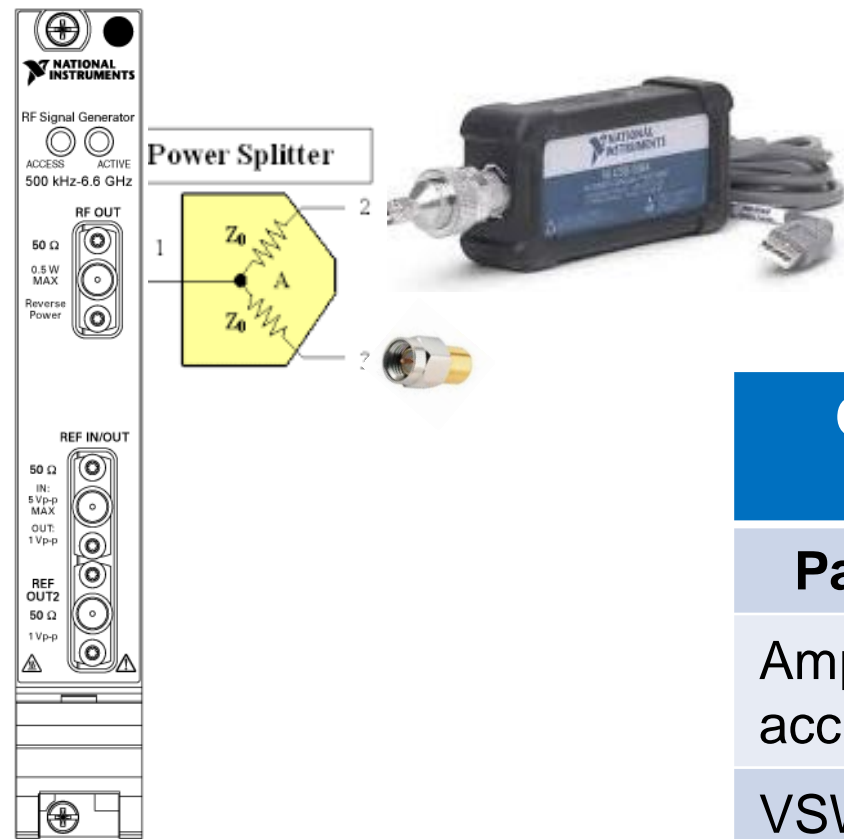
Example Characterization UA

Stand Alone Source + Power Sensor + Power Splitter



Example Characterization UA

Stand Alone Source + Power Sensor + Power Splitter



Step 1

Characterize Generator/Splitter Ch. A Amplitude accuracy at 0 dBm @ 4 GHz			
Parameter	Power Splitter	Power Sensor	Generator
Amplitude accuracy	To be characterized	± 0.13 dB	NA
VSWR	1.22:1	1.22:1	NA

Example With Characterization UA

Stand Alone Source + Power Sensor + Power Splitter

Step 1

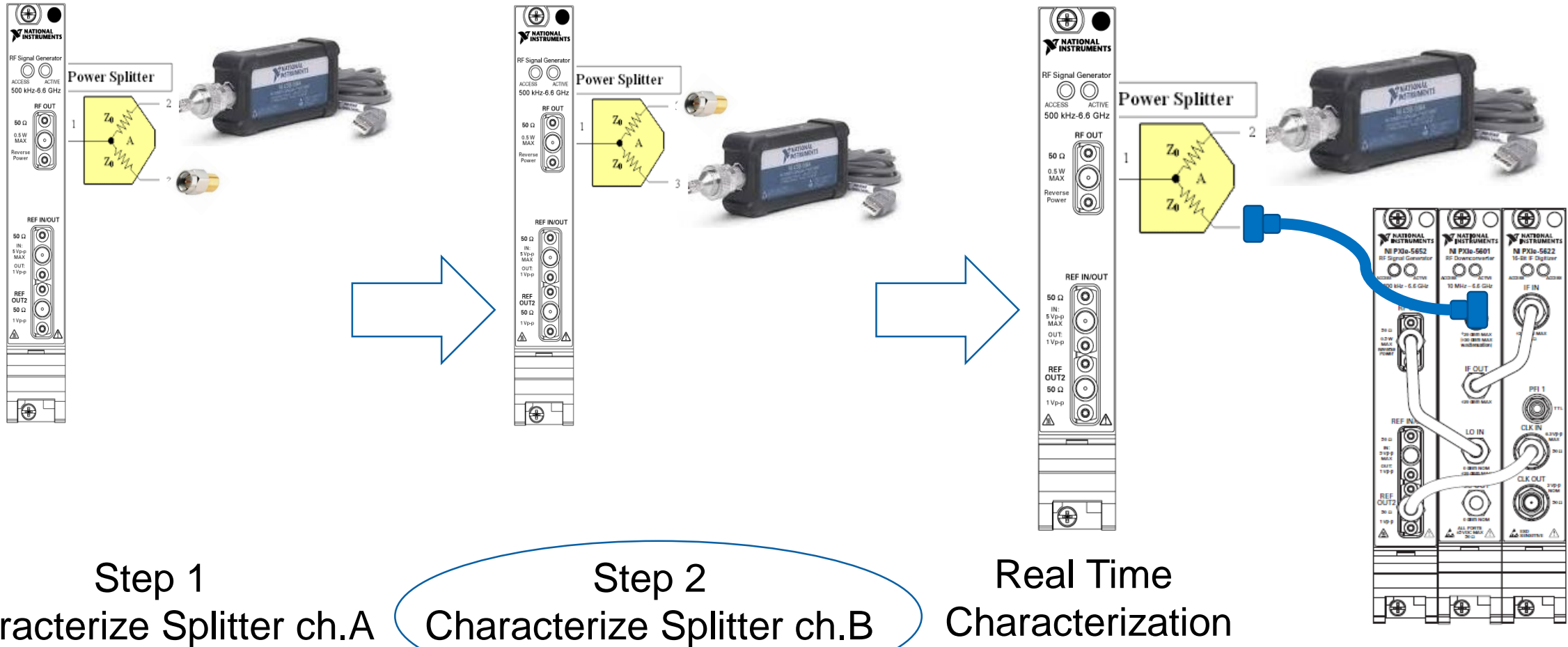
Uncertainty component	Value	
Power sensor absolute accuracy	$\pm 3.0\%$	$\approx \pm 0.13 \text{ dB}$
Mismatch Splitter-Pw Sensor	$\pm 2.0\%$	$\approx \pm 0.08 \text{ dB}$
Measurement repeatability	$\pm 0.5\%$	$\approx \pm 0.04 \text{ dB}$
Characterization Measurement Uncertainty =	$\pm 4.6\%$	$\approx +0.2 \text{ dB}$ $\approx -0.2 \text{ dB}$

Save the Power Sensor average Measurements as the characterized output Splitter ch.A

For example = $+0.002 \text{ dBm} \pm 4.6\% @ 4 \text{ GHz}$

Example Characterization UA

Stand alone source + power sensor + power splitter



Example With Characterization UA

Stand Alone Source + Power Sensor + Power Splitter

Step 2

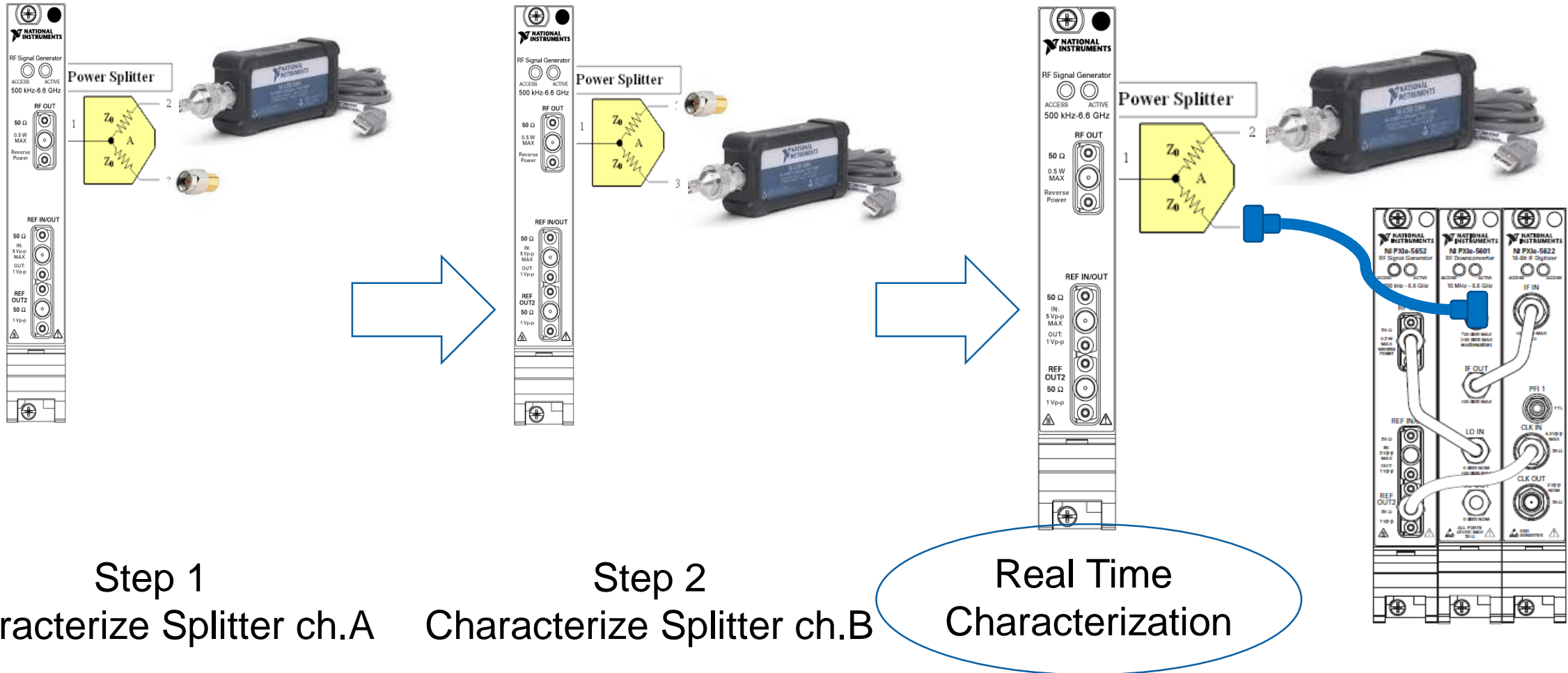
Uncertainty component	Value	
Power sensor absolute accuracy	$\pm 3.0\%$	$\approx \pm 0.13 \text{ dB}$
Mismatch Splitter-Pw Sensor	$\pm 2.0\%$	$\approx \pm 0.08 \text{ dB}$
Measurement repeatability	$\pm 0.5\%$	$\approx \pm 0.04 \text{ dB}$
Characterization Measurement Uncertainty =	$\pm 4.6\%$	$\approx +0.2 \text{ dB}$ $\approx -0.2 \text{ dB}$

**Save the Power Sensor average Measurements as the
characterized output Splitter ch.B**

For example = $+0.009 \text{ dBm} \pm 4.6\%$ @ 4 GHz

Example Characterization UA

Stand Alone Source + Power Sensor + Power Splitter



Example With Characterization UA

Stand Alone Source + Power Sensor + Splitter

Step 3

Uncertainty component	Value	
Power sensor absolute accuracy	$\pm 3.0\%$	$\approx \pm 0.13$ dB
Uncertainty characterization step 1	$\pm 4.6\%$	$\approx \pm 0.13$ dB
Uncertainty characterization step 2	$\pm 4.6\%$	$\approx \pm 0.13$ dB
Mismatch Splitter-DUT	$\pm 6.6\%$	$\approx \pm 0.28$ dB
Measurement repeatability	$\pm 0.5\%$	$\approx \pm 0.04$ dB
Total Characterization Measurement Uncertainty =	$\pm 11.8\%$	$\approx +0.48$ dB ≈ -0.55 dB

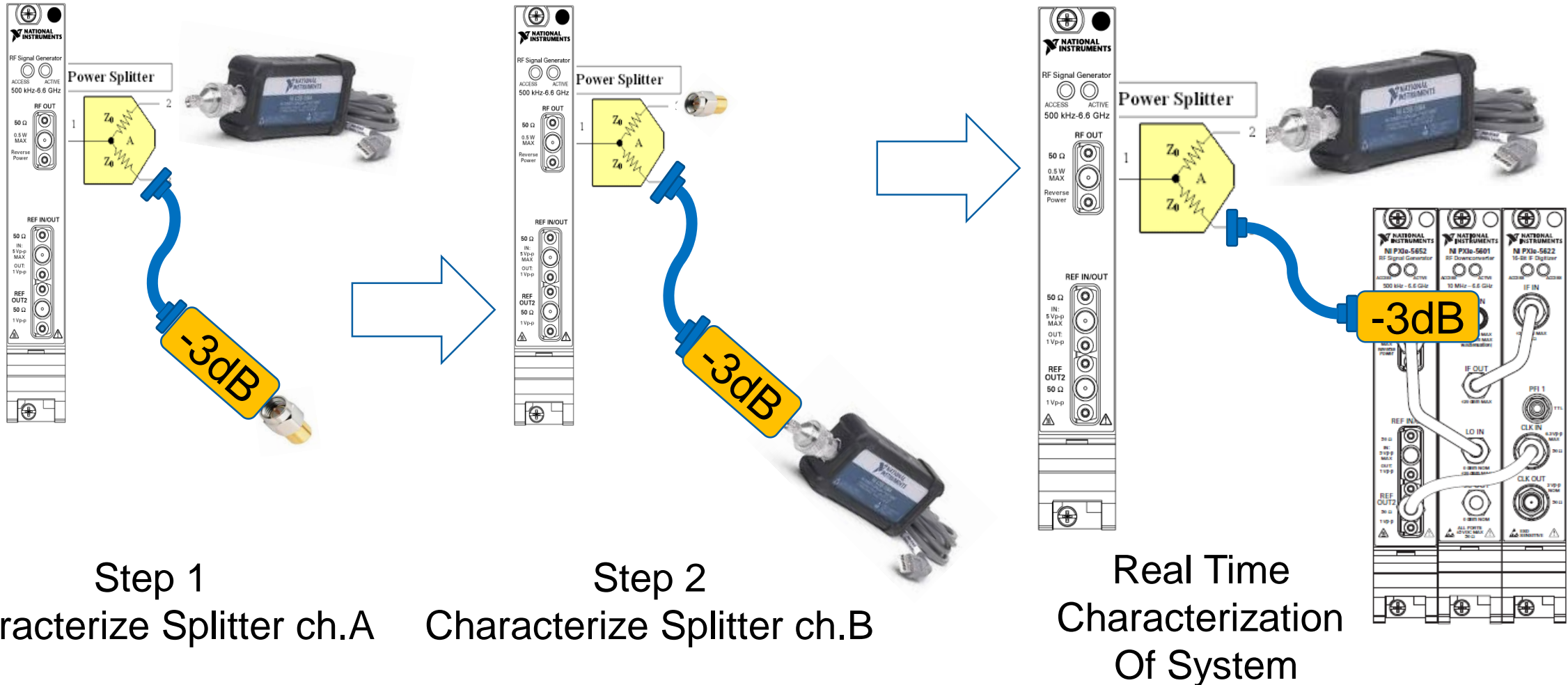
DUT Accuracy $\pm 44.54\%$ (1.6 dB)

Measurement Uncertainty $\pm 11.8\%$

TUR= 3.8 \approx 4.0 Practically Acceptable

Example Characterization UA

Stand Alone Source + Power Sensor + power Splitter + Attenuator



Example With Characterization UA

Uncertainty component	Value	
Power sensor absolute accuracy	$\pm 3.0\%$	$\approx \pm 0.13$ dB
Uncertainty characterization step 1	$\pm 4.6\%$	$\approx \pm 0.13$ dB
Uncertainty characterization step 2	$\pm 4.6\%$	$\approx \pm 0.13$ dB
Mismatch Splitter-DUT	$\pm 3.2\%$	$\approx \pm 0.14$ dB
Measurement repeatability	$\pm 0.5\%$	$\approx \pm 0.04$ dB
Total Characterization Measurement Uncertainty =	$\pm 8.6\%$	$\approx +0.33$ dB ≈ -0.36 dB

DUT Accuracy $\pm 44.54\%$ (1.6 dB)

Measurement Uncertainty $\pm 8.6\%$

TUR = 5.1 > 4.0 Acceptable

Characterization Summary

Characterization method	Uncertainty	Improvement
No characterization – Generator direct	$\pm 40\%$	Reference
Pre-Characterization – one step	$\pm 15\%$	2.6x better
Real time output characterization – 3 step	$\pm 11.8\%$	3.5x better
Real time output characterization – 3 step with attenuator	$\pm 8.6\%$	4.7x better

System Characterization Frequency

- If no historical data – Characterize before use
- Save characterization data
- Performance is **system** and **method** specific



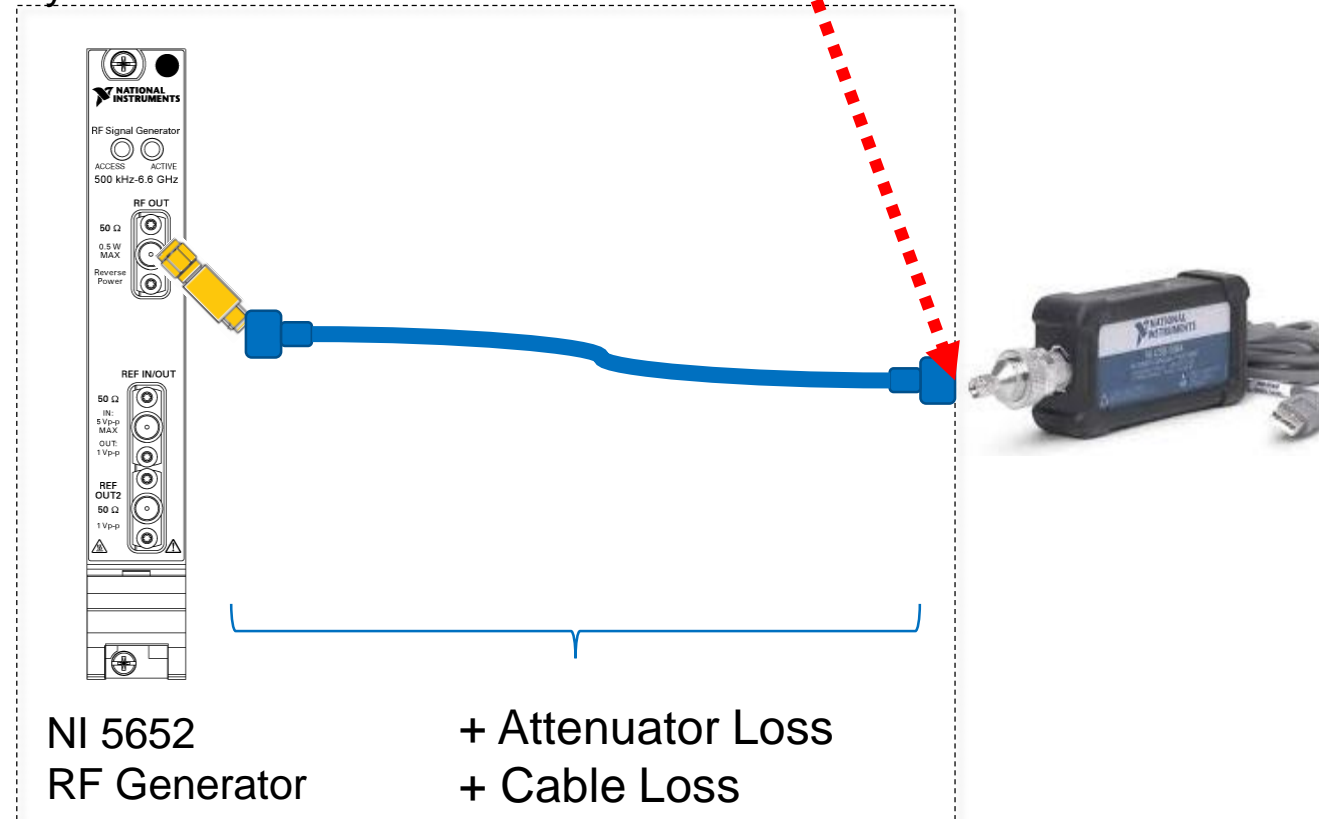
Characterization – Other Benefits

- Characterized devices do not need to be calibrated or directly traceable to SI units
- Only the standards used in the characterization need calibration and traceability to SI units
- Less station down time and less maintenance costs
 - Only standards require external calibration
 - One set of standards can characterize multiple stations
- Trend data available for analysis to determine:
 - Characterization interval of the calibration system
 - Early detection of equipment malfunction
 - Excessive system drift and noise

Characterize System Accuracy

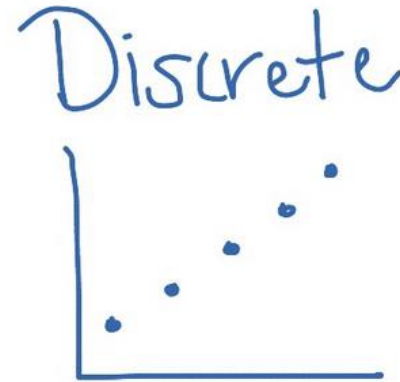
System Characterization Plane

System

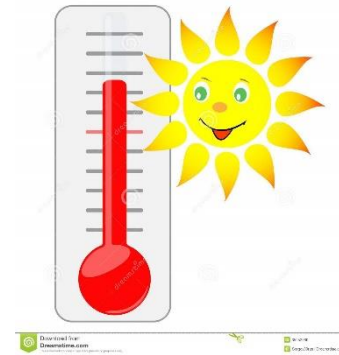
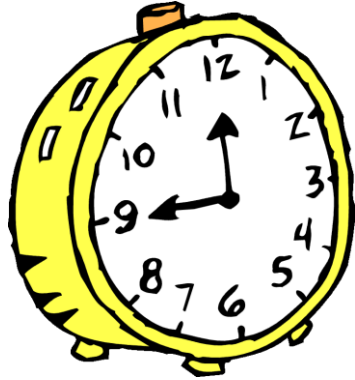


General Purpose vs. Specific Application

- Specific Applications
 - Discrete set of modes and ranges
- General Purpose Applications
 - Wide range or unbounded/continuous sets of modes and ranges



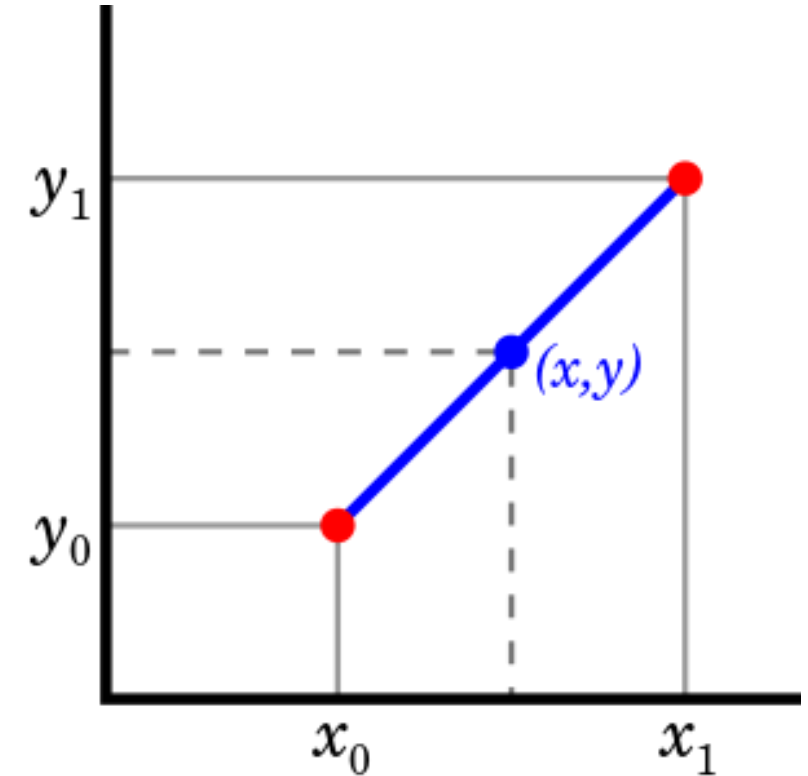
General Purpose Application Challenges



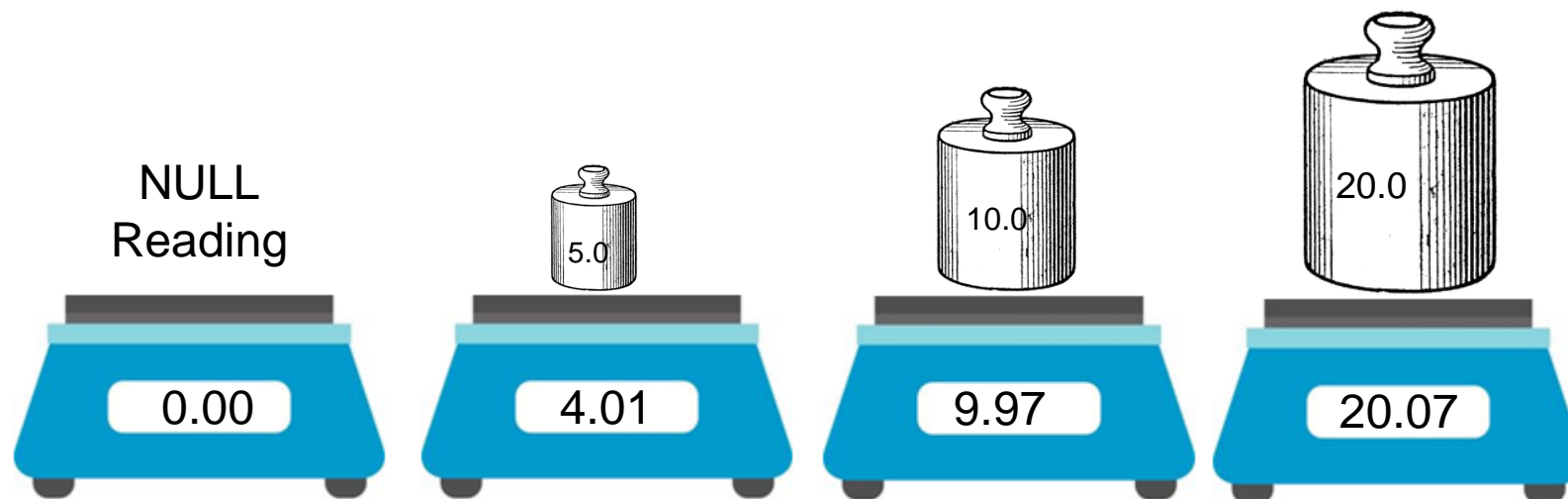
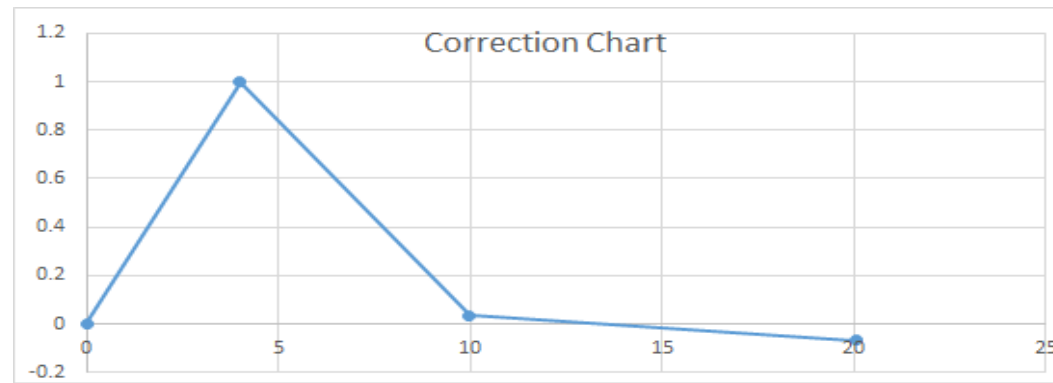
Continuous Range (32-bit integer = 4.2 billion points)

Characterization Interpolation

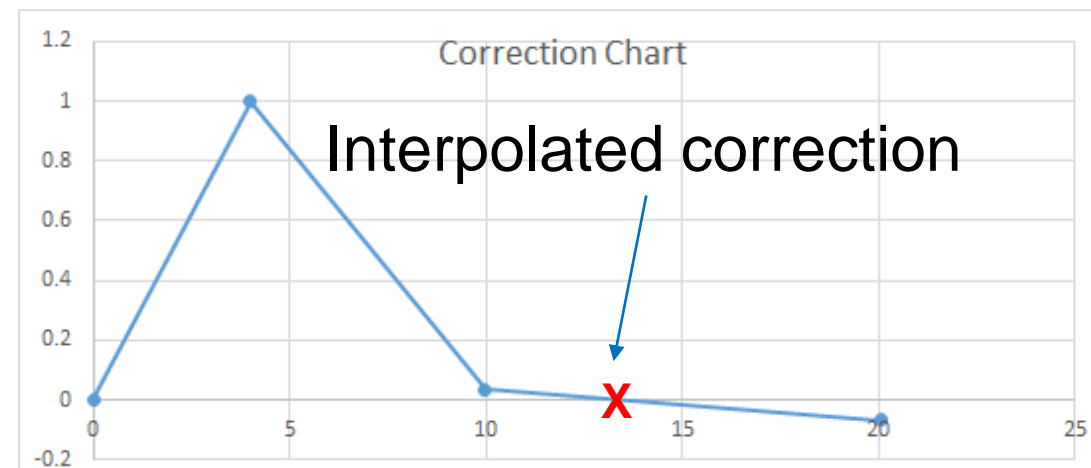
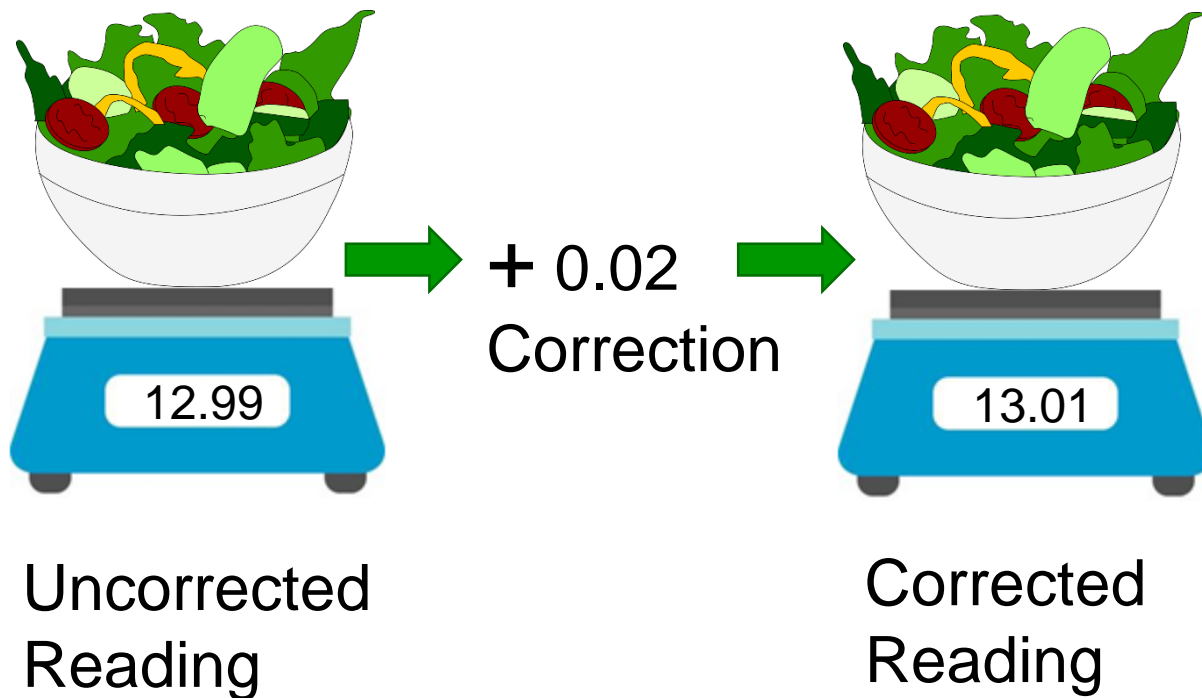
- Limited data points... requires **Interpolation** between readings
- Primary source of interpolation error is due to linearity



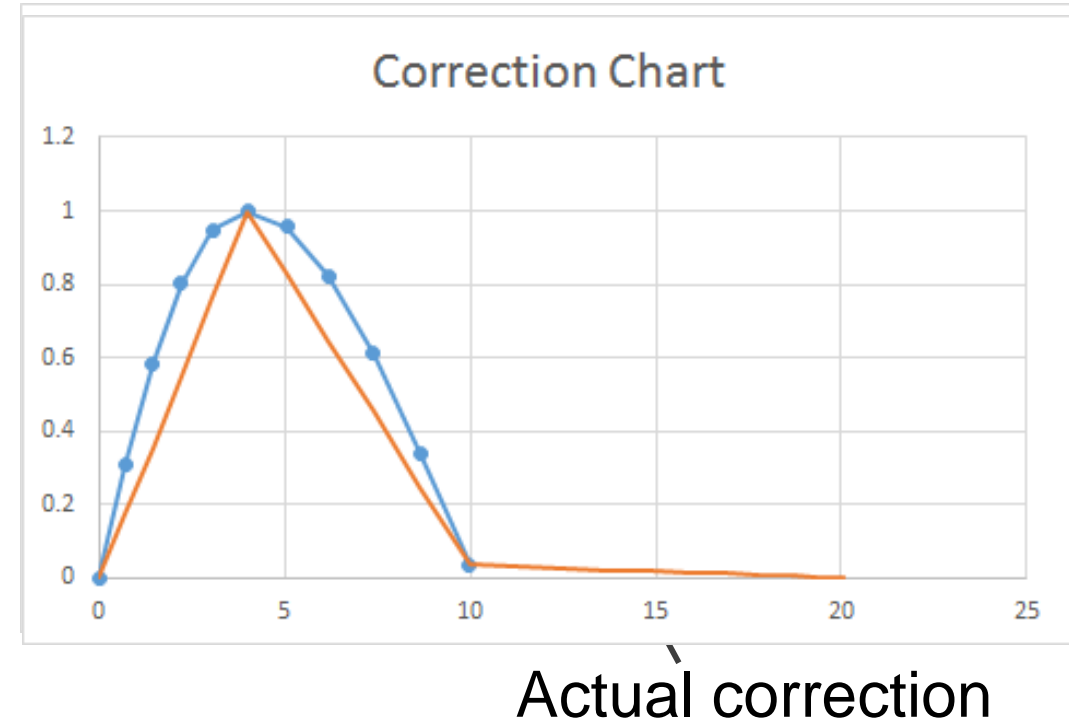
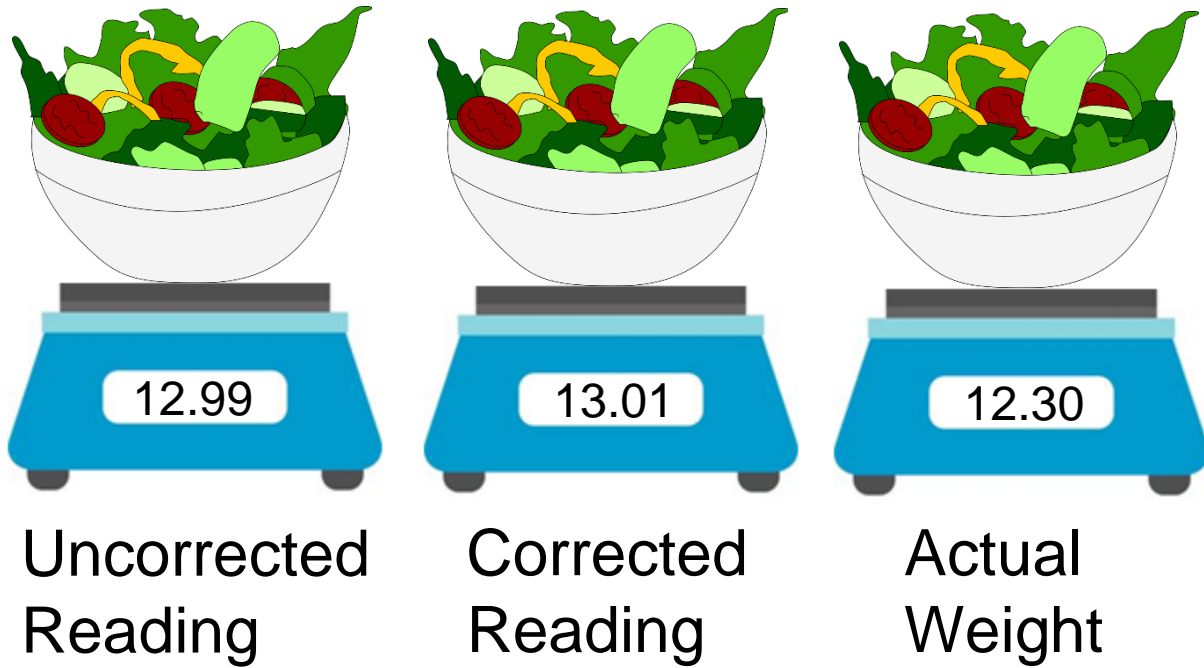
Building a Table of Corrections



Using a Correction Table

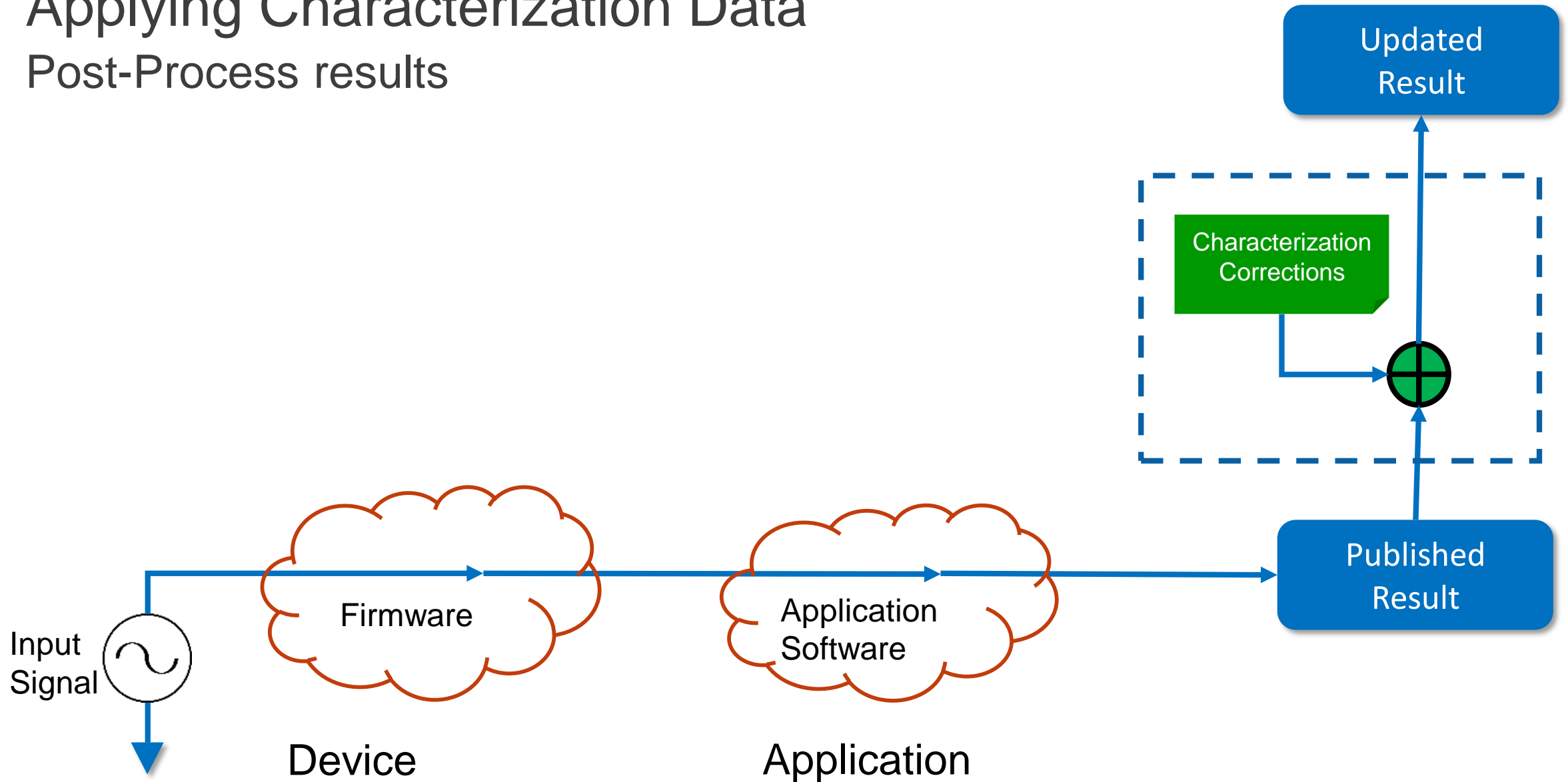


Increase the Number of Points



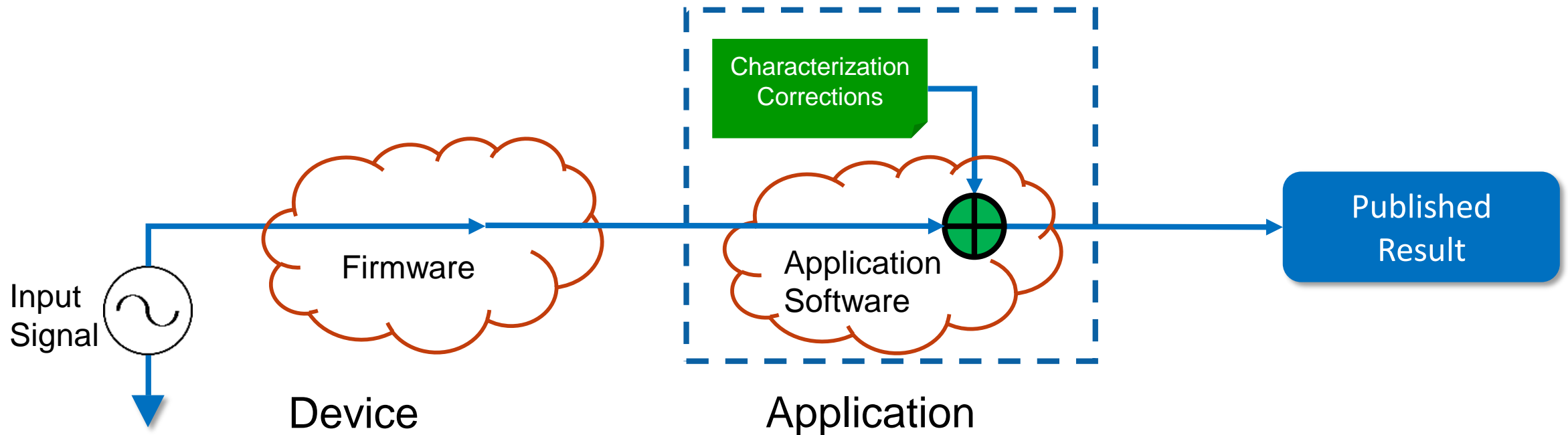
Applying Characterization Data

Post-Process results



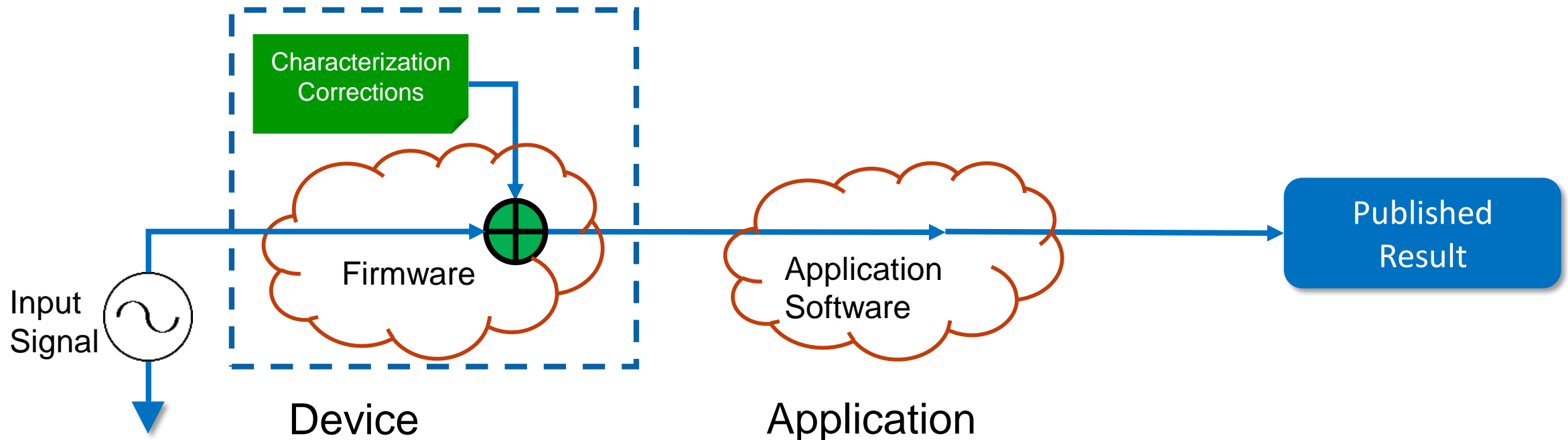
Applying Characterization Data

Process characterization inside the application

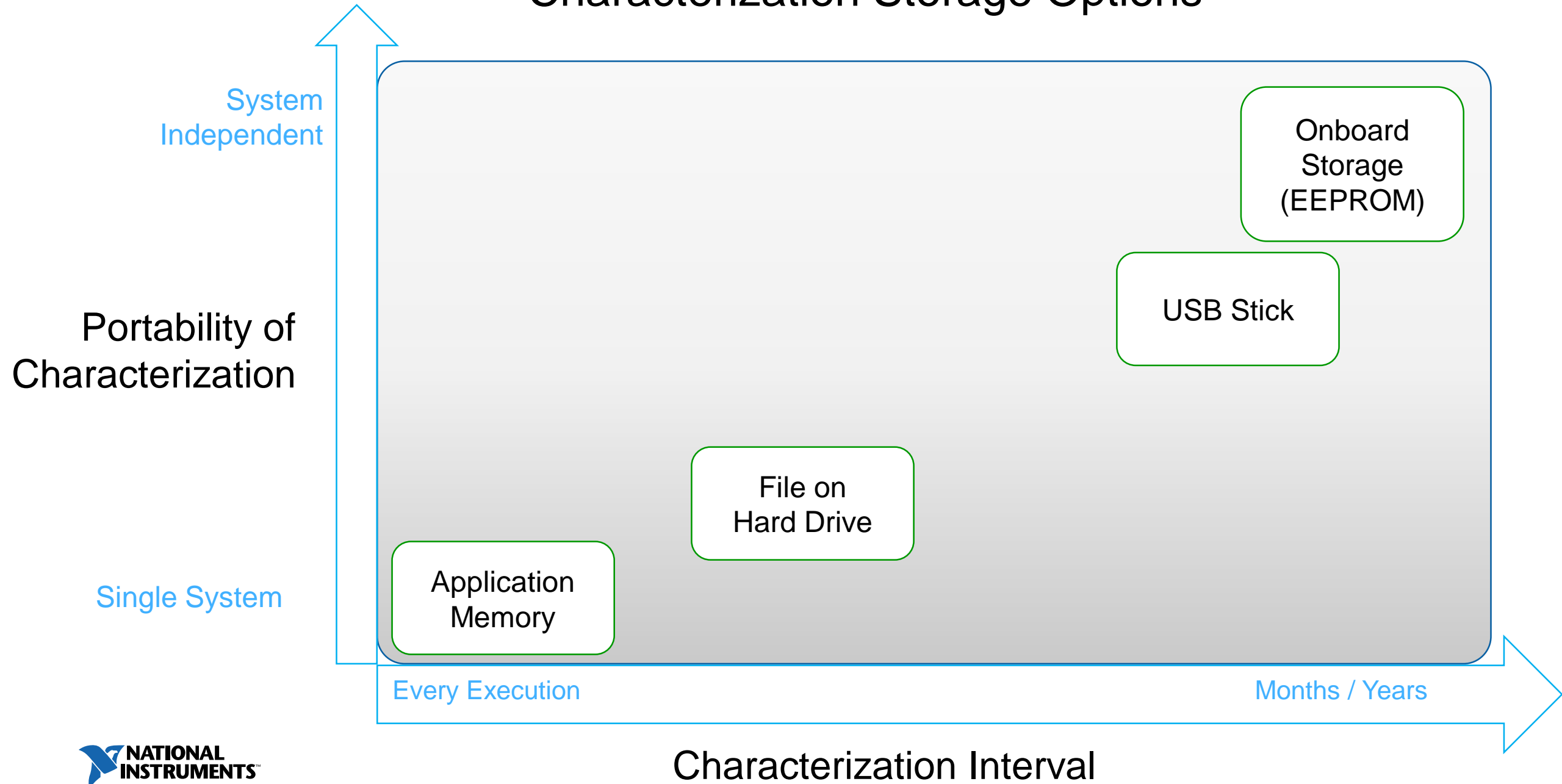


Applying Characterization Data

Process characterization inside device firmware



Characterization Storage Options



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