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INSTRUMENTS™

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

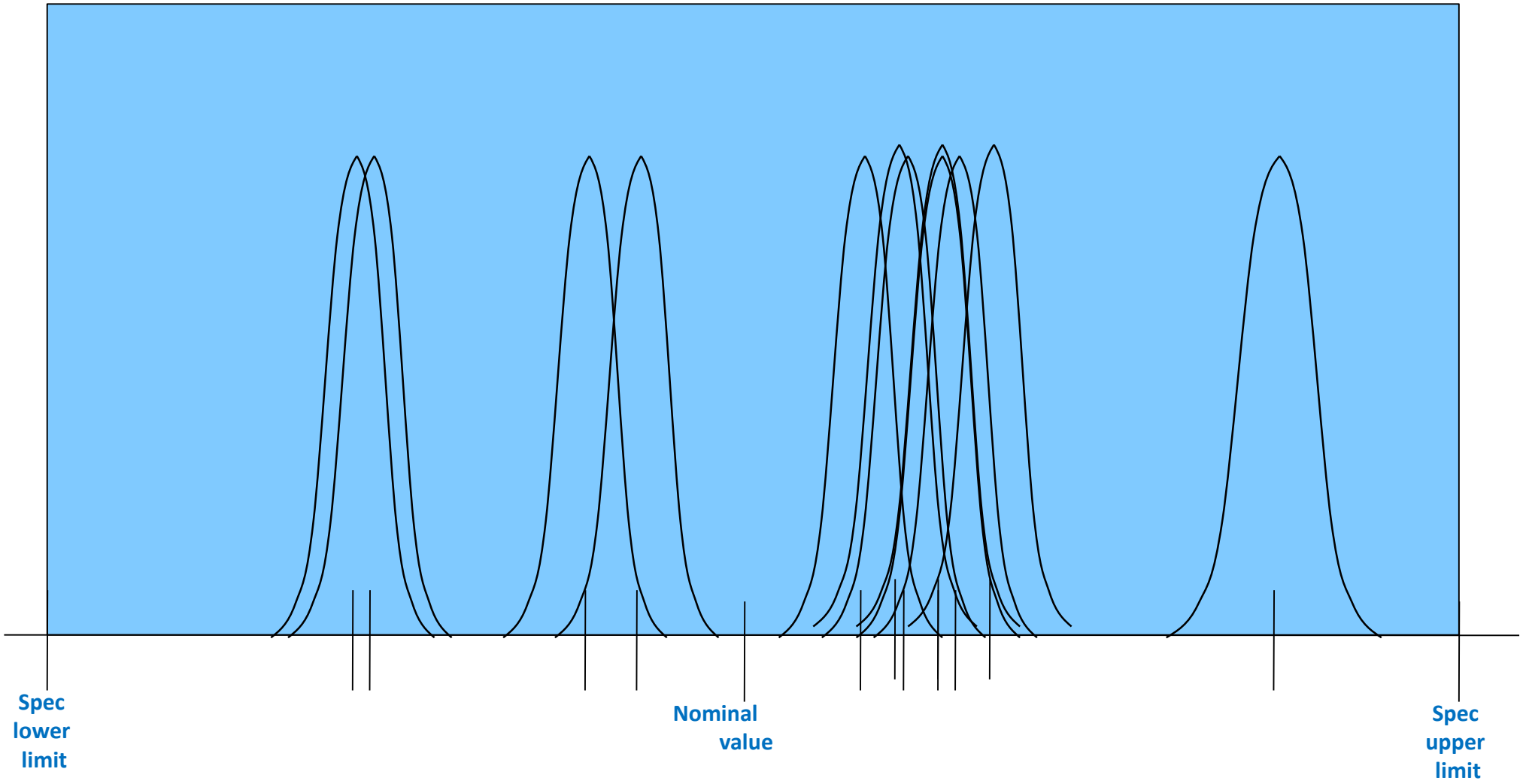
- Characterization of calibration system:
  - Using more accurate standards
  - Improved measurement method

- 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



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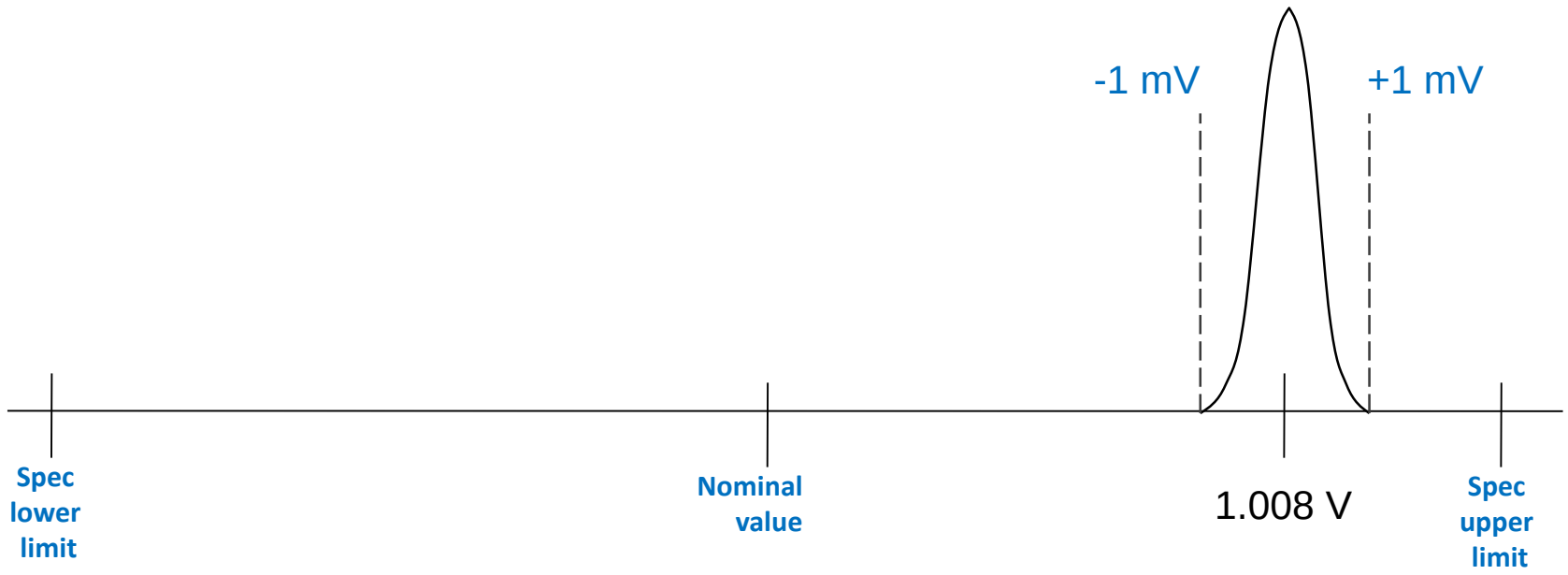
How it Works

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



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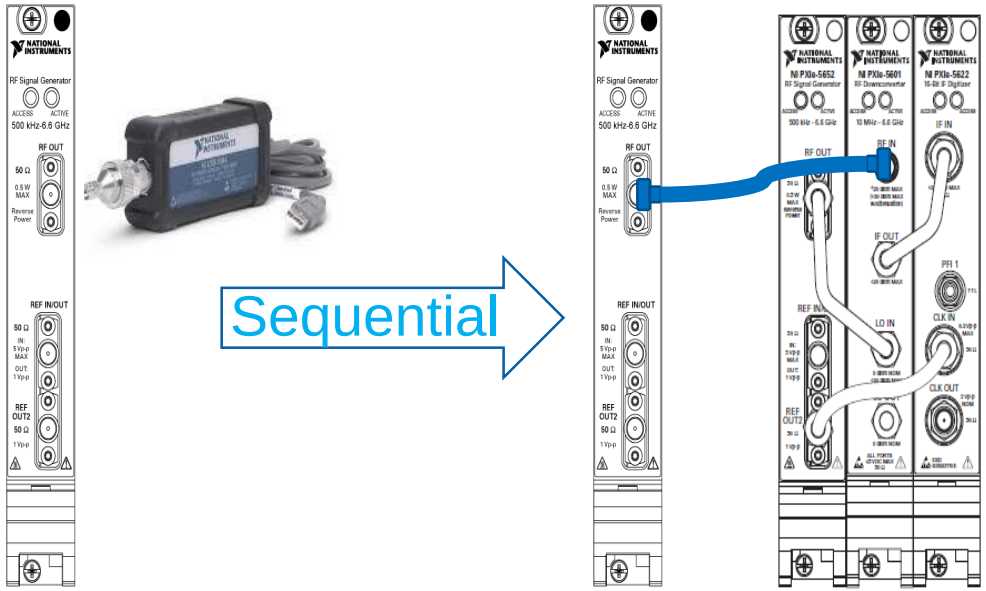
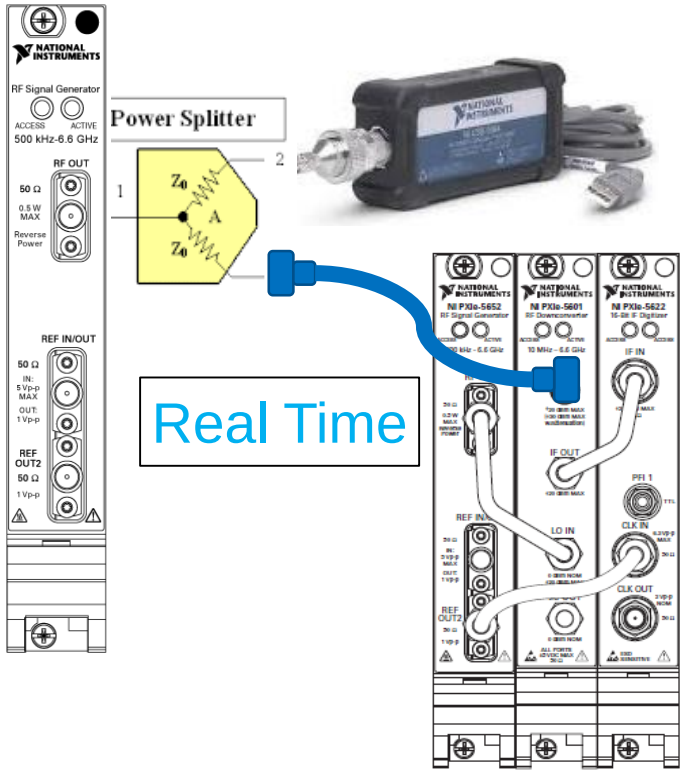
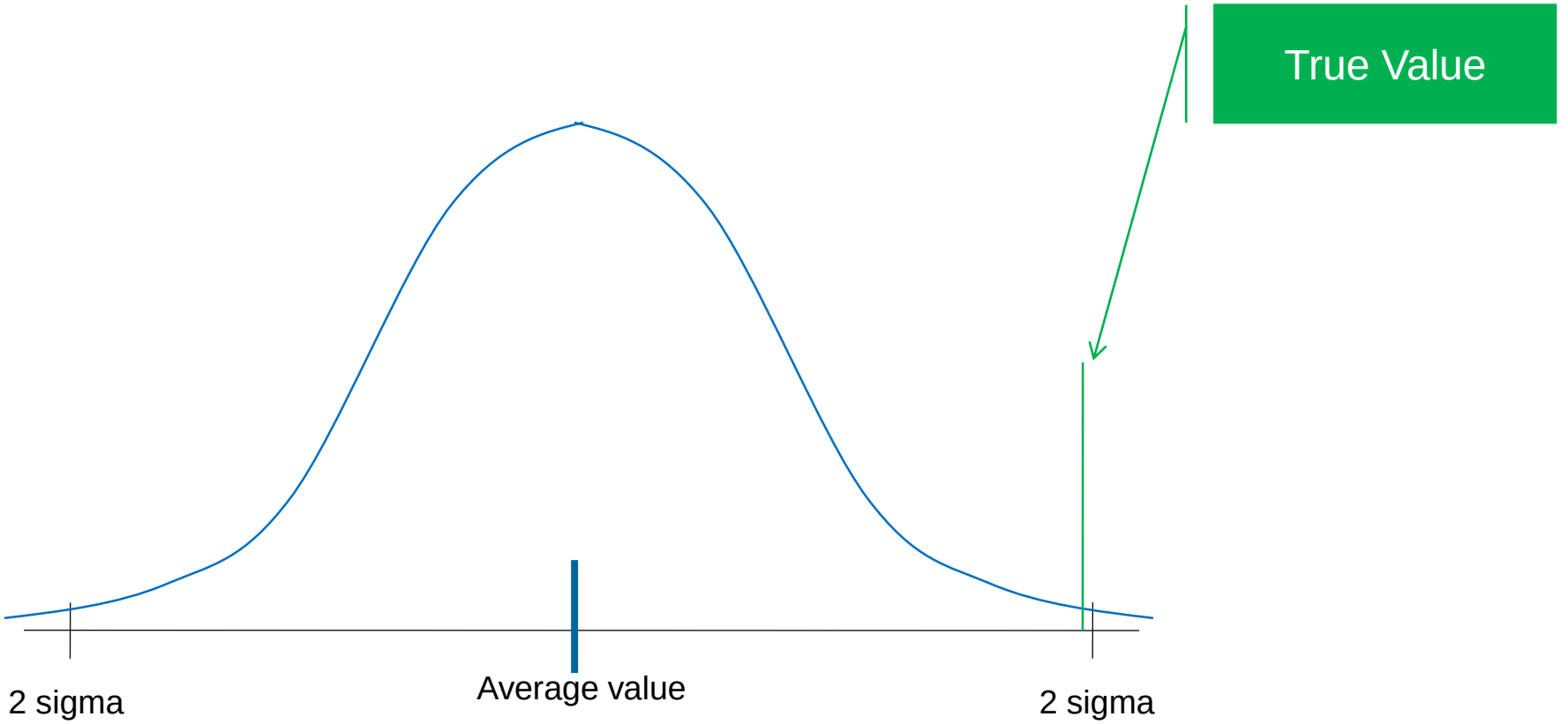
Types of Characterization





Measurement Uncertainty



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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?

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

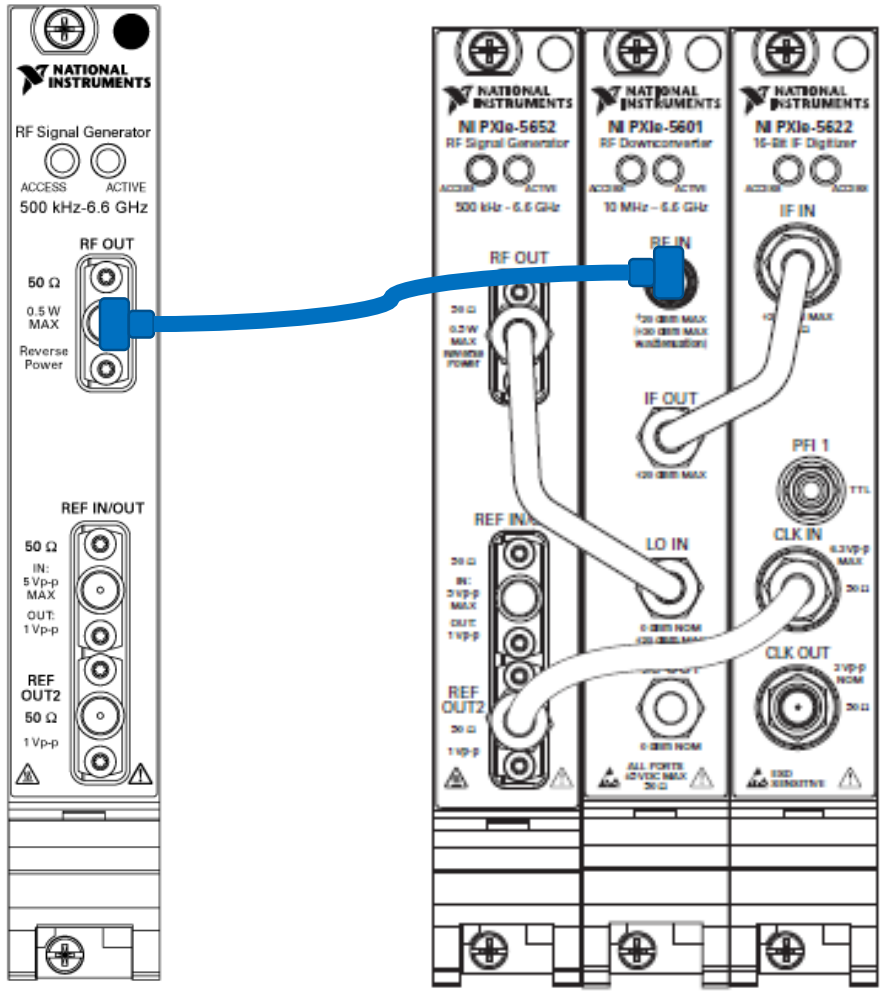
- Rule of thumb:
  - TUR ≥ 4:1 ⇨ We are done
  - TUR < 4:1 ⇨ Review the characterization process

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

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Example Without Characterization Uncertainty Analysis (UA)

Stand Alone Source

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

DUT Accuracy	± 44.5 % (1.6 dB)
Measurement Uncertainty	± 40%

TUR= 1.1 << 4.0 Unacceptable

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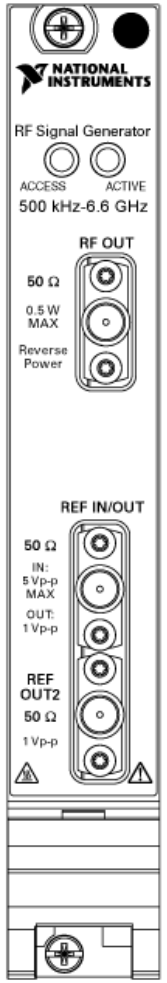
Example Characterization UA

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

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Example Characterization UA

Stand alone source + power sensor

Uncertainty component	Value	
Power sensor absolute accuracy	±3.0%	≈ ±0.13 dB
Mismatch Generator - Pw Sensor	±6.6%	≈ ±0.28 dB
Measurement repeatability	±0.5%	≈ ±0.04 dB
Characterization Measurement uncertainty	±10%	≈ +0.4 dB ≈ -0.5 dB

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

For example = +0.124 dBm ± 10% @ 4 GHz

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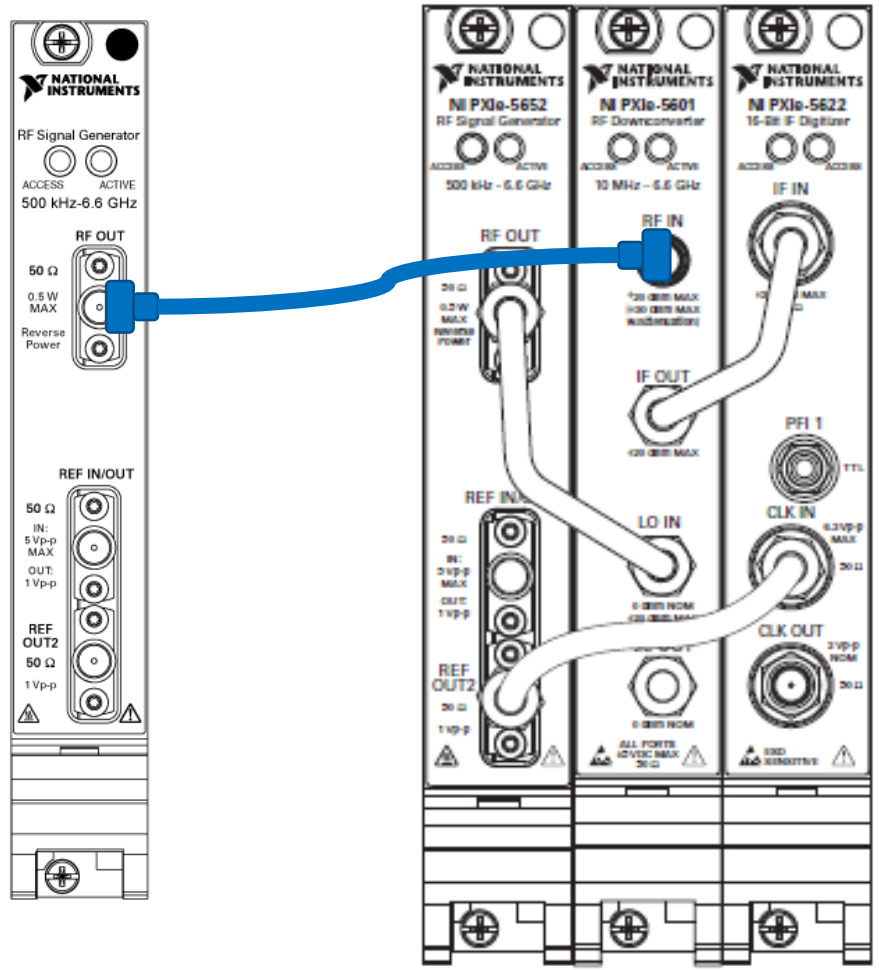
Example Characterization UA

Stand Alone Source + Power Sensor

Second Step
Calibrate DUT with Characterized Source



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Example With Characterization UA

Stand Alone Source + Power Sensor

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

Characterized output of the generator [0 dBm] = +0.124 dBm ± 15% @ 4 GHz

DUT Accuracy	± 44.54 % (1.6 dB)
Measurement Uncertainty	± 14.9%

TUR= 3.0 << 4.0 Unacceptable but better

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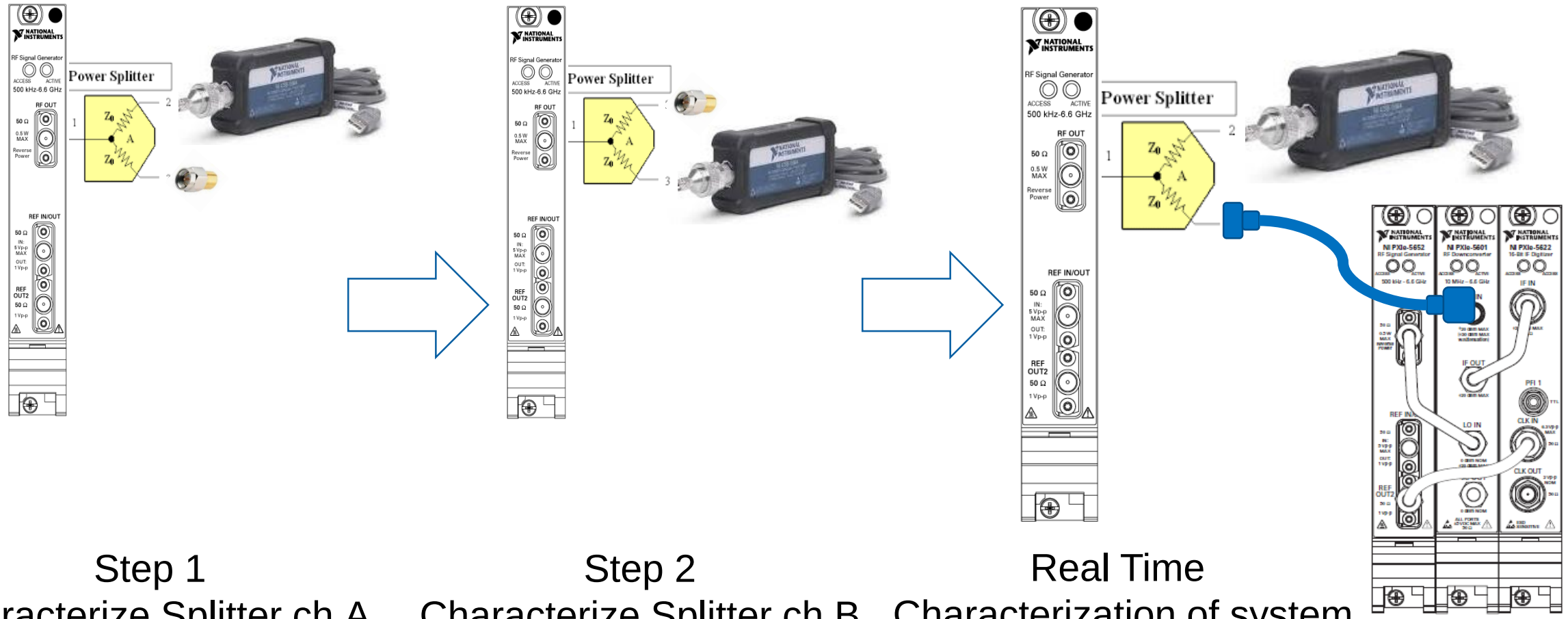
Example Characterization UA

Stand Alone Source + Power Sensor + Power Splitter



Step 1
Characterize Splitter ch.A

Step 2
Characterize Splitter ch.B

Real Time
Characterization of system

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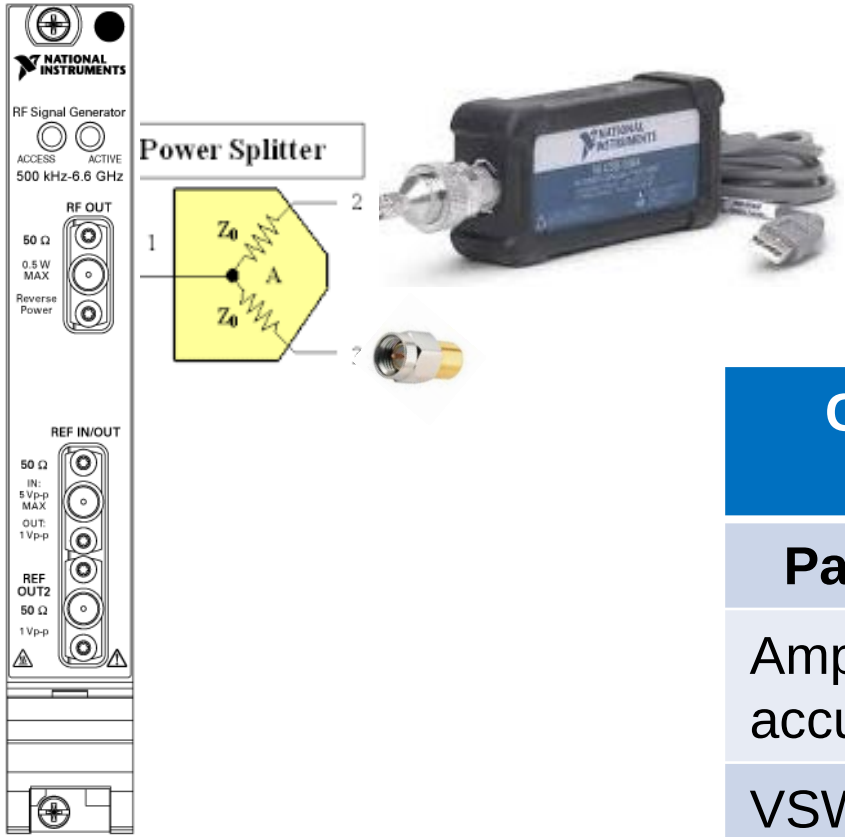
Example Characterization UA

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

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Example With Characterization UA

Stand Alone Source + Power Sensor + Power Splitter

Step 1

Uncertainty component	Value	
Power sensor absolute accuracy	±3.0%	≈ ±0.13 dB
Mismatch Splitter-Pw Sensor	±2.0%	≈ ±0.08 dB
Measurement repeatability	±0.5%	≈ ±0.04 dB
Characterization Measurement Uncertainty =	**±4.6%**	≈ +0.2 dB ≈ –0.2 dB

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

For example = +0.002 dBm ± 4.6% @ 4 GHz

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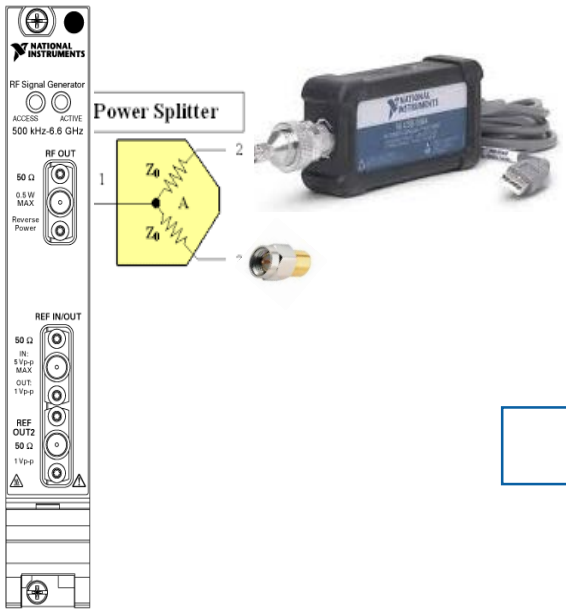
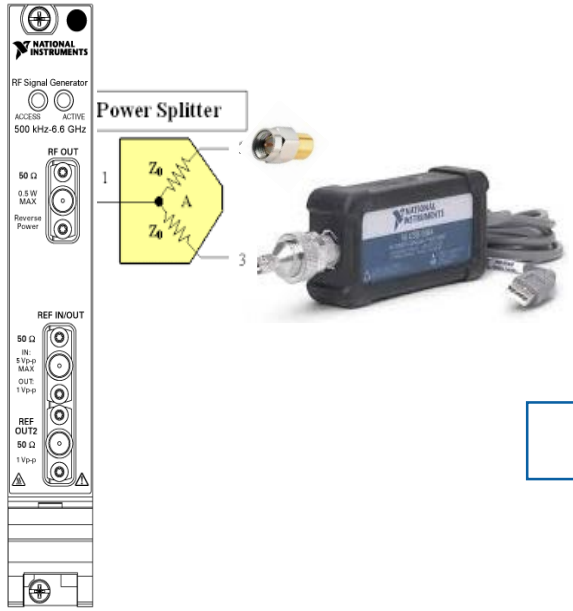
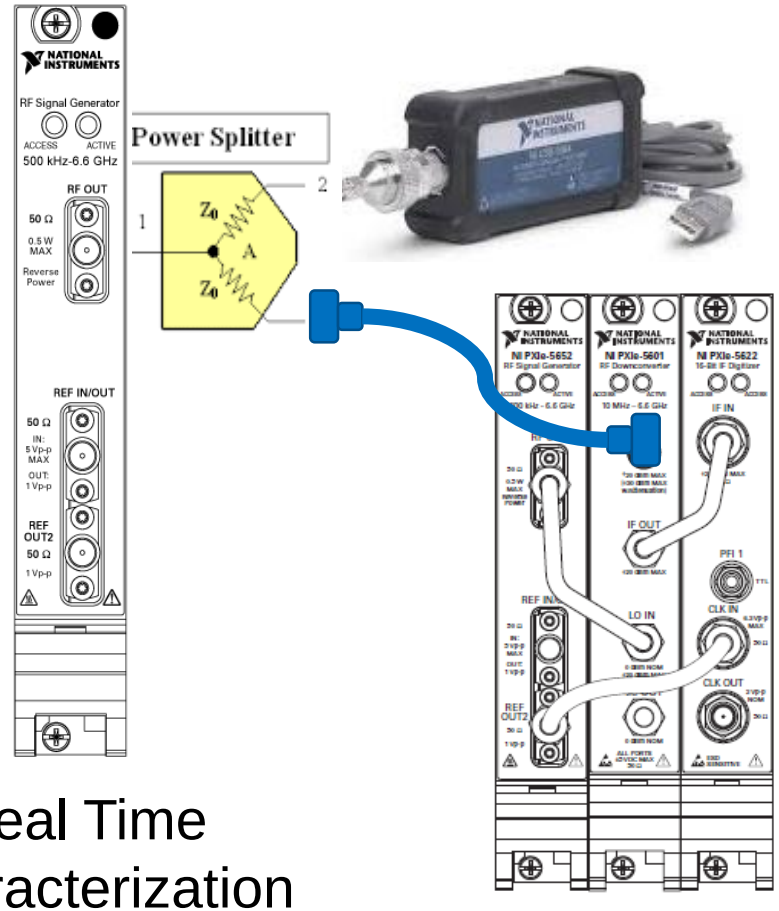
Example Characterization UA

Stand alone source + power sensor + power splitter







Step 1
Characterize Splitter ch.A

Step 2
Characterize Splitter ch.B

Real Time
Characterization

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Example With Characterization UA

Stand Alone Source + Power Sensor + Power Splitter

Step 2

Uncertainty component	Value	
Power sensor absolute accuracy	±3.0%	≈ ±0.13 dB
Mismatch Splitter-Pw Sensor	±2.0%	≈ ±0.08 dB
Measurement repeatability	±0.5%	≈ ±0.04 dB
Characterization Measurement Uncertainty =	**±4.6%**	≈ +0.2 dB ≈ -0.2 dB

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

For example = +0.009 dBm ± 4.6% @ 4 GHz

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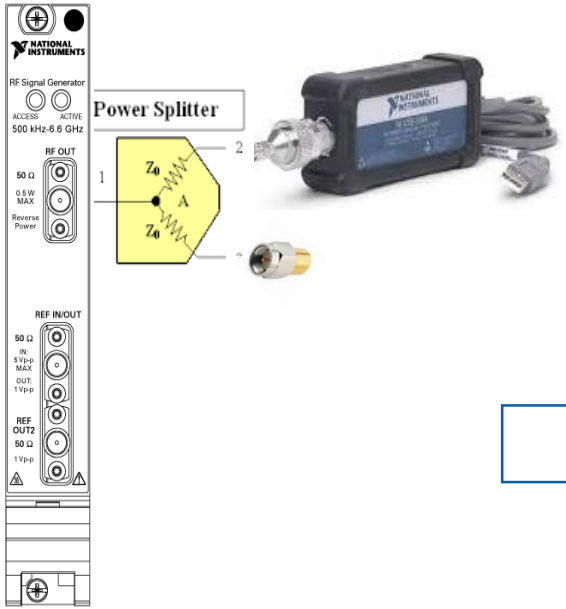
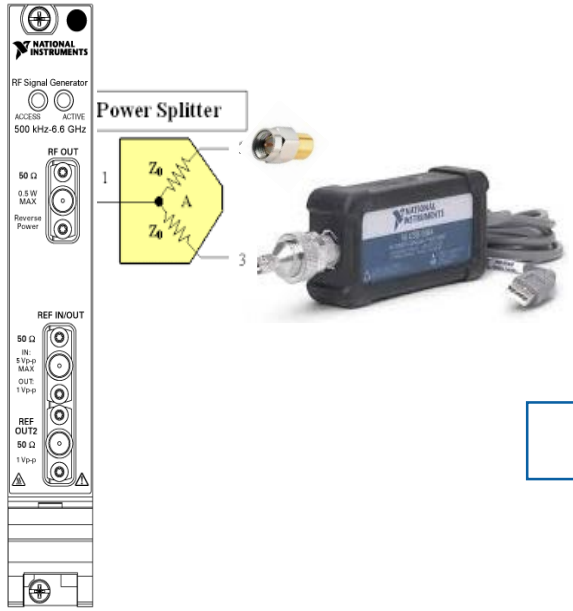
Example Characterization UA

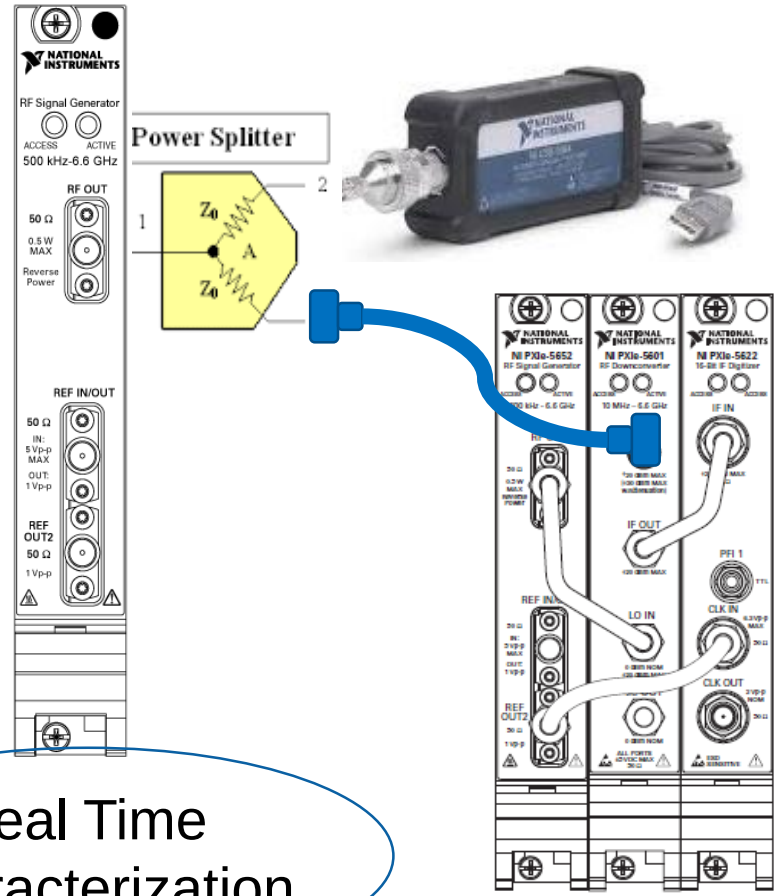
Stand Alone Source + Power Sensor + Power Splitter



Step 1
Characterize Splitter ch.A



Step 2
Characterize Splitter ch.B



Real Time
Characterization

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Example With Characterization UA

Stand Alone Source + Power Sensor + Splitter

Step 3

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

DUT Accuracy	± 44.54 % (1.6 dB)
Measurement Uncertainty	± 11.8%

TUR= 3.8 ≈ 4.0 Practically Acceptable

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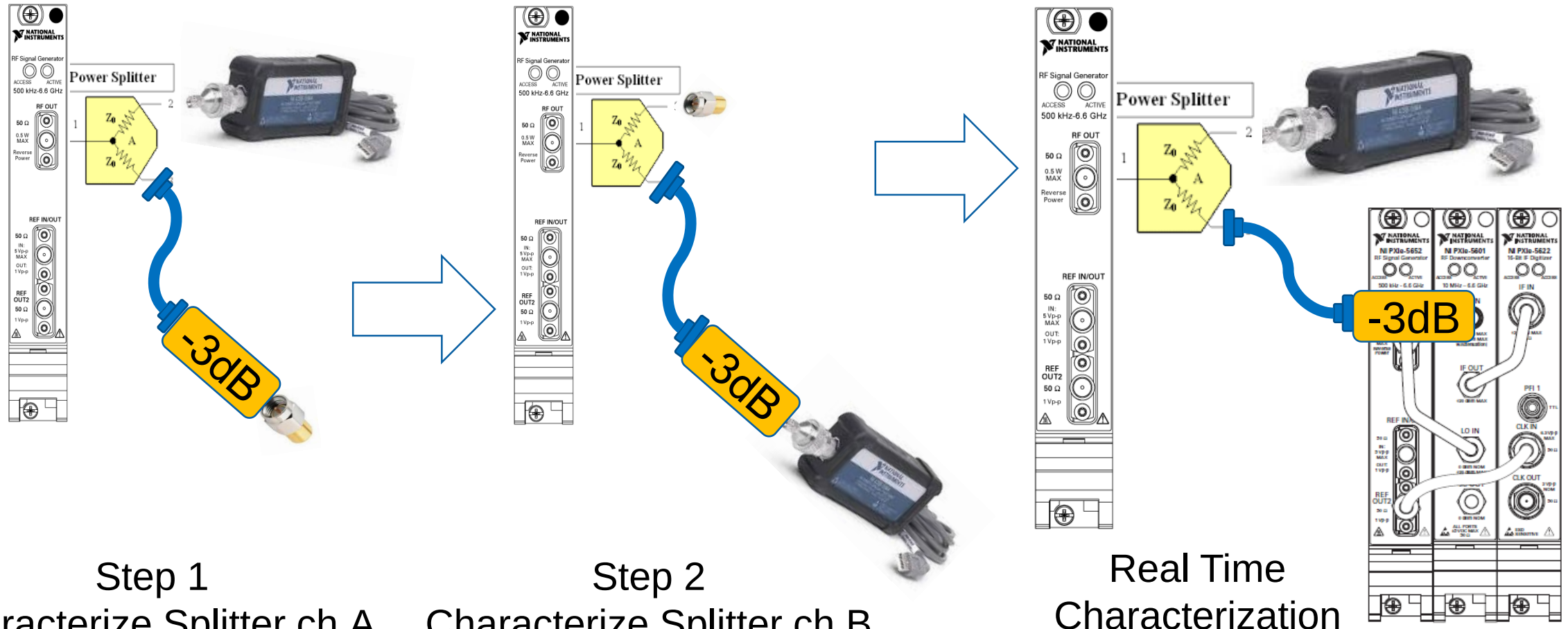
Example Characterization UA

Stand Alone Source + Power Sensor + power Splitter + Attenuator



Step 1
Characterize Splitter ch.A

Step 2
Characterize Splitter ch.B

Real Time
Characterization
Of System

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Example With Characterization UA

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

DUT Accuracy	± 44.54 % (1.6 dB)
Measurement Uncertainty	± 8.6%

TUR= 5.1 > 4.0 Acceptable

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Characterization Summary

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

System Characterization Frequency

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

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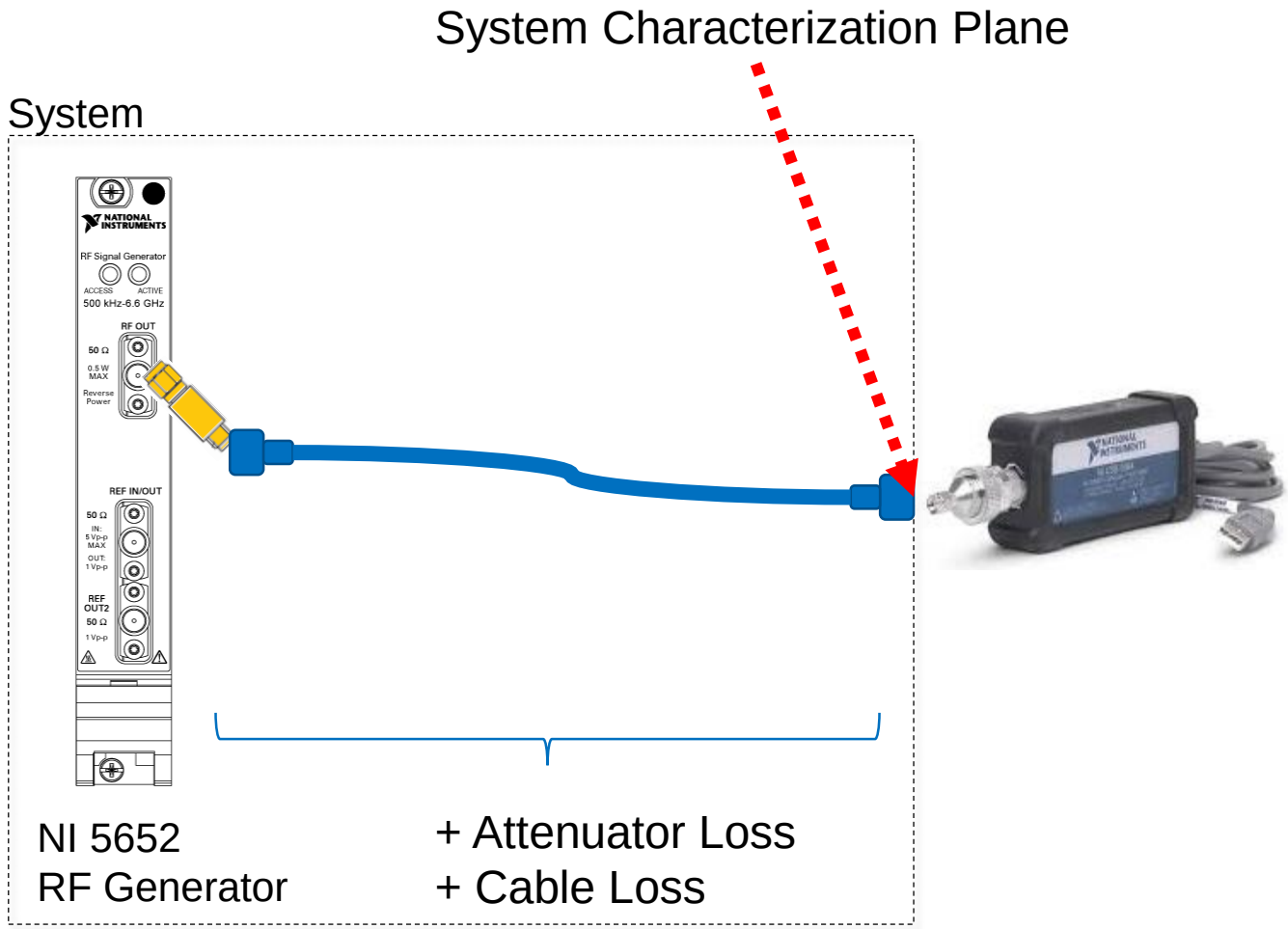
Characterization – Other Benefits

- 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



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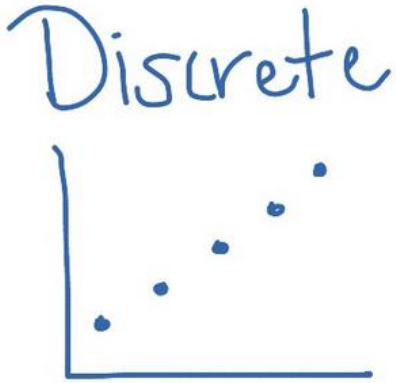
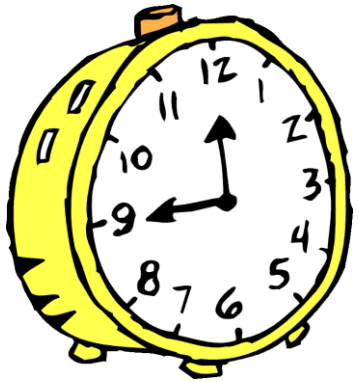
General Purpose vs. Specific Application

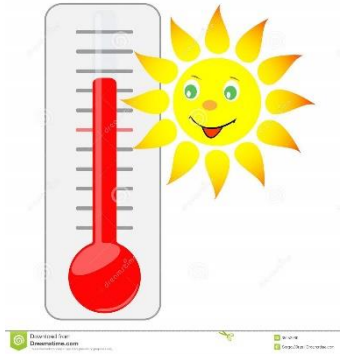
- Specific Applications
  - Discrete set of modes and ranges



- 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)

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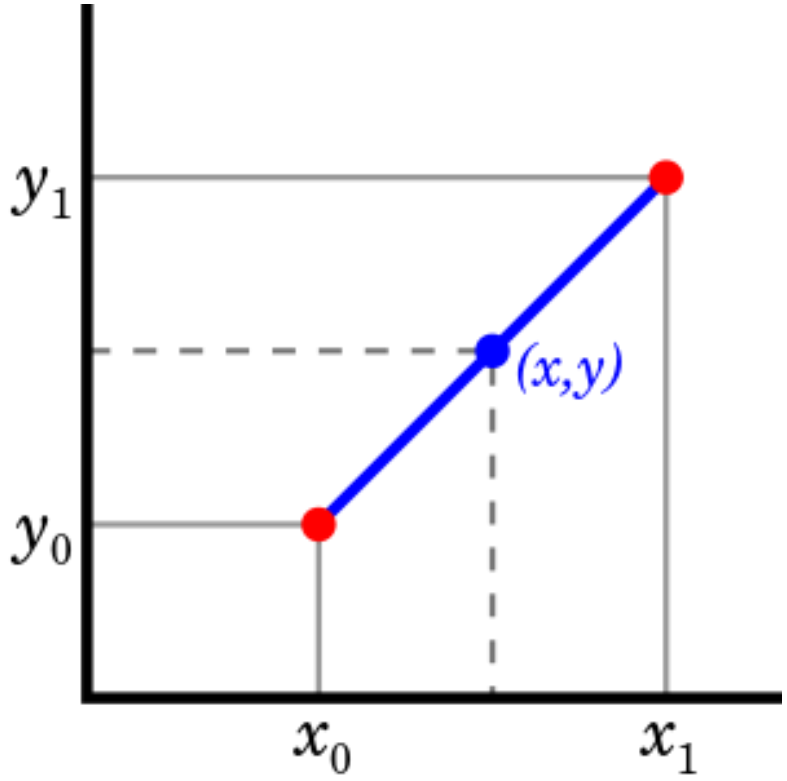
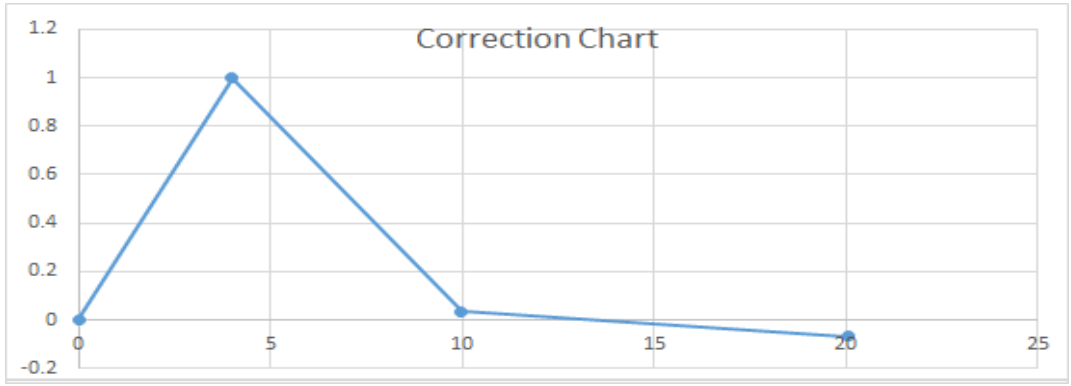
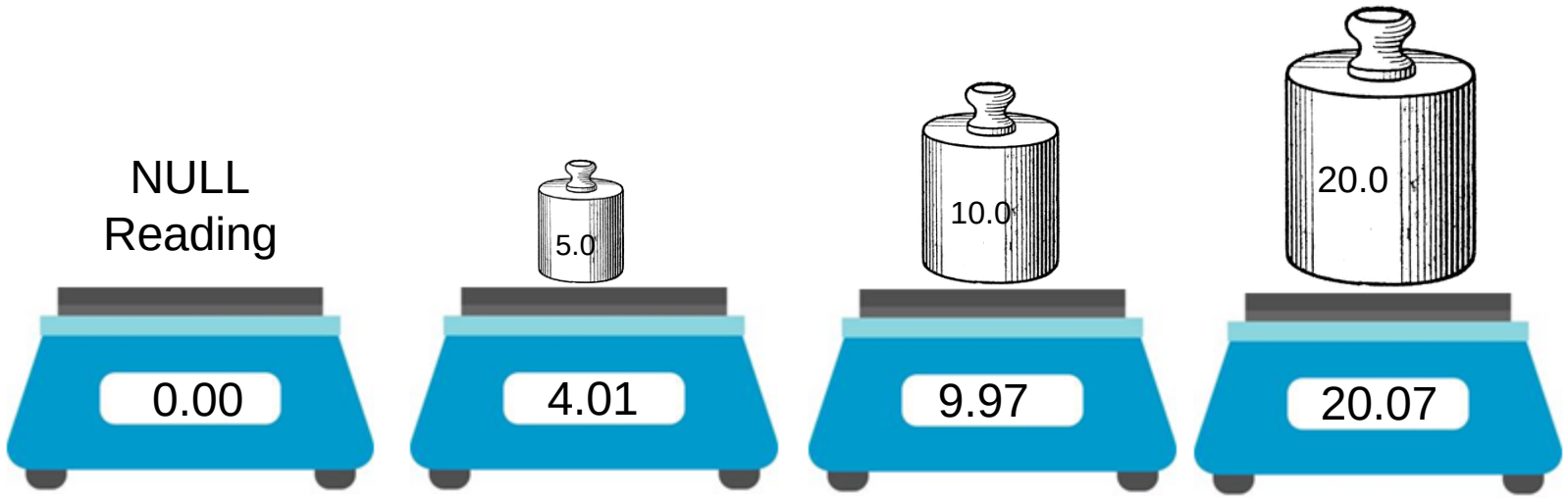
Characterization Interpolation

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



Building a Table of Corrections





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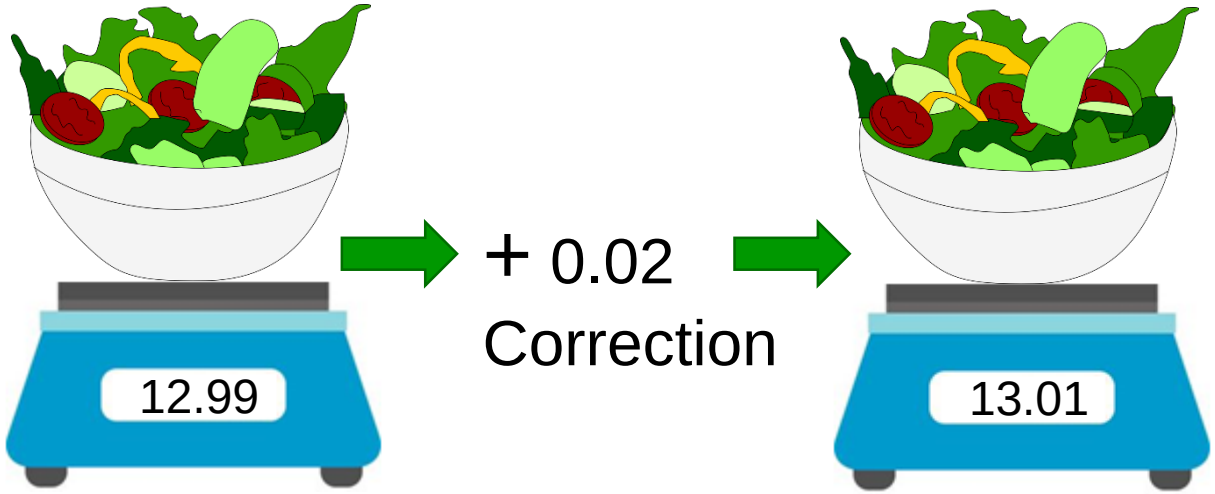
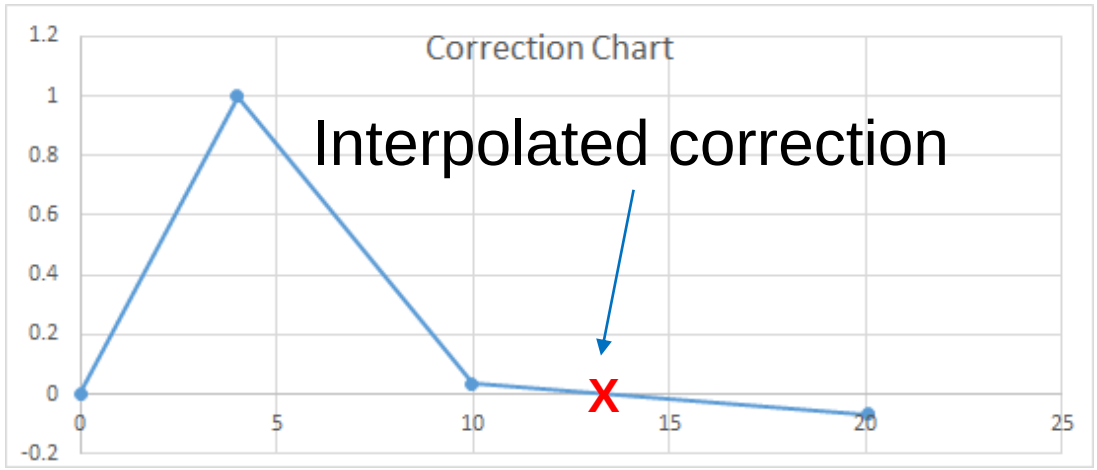
Using a Correction Table



Uncorrected Reading

Corrected Reading



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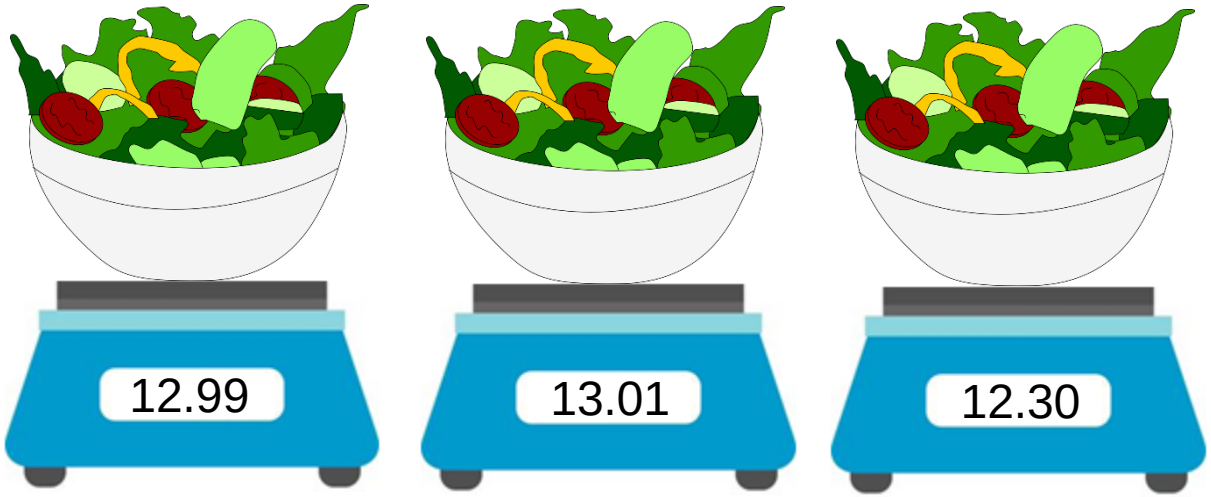
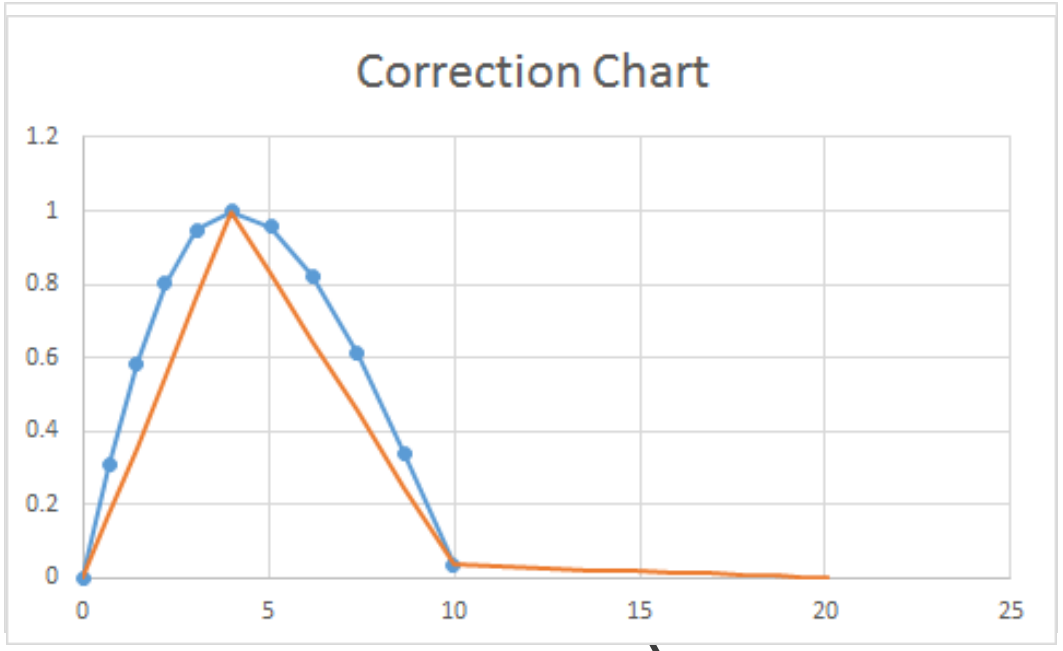
Increase the Number of Points



Uncorrected Reading

Corrected Reading

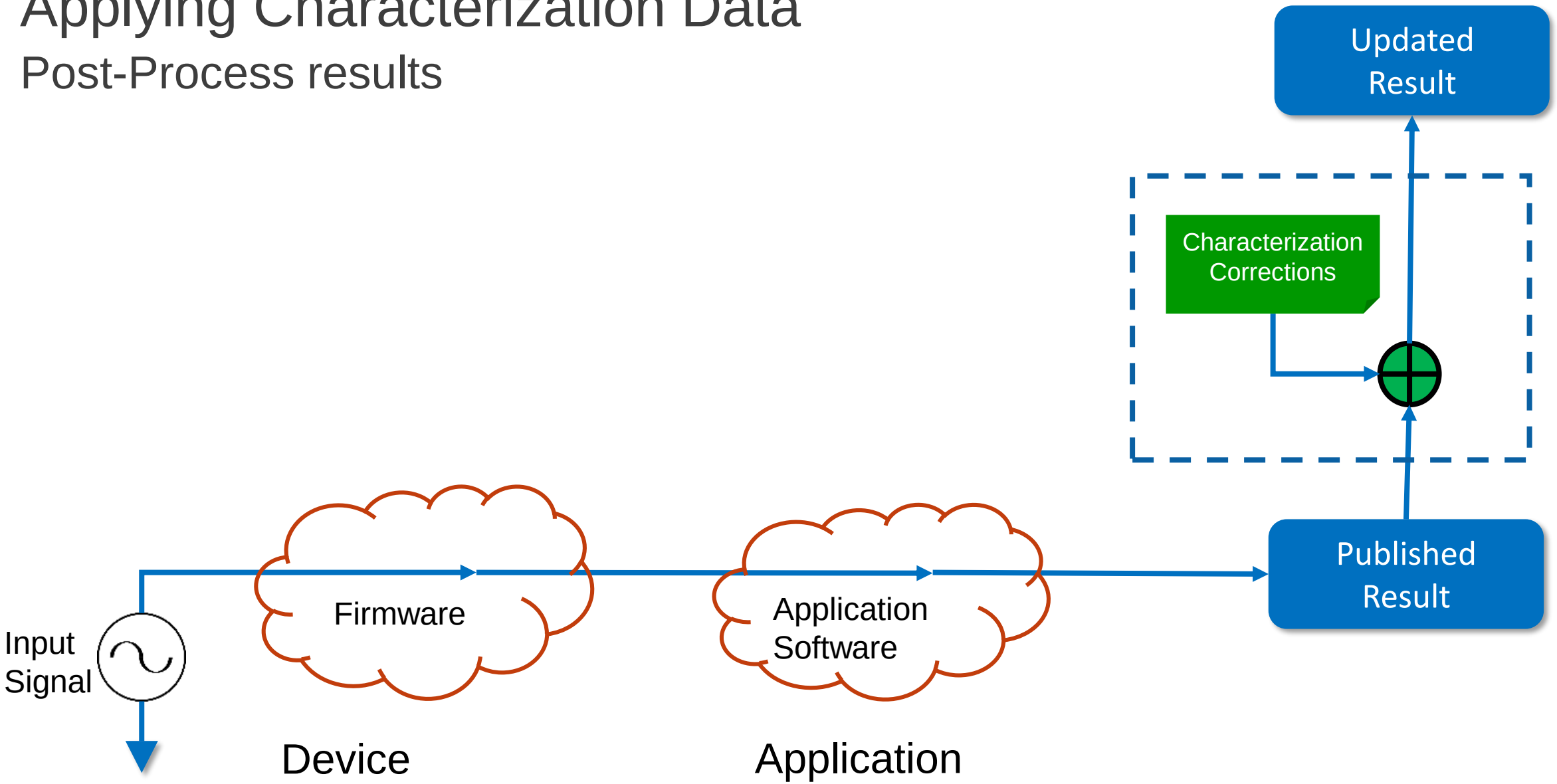
Actual Weight



Actual correction

Applying Characterization Data

Post-Process results



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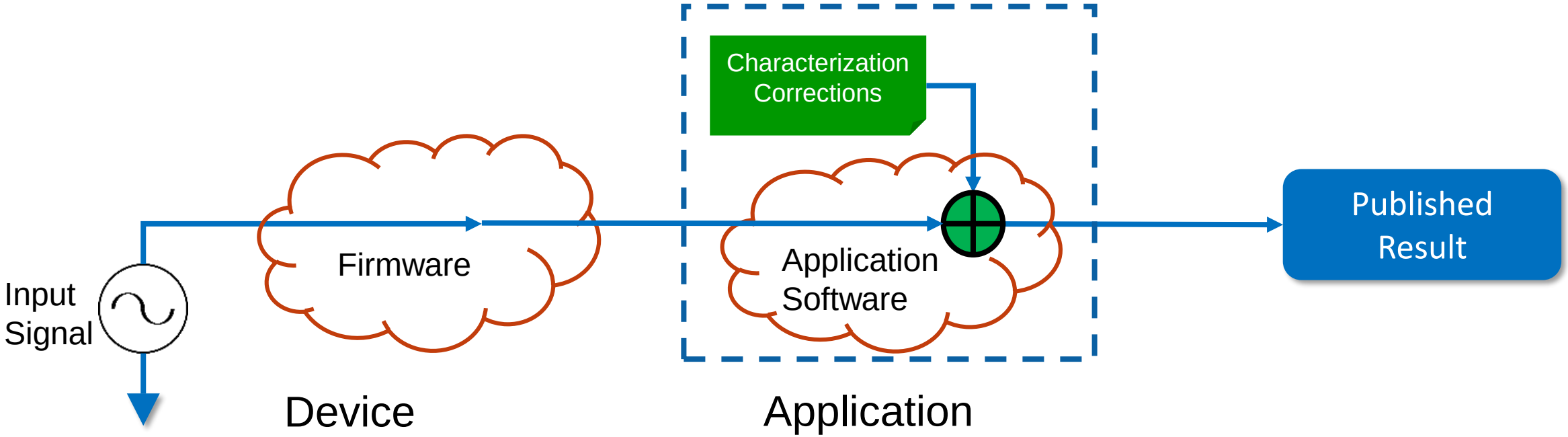
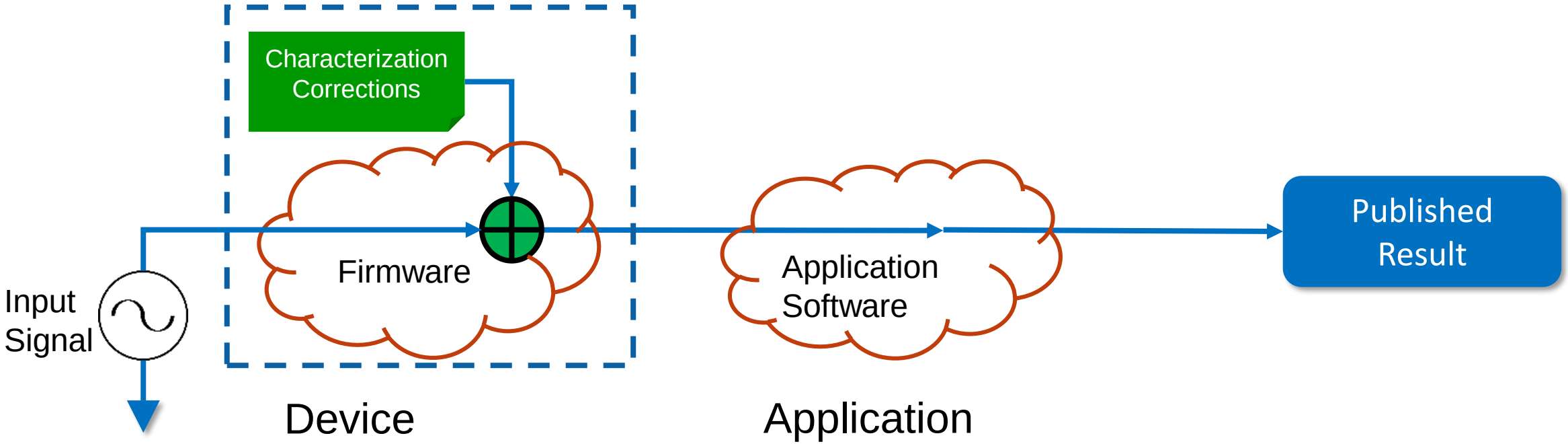
Applying Characterization Data

Process characterization inside the application

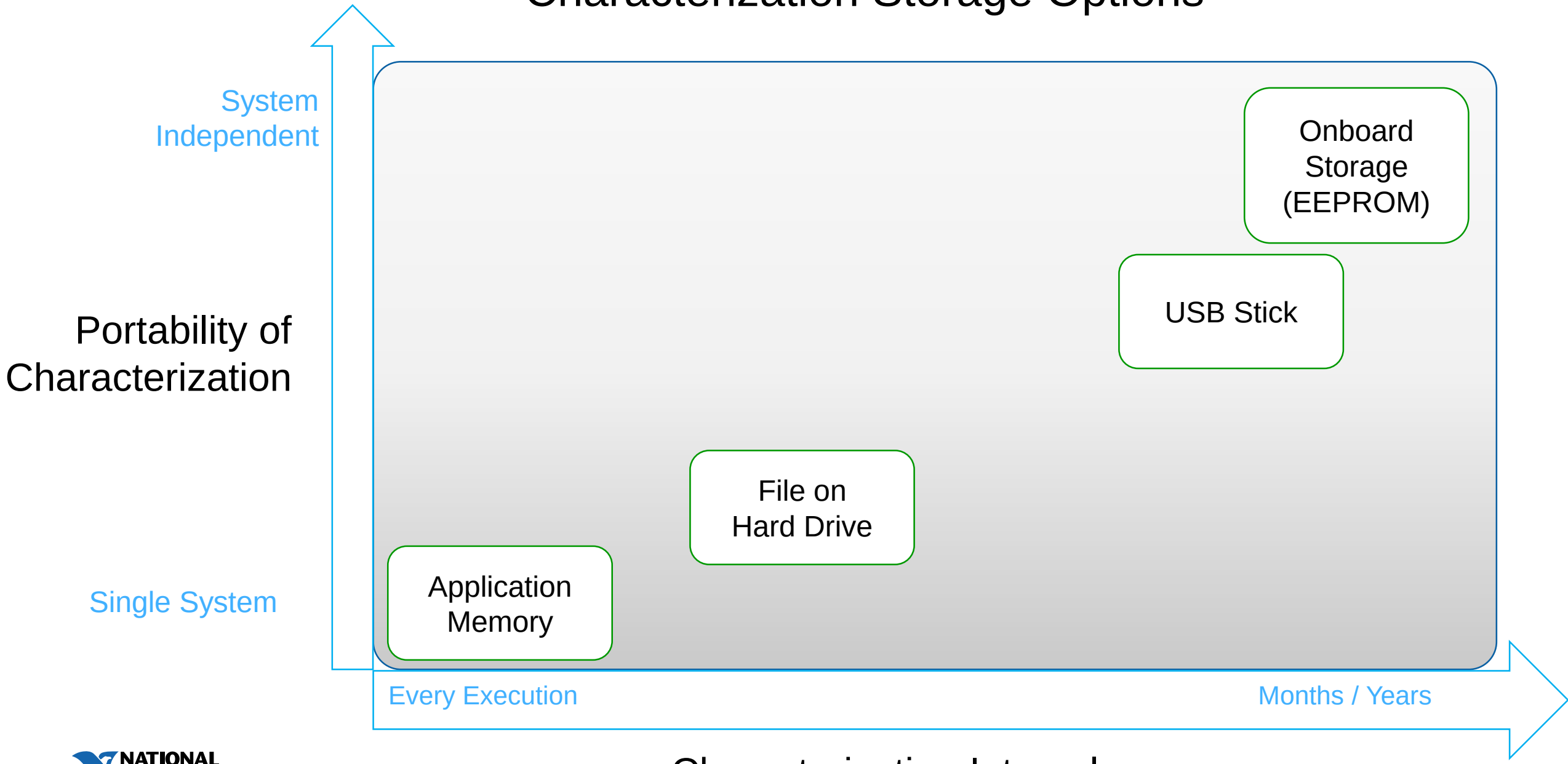


Applying Characterization Data

Process characterization inside device firmware



Characterization Storage Options



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