A Guide to Standardizing Digital Calibration and Measurement Capabilities

Mark Kuster, mjk@ieee.org

NCSLI 141 MII and Automation Committee

Measurement-Information Infrastructure

Section 1

Introduction

Today's Topics

1 Introduction

Today's Topics

1. Introduction
2. Measurand Taxonomy for Digital Transformation

Today's Topics

1. Introduction
2. Measurand Taxonomy for Digital Transformation
3. Air-Flow Taxon and CMC Example

Today's Topics

1. Introduction
2. Measurand Taxonomy for Digital Transformation
3. Air-Flow Taxon and CMC Example
4. Further Examples

Today's Topics

1. Introduction
2. Measurand Taxonomy for Digital Transformation
3. Air-Flow Taxon and CMC Example
4. Further Examples
5. Conclusion

Acronyms

- DX—digital transformation
- IQI—international quality infrastructure
- SoA—scope of accreditation
- DCC—digital calibration certificate (PTB)
- CMC—calibration and measurement capability
- MPE—maximum permissible error
- NCSLI—NCSL International
- M-Layer—metrology information layer to support measurement systems

Definition

MII (measurement information infrastructure)
—set of normative standards that unambiguously define data structures, taxonomies, service protocols and security for locating, communicating and sharing measurement information

NCSL International and the MII

- NCSL International
  - Established 1960, now at https://ncsli.org/
  - Volunteer-driven, measurement-science professional organization
  - Annual conference, standards & practice publications, tutorials, webinars
  - *Metrologist* magazine, *Measure* journal
- NCSL International 141 MII and Automation Committee
  - Reformulated at the 2015 annual conference
  - Chartered to develop MII digital documents and facilitate related products
  - Updates in *Metrologist* and *Cal Lab*
  - Also see http://miiknowledge.wikidot.com/

Section 2

Measurand Taxonomy for Digital Transformation

Digital Transformation Stages

Progress	Music Market	Metrology
manual		
analog		
digitized		
digitalized		
digitally transformed		

Digital Transformation Stages

Progress	Music Market	Metrology
manual	hire musicians	typewritten paper certs
analog		
digitized		
digitalized		
digitally transformed		

Digital Transformation Stages

Progress	Music Market	Metrology
manual	hire musicians	typewritten paper certs
analog	records, tapes	automated paper certs
digitized		
digitalized		
digitally transformed		

Digital Transformation Stages

Progress	Music Market	Metrology
manual	hire musicians	typewritten paper certs
analog	records, tapes	automated paper certs
digitized	compact disc	PDF certs (mostly)
digitalized		
digitally transformed		

Digital Transformation Stages

Progress	Music Market	Metrology
manual	hire musicians	typewritten paper certs
analog	records, tapes	automated paper certs
digitized	compact disc	PDF certs (mostly)
digitalized	tagged MP3 files	?
digitally transformed		

Digital Transformation Stages

Progress	Music Market	Metrology
manual	hire musicians	typewritten paper certs
analog	records, tapes	automated paper certs
digitized	compact disc	PDF certs (mostly)
digitalized	tagged MP3 files	?
digitally transformed	Pandora, SiriusXM	?

Digital Transformation Stages

Progress	**Music Market**	**Metrology**
manual	hire musicians	typewritten paper certs
analog	records, tapes	automated paper certs
digitized	compact disc	PDF certs (mostly)
digitalized	tagged MP3 files	MII, DCC, et al.
digitally transformed	Pandora, SiriusXM	new innovation

Digital Transformation Stages

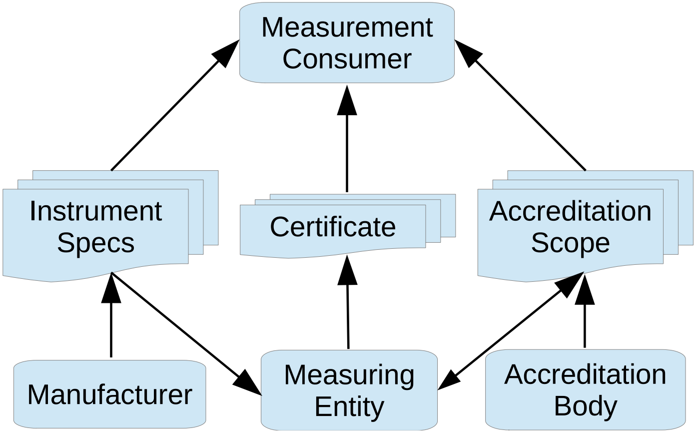
Progress	Music Market	Metrology
manual	hire musicians	typewritten paper certs
analog	records, tapes	automated paper certs
digitized	compact disc	PDF certs (mostly)
digitalized	tagged MP3 files	MII, DCC, et al.
digitally transformed	Pandora, SiriusXM	new innovation

Metrology's DX has begun but lags other industries:

- science, manufacturing, travel, banking, entertainment, . . .

Simple digitization will not suffice.

Partial Metrology Information Flow



Machines require metadata to process documents.

Measurement metadata = measurand descriptions = MII taxons

We want a standard measurand taxonomy.

Spec: `Source.Voltage.DC`

SoA: `Measure.Voltage.DC`

Cert: `Source.Voltage.DC`

The Measurement-Information Infrastructure and the M-Layer

- M-Layer aspect IDs disambiguate quantities for digital processing: calculations, uncertainty propagation, etc.
  - $q\ [Q]\ \langle\text{voltage}\rangle$
  - $q\ [Q]\ \langle\text{pressure}\rangle$
  - 1990 Conventional Voltage differs from SI-9 voltage differs from SI-8 voltage.
- MII taxons disambiguate full measurands for communicating measurement information in digitalized documents.
  - Source.Voltage.AC.Sinewave[.RearOutput]
  - Measure.Pressure.Pneumatic.Differential.Static[.Port1]
- Each MII taxon's quantity token uniquely maps to an M-Layer aspect ID.

Section 3

Air-Flow Taxon and CMC Example

Air-Flow Example

Why air flow?

- complex enough to illustrate most cases
- tackles a measurement area not yet developed

We'll develop a measurand taxon and associated CMC TEMPLATE step-by-step.
MII editor tools will facilitate this process.

Step 0: Understand the measurement process!
Imaginary scenario:

- We have air-flow measurement experience and will learn as we go.
- We calibrate mass and volume flow meters with air and dry nitrogen.
- The MII has no existing taxon for air flow.
- The MII (M-Layer) has defined no relevant quantity token (aspect).

Step 1: Name the Taxon

Step 1.1: Select the process type.

Example Taxon: `Source`

Example CMC Table

Measurand	Uncertainty	Comments
		Source for calibrating flow meters

Rule: A taxon's first token represents the process type, taking either the value `Measure` or `Source` to identify an input- or output-quantity measurement, respectively.[1]

[1] Regardless of whether the measurement process uses a direct, common source, or comparator measurement method

Step 1: Name the Taxon

Step 1.2: Separate tokens with a period.

Example Taxon: `Source.`

Example CMC Table

Measurand	Uncertainty	Comments
		Source for calibrating flow meters

Rule: Each taxon comprises a series of tokens separated by the period (.) character.

Step 1: Name the Taxon

Step 1.3: Add the measured-quantity name.

Example Taxon: `Source.air flow`

Example CMC Table

Measurand	Uncertainty	Comments
		Source for calibrating flow meters

Rule: The taxon's remaining tokens indicate the measured quantity.

Step 1: Name the Taxon

Step 1.4: Create a human-readable alias.

Example Taxon: `Source.air flow`

Example CMC Table

Measurand	**Uncertainty**	**Comments**
Air Flow		Source for calibrating flow meters

Rule: Each taxon may have aliases, such as commonly used equivalents (from *ISO-IEC 80000*, the KCDB, an AB's conventions, etc.). These aliases may appear in human-readable documents generated from the digital document as the user prefers.

Step 1: Name the Taxon

Step 1.5: Format the tokens.

Example Taxon: `Source.AirFlow`

Example CMC Table

Measurand	**Uncertainty**	**Comments**
Air Flow		Source for calibrating flow meters

Rule: Each token uses the UpperCamelCase[1] naming convention.

[1] also known as Pascal or Capitalized

Step 1: Name the Taxon

Step 1.6: Check against the MII quantity database.

Example Taxon: `Source.AirFlow??`

Example CMC Table

Measurand	**Uncertainty**	**Comments**
Air Flow		Source for calibrating flow meters

Rule: The measured quantity's first token identifies the quantity kind, which the taxonomy uniquely name and link to an M-Layer Aspect ID.

Researching Quantity Names

Names from recognized bodies:

- KCDB: “fluid flow” (with “gas flow” or “liquid flow” and species)
- *ISO-IEC 80000*: “mass flow rate” and “volume flow rate”
- NVLAP: “[20/M05] Flow Rate”, plus “liquid flow” and “gas flow”
- DAkkS: ‘Gas flow rate”, “Volume of flowing gases”, and “Mass of flowing gases”

Neither names nor quantities consistent!

No problem–building this taxon for digital documents solves that.

Researching Quantity Names

Looking at approved SoAs from various ABs and Laboratories, we additionally find

> *"Mass Flow", "Liquid Flow", "Gas Flow", "Flow - Air", "Flow - Gas", "Flow - Liquid", "Flow - Gas (Air)", "Air/Nitrogen Flow", "Flow Rate by Volume", "Air Volume Flow", "Flow Hydraulic", "Fuel Flow", "Flow Rate by Volume for Compressible Gas", "Volumetric Flow Rate (Water)", "Liquid Flow Rate Inline", "Liquid Flow Rate Non-Intrusive", "Gas Flow - Leak", "Gas Leak", "Gas Flow Rate Into Vacuum", "mole-flow-rate", "Flow Meter Factor", "Flow Calibration Factor", "Flow Meter", "Determination of Flow Meter" (by gas or liquid species), "Electrical Output of Flow & Pressure Devices",*

and many other categorizations by flow instrumentation.

Further confusion: melt-flow index, flow velocity, air velocity, evaporation, load rate. Wow!

Researching Quantity Names

Sorting it out for the taxonomy:

- Unique quantity kinds: mass flow, volume flow, ratios, coefficients
- The MII taxonomy already defines `Ratio` and `Coefficient`.
- Mass flow covers leaks.
- Fluids include gases and liquids but their measurement processes differ.
- A species-type property would identify the fluid.
- Both inline and non-intrusive Measure processes exist, though the Source process seems the same.

Solution: Propose adding `MassFlowRate` and `VolumeFlowRate` to the MII quantity-kind list.

Step: Organize a Hierarchical Taxonomy Tree

- `Source.MassFlowRate.Gas`
- `Measure.MassFlowRate.Gas.Inline`
- `Measure.MassFlowRate.Gas.NonIntrusive`
- `...MassFlowRate.Liquid...`
- `Source.VolumeFlowRate.Gas`
- `Measure.VolumeFlowRate.Gas.Inline`
- `Measure.VolumeFlowRate.Gas.NonIntrusive`
- `...VolumeFlowRate.Liquid...`
- `Source.Ratio.MassFlowRate.Gas.MeterFactor`
- `Source.Coefficient.Voltage.MassFlowRate.DC.Gas`

Only the whole taxon has machine meaning; individual tokens (except Measure and Source) only facilitate development.

Step 1: Name the Taxon

Step 1.6: Check against the MII quantity database.

Example Taxon: Source.MassFlowRate

Example CMC Table

Measurand	**Uncertainty**	**Comments**
Mass flow rate		Source for calibrating flow meters

Rule: The measured quantity's first token identifies the quantity kind, which the taxonomy uniquely name and link to an M-Layer Aspect ID.

Step 1: Name the Taxon

Step 1.7: Completely qualify the measurand.

Example Taxon: `Source.MassFlowRate.Gas.AmbientAir`

Example CMC Table

Measurand	Uncertainty	Comments
Mass flow rate Gas: ambient air, dry nitrogen		Source for calibrating inline or non-intrusive flow meters

Rule: Any further tokens after the quantity-kind token hierarchically qualify the quantity, proceeding from more general toward more specific quantity descriptors.

Step 1: Name the Taxon

Step 1.8: Omit qualifiers that do not change the measurement process.

Example Taxon: `Source.MassFlowRate.Gas`

Example CMC Table

Measurand	Uncertainty	Comments
Mass flow rate Gas: ambient air, dry nitrogen		Source for calibrating inline or non-intrusive flow meters

Rule: Parameters substitute for additional tokens to distinguish details within the same measurement process.

`Source.Temperature.Simulated.Thermocouple` (types by parameter)
`Source.Temperature.Simulated.PRT` (resistance instead of voltage)

Step 2: Define the Measurand

A clear human-readable definition helps (M-Layer!)

- disambiguate one measurand from another,
- select the correct measurand from a list,
- determine whether the measurand of interest appears in the taxonomy or requires a new entry or differentiation.

Find a suitable definition in a textbook, standard, or other source.

Step 2: Define the Measurand

A clear human-readable definition helps (M-Layer!)

- disambiguate one measurand from another,
- select the correct measurand from a list,
- determine whether the measurand of interest appears in the taxonomy or requires a new entry or differentiation.

Find a suitable definition in a textbook, standard, or other source.

In our case, we find a succinct mathematical definition in *ISO-IEC 80000*: $q_m = dm/dt$

Step 2: Define the Measurand

A clear human-readable definition helps (M-Layer!)

- disambiguate one measurand from another,
- select the correct measurand from a list,
- determine whether the measurand of interest appears in the taxonomy or requires a new entry or differentiation.

Find a suitable definition in a textbook, standard, or other source.
In our case, we find a succinct mathematical definition in *ISO-IEC 80000*: $q_m = dm/dt$
We might then expound upon that to give more explanation:

> *This process sources a reference mass flow rate of gas for calibrating gas flow meters. The instantaneous mass flow rate q_m equals dm/dt, sometimes estimated as $\Delta m/\Delta t$ using the total mass Δm flowing through a defined space in time Δt.*

Lies, Damned Lies, and Statistics

If a probability equals p only under conditions (x, y, z), then we abuse the facts to quote the probability without stating the conditions.

Lies, Damned Lies, and Statistics

If a probability equals p only under conditions (x, y, z), then we abuse the facts to quote the probability without stating the conditions.

Similarly, we devalue calibration without fully knowing and stating the measurement conditions, the measurand's state.
(Calibrate as used, use as calibrated! How? Define the state!)

Lies, Damned Lies, and Statistics

If a probability equals p only under conditions (x, y, z), then we abuse the facts to quote the probability without stating the conditions.

Similarly, we devalue calibration without fully knowing and stating the measurement conditions, the measurand's state.
(Calibrate as used, use as calibrated! How? Define the state!)

- Specifying the measurand's full state restricts its *definitional* uncertainty.
- Unrecognized definitional uncertainty may swamp other uncertainty components.
- At worst, it will exceed the instrument MPE specification, essentially making the calibration worthless.

Lies, Damned Lies, and Statistics

If a probability equals p only under conditions (x, y, z), then we abuse the facts to quote the probability without stating the conditions.

Similarly, we devalue calibration without fully knowing and stating the measurement conditions, the measurand's state.
(Calibrate as used, use as calibrated! How? Define the state!)

Define the measurand's state via "parameters" included as metadata in instrument specifications, calibration certificates and SoA CMCs.

- Influence quantity values (e.g., frequency in AC voltage)
- Input quantity values (e.g., temperature for length correction)
- Property values (e.g., thermocouple type)
- Instrument operating conditions (might challenge some labs)

Step 3: Identify the Measurand's Parameters

Step 3.1: Research the measurand's calibration processes to generalize the template.

- Mass flow rate
- Gas Type
- Gas Temperature
- Gas Pressure
- Gas Relative Humidity
- Gas Compressibility
- Reference Temperature
- Reference Pressure
- Reference Relative Humidity
- Reference Compressibility
- Ambient Temperature
- Ambient Pressure
- Ambient Relative Humidity
- Outlet Pressure
- Reynolds Number
- Gas Velocity

Step 3: Identify the Measurand's Parameters

Step 3.1: Research the measurand's calibration processes to generalize the template.

- Mass flow rate
- Gas Type
- Gas Temperature
- Gas Pressure
- Gas Relative Humidity
- Gas Compressibility
- Reference Temperature
- Reference Pressure
- Reference Relative Humidity
- Reference Compressibility
- Ambient Temperature
- Ambient Pressure
- Ambient Relative Humidity
- Outlet Pressure
- Reynolds Number
- Gas Velocity

Not all parameters matter for a given laboratory or customer—uncertainty level and instrument type.

Step 3: Identify the Measurand's Parameters

Step 3.2: Classify parameters as required or optional (default-valued).

- Mass flow rate
- Gas Type
- Gas Temperature
- Gas Pressure
- Gas Relative Humidity
- Gas Compressibility
- Reference Temperature
- Reference Pressure
- Reference Relative Humidity
- Reference Compressibility
- Ambient Temperature
- Ambient Pressure
- Ambient Relative Humidity
- Outlet Pressure
- Reynolds Number
- Gas Velocity

Not all parameters matter for a given laboratory or customer—uncertainty level and instrument type.

Step 3: Identify the Measurand's Parameters

Step 3.2: Classify parameters as required or optional (default-valued).

- Mass flow rate (R)
- Gas Type
- Gas Temperature
- Gas Pressure
- Gas Relative Humidity
- Gas Compressibility
- Reference Temperature
- Reference Pressure
- Reference Relative Humidity
- Reference Compressibility
- Ambient Temperature
- Ambient Pressure
- Ambient Relative Humidity
- Outlet Pressure
- Reynolds Number
- Gas Velocity

Not all parameters matter for a given laboratory or customer—uncertainty level and instrument type.

Step 3: Identify the Measurand's Parameters

Step 3.2: Classify parameters as required or optional (default-valued).

- Mass flow rate (R)
- Gas Type (O)
- Gas Temperature (O)
- Gas Pressure (O)
- Gas Relative Humidity (O)
- Gas Compressibility (O)
- Reference Temperature (O)
- Reference Pressure (O)
- Reference Relative Humidity (O)
- Reference Compressibility (O)
- Ambient Temperature (O)
- Ambient Pressure (O)
- Ambient Relative Humidity (O)
- Outlet Pressure (O)
- Reynolds Number (O)
- Gas Velocity (O)

Not all parameters matter for a given laboratory or customer—uncertainty level and instrument type.

Step 3: Identify the Measurand's Parameters

Step 3.2: Classify parameters as required or optional (default-valued).

- Mass flow rate (R)
- Gas Type (O)
- Gas Temperature (O)
- Gas Pressure (O)
- Gas Relative Humidity (O)
- Gas Compressibility (O)
- Reference Temperature (O)
- Reference Pressure (O)
- Reference Relative Humidity (O)
- Reference Compressibility (O)
- Ambient Temperature (O)
- Ambient Pressure (O)
- Ambient Relative Humidity (O)
- Outlet Pressure (O)
- Reynolds Number (O)
- Gas Velocity (O)

Laboratories may change the required-optional assignment and omit parameters altogether in their CMCs.

Example Human-Readable MII Air-Flow Taxon

Source.MassFlowRate.Gas

This process sources a reference mass flow rate of gas for calibrating gas flow meters. The instantaneous mass flow rate q_m equals dm/dt, sometimes estimated as $\Delta m/\Delta t$ using the total mass Δm flowing through a defined space in time Δt.

- **Required Parameters (with ranges)**
  - Mass flow rate
- **Optional Parameters (with ranges)**
  - Gas Type
  - Gas Temperature
  - Gas Pressure
  - Gas Relative Humidity
  - Gas Compressibility
  - Reference Temperature
  - Reference Pressure
  - Reference Relative Humidity
  - Reference Compressibility
  - Ambient Temperature
  - Ambient Pressure
  - Ambient Relative Humidity
  - Outlet Pressure
  - Reynolds Number
  - Gas Velocity

Example Human-Readable CMC

Measurand	Uncertainty	Comments
Mass flow rate, 1 slpm to 1000 slpm Gas: ambient air, dry nitrogen Gas Temp. (inlet): 23 °C Gas Pressure (inlet): 800 kPa 100 kPa to 1000 kPa Gas Relative Humidity: 45 % Ref. Temperature: 20 °C Ref. Pressure: 101.325 kPa Ref. Relative Humidity: 36 % Ref. Compressibility: 0.9997 Ambient Temperature: 23 °C Ambient Pressure: 800 kPa . . .	±0.3 % of reference value*	Source for calibrating inline or non-intrusive flow meters

Section 4

Further Examples

Microphone Sensitivity Example—Description

Measurand Quantity: Pressure sensitivity (ratio of dynamic output voltage to dynamic pressure), typically expressed as a logarithmic level quantity relative to 1 V/Pa

Primary Calibration Method: Reciprocal measurements between pairs of microphones under controlled conditions per IEC 61094-2. The results trace to fundamental electrical, mechanical and physical parameters such as DC voltage, frequency, air density, temperature, static pressure, etc. The method therefore requires no standard microphone.

Secondary Calibration Method: Comparison between the unknown microphone and a standard microphone

Microphone Sensitivity Example—CMC and Service Data

One KCDB CMC:

- Quantity Value: Pressure sensitivity level
- Unit: dB (reference: 1 V/Pa)
- Instrument: Measurement microphone type LS1P (nominal sensitivity -26.5 dB at 20 °C)
- Method: IEC 61094-2:2009
- Parameter: Frequency, Parameter Value: 25 Hz to 62 Hz
- Uncertainty ($k = 2$): 0.05 dB

NRC Service: A33-01-01-01 Pressure sensitivity level of measurement microphone by the reciprocity technique. Up to two Laboratory Standard measurement microphones of the same type by the reciprocity method of IEC 61094-2

Microphones immersed in reference environmental conditions (23 °C, and 50 % RH) with static pressure adjusted from 94 kPa to 106 kPa in 1 kPa steps. Measurements at each pressure occur from 40 Hz to 20 kHz in one-third octave steps.

Microphone Sensitivity Example—Taxon Tokens

`Measure.Coefficient.Voltage.Pressure.AC.RMS.Differential.RMS.PressureField`

- `Measure`: Microphones source their coefficients just as gage blocks source lengths and mass artifacts source mass. To calibrate a `Source` device we want a `Measure` CMC.
- `Coefficient.Voltage.Pressure`: We report a ratio of two different quantities (coefficient) and specify them as `Numerator.Denominator`.
- `AC.RMS.Differential.RMS`: Differentiates the measurand from, e.g., other pressure transducers that output DC voltage in response to absolute pressure. `RMS` (as opposed to peak-to-peak, peak, etc.) further defines the quantities.
- `PressureField`: Customers may want this result or a correction to `FreeField` or `DiffuseField` alternatives.

Microphone Sensitivity Example—CMC Parameters

`Measure.Coefficient.Voltage.Pressure.AC.Differential.PressureField`

Parameters:

- Sensitivity: -26.5 dB re 1 V/Pa
- Acoustic Frequency: 25 Hz to 62 Hz
- Fluid: Ambient Air
- Static Pressure: 94 kPa to 106 kPa
- Reference Temperature: 20 °C, 23 °C
- Reference Humidity: 50 %
- Reference Pressure: 101.325 kPa

The measurement and its uncertainty involves other factors: cavity dimensions, microphones' acoustic impedance, coupler cavity volume, coupler thermodynamic properties, transmission-line parameters, voltage, current, microphone's temperature and pressure coefficients, etc. These however, assuming they do not involve the customer's choice of calibration requirements, do not take the form of CMC parameters.

Microphone Sensitivity Example—Other Considerations

`Measure.Coefficient.Voltage.Pressure.AC.Differential.PressureField`

- We assumed reporting modulus only, not phase. A `Complex` token might apply.
- What about a `Level` token to differentiate the log quantity from a simple ratio? No, the M-Layer handles this as a scale conversion.
- Secondary calibration:
  - The taxonomy may remain the same, depending on the customer choices. (Might drop `PressureField` et al. if not applicable.)
  - Consider `Source.Voltage.DC` at different traceability levels—no taxon change.
  - Parameter options and uncertainty will change for every CMC, regardless of primary, secondary, etc. classification.

Radiometric Measurands

- Starting Taxonomy
  - Diffuse reflectance factor: `Ratio.RadiantFlux.Reflectance.Diffuse`
  - Regular reflectance factor: `Ratio.RadiantFlux.Reflectance.Specular`
  - Transmittance factors: `Ratio.RadiantFlux.Transmittance...`
  - Radiance factor: `Ratio.Radiance.Bidirectional`
  - Gloss: `Ratio.Radiance.Delta.Angle`
- Parameters for which to specify ranges or values
  - Wavelength
  - Inicidence Angle, ViewAngle
  - Sample Size
  - Polarization

Other Taxons

Capacitance
Conductance
Conductivity
Current.AC
Current.AC.Noise.RMS
Current.AC.Sinewave
Current.AC.Sinewave.2Phase
Current.AC.Sinewave.3Phase
Current.AC.Squarewave
Current.AC.Trianglewave
Current.DC
Current.DC.Delta.Current.LoadEffect
Current.DC.Delta.Current.SourceEffect
Current.DC.OutputAndReadback
Density.Mass.Gas
Density.Mass.Liquid
Density.Mass.Solid
Energy.AC.Sinewave
Energy.AC.Sinewave.Simulated
Energy.AC.Sinewave.Simulated.2Phase
Energy.AC.Sinewave.Simulated.3Phase
Energy.DC
Energy.DC.Simulated
Force
Frequency
Frequency.AmplitudeModulation.Rate
Frequency.FrequencyModulation.Deviation
Frequency.FrequencyModulation.Rate
Frequency.PhaseModulation.Rate
Humidity.Absolute
Impedance
Inductance
Length
Length.Circumference
Length.Diameter
Length.Form.Flatness
Length.Form.Parallelism
Length.Form.Perpendicularity
Length.Form.Roughness
Length.Form.Roundness
Length.Form.Sphericity
Length.Form.Straightness.Axis
Length.Form.Straightness.Surface
Length.Radius
Mass.Apparent
Mass.Conventional
Mass.True
Phase.PhaseModulation
Phase.ReflectionFactor.RF
Phase.TransmissionFactor
PhaseNoise.SideBand
Power.AC.Sinewave
Power.AC.Sinewave.Simulated
Power.AC.Sinewave.Simulated.2Phase
Power.AC.Sinewave.Simulated.3Phase
Power.DC
Power.DC.Simulated
Power.RF.Sinewave
Pressure.Hydraulic.Static
Pressure.Pneumatic.Absolute.Static
Pressure.Pneumatic.Differential.Static
Pressure.Pneumatic.Gage.Static
Ratio.AmplitudeModulation
Ratio.AmplitudeModulation.Delta.Rate
Ratio.Density.Mass
Ratio.Distortion
Ratio.Distortion.AmplitudeModulation
Ratio.Distortion.FrequencyModulation
Ratio.Distortion.PhaseModulation
Ratio.DutyCycle
Ratio.FrequencyModulation.Delta.Rate
Ratio.Humidity.Relative
Ratio.Humidity.Specific
Ratio.PhaseModulation.Delta.Rate
Ratio.Power.ReflectionFactor.RF
Ratio.Power.RF.Sinewave.Delta.Frequency
Ratio.Power.RF.Sinewave.Delta.Power
Ratio.Power.RF.Sinewave.Harmonic
Ratio.Power.RF.Sinewave.Spur
Ratio.Power.TransmissionFactor
Ratio.PulseModulation.CWtoPulsedPower
Ratio.PulseModulation.OnOffPower
Ratio.Torque
Ratio.Voltage.AC.Ripple.OnDC

Other Taxons

Ratio.Voltage.AC.Sinewave.Delta.Frequency
Ratio.Voltage.AC.Sinewave.Delta.Voltage
Resistance
Resistance.Insulation
Temperature
Temperature.Radiometric
Temperature.Simulated.PRT
Temperature.Simulated.RTD
Temperature.Simulated.Thermocouple
Time.Interval

Time.Period
Time.PulseWidth
Time.Transient
Time.Transition
Time.Transition.PulsedRF
Time.UTC
Torque
Torque.HydraulicPressure
Voltage.AC
Voltage.AC.NoisePeakToPeak
Voltage.AC.Ripple.OnDC

Voltage.AC.Sinewave
Voltage.AC.Sinewave.2Phase
Voltage.AC.Sinewave.3Phase
Voltage.AC.Squarewave
Voltage.AC.Trianglewave
Voltage.DC
Voltage.DC.Delta.Voltage.LoadEffect
Voltage.DC.Delta.Voltage.SourceEffect
Voltage.DC.OutputAndReadback
Voltage.DC.Segemented.Delta
Voltage.PeakToPeak

Section 5

Conclusion

Digitize your CMCs!

1. Metrology's digital transformation has begun; coming our way soon!
2. The MII initiative paves a way to digitize your CMCs.
3. Digital CMCs will draw new business and reduce costs.
4. MII taxons fully qualify measurands for interoperable digital documents.
5. We will reuse the taxonomy in digital instrument specifications and calibration certificates.
6. We'd like to collaborate on your CMCs.
7. SoA content and formatting remains under the laboratory's and AB's control.

Collaboration

- Going forward
  - GitHub for configuration management: collaboration, submissions, approvals
  - Taxonomy, CMC templates, specification and governance documents
  - https://github.com/NCSLI-MII
  - Ryan.White@nrc-cnrc.gc.ca, mjk@ieee.org
- Current information
  - Taxonomy, open-source taxonomy and SoA editors
  - https://github.com/CalLabSolutions/Metrology.NET_Public
  - Informal list at https://www.metrology.net/home/metrology-taxonomy/
  - Further info: http://miiknowledge.wikidot.com/

Acknowledgments

Please see the paper for further taxon-writing details.
Further work, governance doc

Many thanks go to

- SIM MWG for the kind invitation
- NCSL International for its MII support
- NCSL International Committee members for their MII development work
- Cherine-Marie Kuster

And Thank You for your time!

Collaboration opportunities? Please bring your expertise!

Questions?