A Taxonomy of Electrical Measurands

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Abstract: Metrology has entered the digital era. Some years ago, the NCSLI MII & Automation Committee and its collaborators began developing a taxonomy to uniquely identify and distinguish measurands in machine-actionable digital metrology documents such as calibration certificates, accreditation scopes, and instrument specifications. The committee has set a goal to link one or more measurand taxa to each calibration and measurement capability (CMC) contained in the key-comparison database (KCDB) managed at the International Bureau of Weights and Measures (BIPM). Further extensions would cover national metrology institutes' and accredited laboratories' CMCs not directly mapped to KCDB service codes. This paper outlines the taxonomy structure and presents current progress toward covering the KCDB's electricity and magnetism measurement area. We report the coverage to date and describe the relations between the taxa and the KCDB's services, sub services, individual services and quantity designations.

1. Introduction

The NCSLI MII & Automation Committee (MII&AC) and its collaborators continues to develop a taxonomy to uniquely identify and distinguish measurands in machine-actionable digital metrology documents such as calibration certificates, accreditation scopes, and instrument specifications. The taxonomy constitutes a publicly available *reference metadata* set, the mortar that joins the building blocks of digital measurement data together.

The committee set a goal to link one or more measurand taxa to each calibration and measurement capability (CMC) contained in the key comparison database (KCDB) managed at the BIPM. Given that the KCDB CMCs catalog most NMI services from which lower-level laboratories derive accredited capabilities, the committee expects that the resulting taxonomy will cover most worldwide calibration services. Follow-up projects will extend the taxonomy to those lower-level services not directly represented in the KCDB.

This project aims to review the relations between the taxa and the services, sub services, individual services and quantity designations listed in the KCDB "Classification of Services in Electricity and Magnetism" [1]. Using the mapping established thereby, the project will then assign taxa to the electricity and magnetism CMCs published in the KCDB.

Because of the authors' expertise, the initial work has focused on the DC, low-frequency AC, and radio-frequency measurement services. A preliminary project [2] investigated the feasibility and developed the methodology while covering the KCDB's photometry CMCs. We intend to continue the work to cover the remaining service classifications.

We also note that the results presented herein do not constitute a final taxonomy product, but only a first-draft taxonomy section to cover the respective KCDB CMCs. Each taxon requires a complete structure (e.g., measurand definition, influence- and input-quantity parameter definitions) not yet fully constructed for all new taxa. Both the new taxa and the old taxa modified as a result of this project require approval through the (MII&AC)'s taxonomy-governance process before adoption.

2. The BIPM Key Comparison Database

The CIPM Mutual Recognition Arrangement (CIPM MRA) is the framework through which NMIs (national metrology institutes) and DIs (designated institutes) demonstrate the international equivalence of their measurements and the calibration and measurement certificates they issue. The BIPM KCDB supports the CIPM MRA. The KCDB contains information on the internationally recognized, peer-reviewed and approved CMCs for the services available from the NMIs and DIs participating in the CIPM MRA, and the key and supplementary comparisons supporting these CMCs.

The CMCs published in the KCDB are organized by metrology area. The services in each metrology area are further divided into branches, services, sub services and individual services. The relevant Consultative Committee (CC) of the CIPM publishes the classification of services in each metrology area. These documents intend to provide a definitive list of all the measurement services carried out by the NMIs and DIs.

The Consultative Committee for Electricity and Magnetism (CCEM) reviews the "Classification of Services in Electricity and Magnetism" [1] at its meetings and revises the document as appropriate. The classifications were first published shortly after the signing of the CIPM MRA in 1999 and have remained stable for many years, but the CCEM changed the classifications for "High Voltage and Current" in 2020. Table 1 shows the list of electricity and magnetism branches and services.

Table 1. Electricity and magnetism branches and services [1].

Service Number	Description
BRANCH: DC VOLTAGE, CURRENT, AND RESISTANCE	
1	DC voltage (up to 1100 V, for higher voltages see 8.1)
2	DC resistance
3	DC current (up to 100 A, for higher currents see 8.7)
BRANCH: IMPEDANCE UP TO THE MEGAHERTZ RANGE	
4	Impedance (up to the MHz range)
BRANCH: AC VOLTAGE, CURRENT, AND POWER	
5	AC voltage (up to the MHz range)
6	AC current
7	AC power
BRANCH: HIGH VOLTAGE AND CURRENT	
8	High voltage and current
BRANCH: OTHER DC AND LOW FREQUENCY MEASUREMENTS	
9	Other DC and low frequency measurements
BRANCH: ELECTRIC AND MAGNETIC FIELDS	
10	Electric and magnetic fields
BRANCH: RADIO FREQUENCY MEASUREMENTS	
11	Radio frequency measurements
BRANCH: MATERIALS	
12	Measurements on materials

3. Taxa and Service Classifications

We reviewed the branches, services, sub services and individual services in the "Classification of Services in Electricity and Magnetism" [1] and assigned appropriate taxa to the individual services within the branches "DC Voltage, Current, and Resistance"; "Impedance up to the Megahertz Range"; "AC Voltage, Current, and Power" and "Radio Frequency Measurements". In many cases taxa for these services already existed but required modified or new tokens to cover some of the individual services.

Also of note, the CCEM classifies some measurements (e.g., AC voltage) differently according to the measurement's frequency range, presumably due to the different techniques and equipment involved. The MII taxonomy aims to remain agnostic to both technique and uncertainty (capturing this information elsewhere) and so a given taxon such as "Measure.Voltage.AC" will apply to all measurands no matter the uncertainty, frequency value, or measurement technique.

We generated taxa appropriate for CMCs, in which the tokens "Source" and "Measure" indicate a capability to calibrate a measuring instrument and calibrate a source, respectively. The taxon structure follows the committee's guidelines (available soon) on GitHub under a Creative-Commons open-source license and developed from [3, 4] and many MII&AC working-group discussions.

The NCSLI GitHub collaboration site [5] allows any contributor to submit new and modified taxa to extend and improve the taxonomy, changes to the taxonomy-development guide and other suggestions. The site also includes a repository in which we have begun developing a Python application [6] to create taxa and export them as GitHub issues, manage the KCDB-taxonomy connections and coverage [2], and also to link taxa to aspects (quantity kinds) and scales (units) in the M-layer [7]. Cal Lab Solutions also developed an open-source taxonomy editor [8] for creating and maintaining taxa and exporting them as XML for submission to GitHub.

4. Taxa in "DC Voltage, Current, and Resistance"

Table 2 shows the KCDB's sub-services and individual services in the "DC Voltage" service. Each defined individual service generally matched a single taxon. The description of classification 1.3.1, "DC Voltage Ratio: Up to 1100 V", includes both resistive dividers (sources), and ratio meters (measuring instruments), so this individual service required both Measure and Source taxa.

The correct taxon for individual service 1.1.4 "Noise voltages" was not clear and a review of the published CMCs for more information found no published CMCs with this classification. A CMC for "DC voltage source, source noise" does exist[1], but this falls under 1.1.2, "Low value ranges". This CMC should perhaps fall under 1.1.4, "Noise voltages". We tentatively assigned Measure.Voltage.AC.Ripple.OnDC to this classification.

Table 2. Taxa in "DC Voltage".

Classification	**Taxon**
1. DC voltage (up to 1100 V, for higher voltages see 8.1)	
1.1 DC voltage sources	
1.1.1 Single values: standard cell, solid state voltage standard	Measure.Voltage.DC
1.1.2 Low value ranges (below or equal to 10 V): DC voltage source, multifunction calibrator	Measure.Voltage.DC
1.1.3 Intermediate values (above 10 V to 1100 V): DC voltage source, multifunction calibrator	Measure.Voltage.DC
1.1.4 Noise voltages (for noise currents see 3.1.5, for RF noise see 11.4): DC voltage source, DC amplifier	Measure.Voltage.AC.Ripple.OnDC
1.2 DC voltage meters	
1.2.1 Very low values (below or equal to 1 mV): nanovoltmeter, microvoltmeter	Source.Voltage.DC
1.2.2 Intermediate values (above 1 mV to 1100 V): DC voltmeter, multimeter, multifunction transfer standard	Source.Voltage.DC
1.3 DC voltage ratios (for input voltages up to 1100 V)	
1.3.1 Up to 1100 V: resistive divider, ratio meter	Source.Ratio.Voltage.DC
	Measure.Ratio.Voltage.DC
1.3.2 Attenuation: attenuators	Measure.Ratio.Voltage.DC

1 KCDB code EURAMET-EM-DE-00000FA8-2

Table 3 shows the sub-services and individual services in the “DC Resistance” service. Each individual service classification here again generally matched a single taxon. Classification 2.1.6, “Temperature, power, and pressure coefficients: fixed resistor”, includes three examples of the special “Coefficient” token, which precedes tokens for the coefficient’s numerator and denominator quantities in that order [4].

Table 3. Taxa in “DC Resistance”.

Classification	**Taxon**
2. DC resistance	
2.1 DC resistance standards and sources	
2.1.1 Low values (below or equal to 1 Ω): fixed resistor, resistance box	Measure.Resistance.DC
2.1.2 Intermediate values (above 1 μΩ to 1 MΩ): fixed resistor, resistance box	Measure.Resistance.DC
2.1.3 High values (above 1 MΩ): fixed resistor, three terminal resistor, resistance box	Measure.Resistance.DC
2.1.4 Standards for high current: DC shunt	Measure.Resistance.DC
2.1.5 Multiple ranges: multifunction calibrator	Measure.Resistance.DC
2.1.6 Temperature, power and pressure coefficients: fixed resistor	Measure.Coefficient.Resistance.Temperature.DC
	Measure.Coefficient.Resistance.Power.DC
	Measure.Coefficient.Resistance.Pressure.DC
2.2 DC resistance meters	
2.2.1 Low values (below or equal to 1 Ω): microohmmeter, multimeter, multifunction transfer standard, resistance bridge	Source.Resistance.DC
2.2.2 Intermediate values (above 1 Ω to 1 GΩ): ohmmeter, multimeter, multifunction transfer standard, resistance bridge	Source.Resistance.DC
2.2.3 High values (above 1 GΩ): multimeter, multifunction transfer standard, teraohmmeter, resistance bridge	Source.Resistance.DC
2.3 DC resistance ratios	
2.3.1 DC resistance ratios: resistance ratio devices	Measure.Ratio.Resistance.DC

Table 4 shows the services, sub-services in the “DC Current” service. Each individual service classification here matched a single taxon. The correct taxon for individual service 3.1.5, “Noise currents”, was not clear and a review of the published CMCs for more information found no published CMCs with this classification. We tentatively assigned Measure.Current.AC.Ripple.OnDC to this classification.

Table 4. Taxa in “DC Current”.

Classification	**Taxon**
3. DC current (up to 100 A, for higher currents see 8.7)	
3.1 DC current sources	
3.1.1 Low values (below or equal to 0.1 mA): current generator, multifunction calibrator	Measure.Current.DC
3.1.2 Intermediate values (above 0.1 mA to 20 A): current generator, multifunction calibrator	Measure.Current.DC
3.1.3 High values (above 20 A to 100 A): current generator	Measure.Current.DC
3.1.4 Transconductance ratio	Measure.Conductance.DC
3.1.5 Noise currents (for noise voltages see 1.1.4, for RF noise see 11.4): DC current source, DC amplifier	Measure.Current.AC.Ripple.OnDC

Classification	**Taxon**
3.2 DC current meters	
3.2.1 Low values (below or equal to 0.1 mA): picoammeter, nanoammeter, multimeter, multifunction transfer standard	Source.Current.DC
3.2.2 Intermediate values (above 0.1 mA to 20 A): current comparator	Source.Current.DC
3.2.3 High values (above 20 A to 100 A): current transducer, dedicated equipment for heavy current	Source.Current.DC
3.3 DC current ratios	
3.3.1 Ratios up to 100 A: resistive dividers, DC current comparators, current transducers	Source.Ratio.Current.DC

5. Taxa in “Impedance up to the Megahertz Range”

Table 5 shows the sub-services and individual services in the “Impedance up to the Megahertz Range” service. We use a nominally-valued parameter to distinguish the real or imaginary components, or magnitude. Some of the classification descriptions mention the imaginary component, dissipation factor, or equivalent series resistance. A review of the published CMCs found that some classifications not mentioning the component required two taxa. The published CMCs for calibration of meters include only one CMC for the imaginary component of AC resistance-measuring instruments[2], only one for the dissipation factor of capacitance-measuring instruments[3], and no published CMCs for the quality factor of inductance-measuring instruments.

Table 5. Taxa in “Impedance up to the Megahertz Range” (taxon parameters not shown).

Classification	**Taxon**
4. Impedance (up to the MHz range)	
4.1 AC resistance	
4.1.1 Real component (or modulus) and imaginary component (or argument or time constant): fixed resistor	Measure.Resistance.AC.Sinewave
4.1.2 AC/DC difference: fixed resistor	Measure.Resistance.AC.Sinewave.Delta.Frequency
4.1.3 Resistors for high current: AC current shunt	Measure.Resistance.AC.Sinewave
4.1.4 Meters: LCR meter (LCR: Inductance, Capacitance, Resistance)	Source.Resistance.AC.Sinewave
4.1.5 AC resistance ratios: resistance ratio devices	Measure.Ratio.Resistance.AC.Sinewave
4.2 Capacitance	
4.2.1 Capacitance and dissipation factor for low loss capacitors: standard capacitor (sealed, dry nitrogen or fused silica dielectric)	Measure.Capacitance
	Measure.Ratio.Impedance.DissipationFactor
4.2.2 Capacitance and dissipation factor for dielectric capacitors: fixed capacitor, switched capacitor, capacitance box	Measure.Capacitance
	Measure.Ratio.Impedance.DissipationFactor
4.2.3 Capacitance and dissipation factor for transformed capacitors: fixed capacitor, switched capacitor	Measure.Capacitance
	Measure.Ratio.Impedance.DissipationFactor
4.2.4 Meters: capacitance bridge, LCR meter (LCR: Inductance, Capacitance, Resistance)	Source.Capacitance
	Source.Ratio.Impedance.DissipationFactor
4.3 Inductance	
4.3.1 Self-inductance and equivalent series resistance, low values (lower than 1 mH): fixed inductor, variable inductor, inductance box	Measure.Inductance
	Measure.Resistance.SeriesEquivalent.Inductance
4.3.2 Self-inductance and equivalent series resistance, intermediate values (above or equal to 1mH to 1 H): fixed inductor, variable inductor, inductance box	Measure.Inductance
	Measure.Resistance.SeriesEquivalent.Inductance

2 KCDB Code EURAMET-EM-CH-00000GHA-1

3 KCDB Code SIM-EM-BR-000008U6-2

Classification	Taxon
4.3.3 Self-inductance and equivalent series resistance, high values (higher than 1 H): fixed inductor, variable inductor, inductance box	Measure.Inductance
	Measure.Resistance.SeriesEquivalent.Inductance
4.3.4 Mutual inductance: fixed mutual inductor	Measure.Inductance
4.3.5 Meters: LCR meter (LCR: Inductance, Capacitance, Resistance)	Source.Inductance
4.3.6 Quality factor: Q-standards	Measure.Ratio.Impedance.QualityFactor

6. Taxa in "AC Voltage, Current, and Power"

Discussion continues on whether to represent the waveform of AC signals as tokens or parameters [4]. The current draft of the taxonomy includes them as tokens but parameters provide more flexibility. The classification document does not mention the measured waveforms in the "AC voltage, current and power" branch. The "High voltage and current" and "Other DC and low frequency measurements" branches do explicitly mention waveforms. Generally, NMIs and DIs calibrate using sine waves, which becomes the default waveform assumed for these services. A review of the CMCs for "AC Voltage, Current, and Power" did not identify any mention of waveforms. We use a nominally-valued parameter to designate the real or imaginary components, or magnitude where appropriate.

Table 6 shows the sub-services and individual services in the "AC Voltage" service. Each defined individual-service classification matched a single taxon.

Table 6. Taxa in "AC Voltage" (taxon parameters not shown).

Classification	Taxon
5. AC voltage (up to the MHz range)	
5.1 AC/DC voltage transfer (for frequencies higher than 1 MHz see 11.7.1)	
5.1.1 AC/DC transfer difference at low voltages (typically below or equal to 0.5 V): thermal converter with amplifier, micropotentiometer, AC/DC transfer standard	Measure.Voltage.AC.Sinewave.Delta.Frequency
5.1.2 AC/DC transfer difference at medium voltages (typically above 0.5 V to 5 V): thermal converter (directly connected), AC/DC transfer standard	Measure.Voltage.AC.Sinewave.Delta.Frequency
5.1.3 AC/DC transfer difference at higher voltages (typically above 5 V): thermal converter with range extender, AC/DC transfer standard	Measure.Voltage.AC.Sinewave.Delta.Frequency
5.2 AC voltage up to 1100 V (for high voltage see 8.3)	
5.2.1 Sources: multifunction calibrator	Measure.Voltage.AC.Sinewave
5.2.2 Meters: AC voltmeter, multimeter, multifunction transfer standard	Source.Voltage.AC.Sinewave
5.3 AC voltage ratio up to 1100 V (voltage transformers excluded), attenuation and gain (for high voltage and voltage transformers, see 8.3)	
5.3.1 Real component (or modulus) and imaginary component (or argument): inductive voltage divider, AC bridge standard, attenuator box, syncro-resolver	Measure.Ratio.Voltage.AC.Sinewave
5.3.2 Attenuation and gain: passive device, attenuator box, inductive voltage divider	Measure.Gain.Voltage.AC.Sinewave

Table 7 shows the sub-services and individual services in the "AC Current" service. The individual services each matched a single taxon except for 6.2.1 where multifunction calibrator, and transconductance amplifier were both listed. It is possible that the transconductance amplifier could be calibrated with a multifunction calibrator as a source, but it could also be calibrated separately requiring a different taxon.

Table 7. Taxa in "AC Current" (taxon parameters not shown).

Classification	Taxon
6. AC current	
6.1 AC/DC current transfer	
6.1.1 AC/DC transfer difference: thermal converter plus shunt, AC/DC transfer standard plus shunt	Measure.Current.AC.Sinewave.Delta.Frequency
6.2 AC current up to 100 A (for high current see 8.6)	
6.2.1 Sources: multifunction calibrator, transconductance amplifier	Measure.Current.AC.Sinewave
	Measure.Conductance.AC.Sinewave
6.2.2 Meters: AC ammeter, multimeter, multifunction transfer standard	Source.Current.AC.Sinewave
6.3 AC current ratio up to 100 A (current transformers excluded, for high current and current transformers, see 8.6)	
6.3.1 Real component (or modulus) and imaginary component (or argument)	Measure.Ratio.Current.AC.Sinewave

Table 8 shows the sub-services and individual services in the "AC Power" service. The individual services are defined in a way that requires several taxa for each classification. We decided to distinguish active, reactive, and apparent power and energy via a nominally-valued parameter to designate the real or imaginary components, or magnitude. The classification document distinguishes between single-phase and three-phase measurements, and this has reinforced the decision to include these tokens in the taxonomy. The taxonomy also distinguishes between real and simulated, or phantom, power.

A review of the CMCs shows a number relating to power loss. This may require a separate taxon. A CMC for "DC Energy" also appears, and we associated it with Source.Energy.DC.

Table 8. Taxa in "AC Power" (taxon parameters not shown).

Classification	Taxon
7. AC power	
7.1 AC power and energy	
7.1.1 Single phase (frequencies below or equal to 400 Hz): power meter, energy meter, power converter, wattmeter 7.1.2 Single phase (frequencies above 400 Hz): power meter, energy meter, power converter, wattmeter	Source.Power.AC.Sinewave.1Phase
	Measure.Power.AC.Sinewave.1Phase
	Source.Energy.AC.Sinewave.1Phase
	Measure.Energy.AC.Sinewave.1Phase
	Source.PowerAC.Sinewave.1Phase.Simulated
	Measure.Power.AC.Sinewave.1Phase.Simulated
	Source.Energy.AC.Sinewave.1Phase.Simulated
	Measure.Energy.AC.Sinewave.1Phase.Simulated
7.1.3 Three phase: power meter, energy meter	Source.Power.AC.Sinewave.3Phase
	Measure.Power.AC.Sinewave.3Phase
	Source.Energy.AC.Sinewave.3Phase
	Measure.Energy.AC.Sinewave.3Phase
	Source.PowerAC.Sinewave.3Phase.Simulated
	Measure.Power.AC.Sinewave.3Phase.Simulated
	Source.Energy.AC.Sinewave.3Phase.Simulated
	Measure.Energy.AC.Sinewave.3Phase.Simulated

7. Taxa in "Radio Frequency Measurements"

Table 9 covers the KCDB's services and sub-services in the "Radio Frequency Measurements" service. Some of these classifications leave the specific measurands unclear. For example, what modulation protocol(s) does 11.1.5 include, if not CW? It becomes more complicated with digital modulation, with which power levels change during transmission, and blank timing gaps exist with no signal transmission. Section 11.4.5 “EM/RF Radio brightness temperature, spectral radiance in free space” presents difficulties because only one laboratory seems to make this measurement, which sounds like a signal-above-noise measurement. 11.7.5 “EM/RF RF transfer impedance” mentions current coils, but with a measurement unit of W or Ω. 11.9.1 “EM/RF Mechanical dimensions” involve lengths that determine, for example, airline impedances.

Table 9. Taxa in “Radio Frequency Measurements” (taxon parameters not shown).

Classification	**Taxon**
11 EM/RF Radio frequency measurements	
11.1 EM/RF RF power	
11.1.1 EM/RF Absolute power in coaxial line 11.1.2 EM/RF Absolute power in waveguide	Measure.Power.AC.Sinewave
	Source.Power.AC.Sinewave
11.1.3 EM/RF Calibration factor and effective efficiency in coaxial line 11.1.4 EM/RF Calibration factor and effective efficiency in waveguide	Measure.Ratio.Power.AC.Sinewave.Delta.Frequency
	Source.Ratio.Power.AC.Sinewave.Delta.Frequency
11.1.5 EM/RF Non-CW power (absolute or relative)	Measure.Power.AC.PulseModulation
	Measure.Ratio.Power.AC.PulseModulation.Delta.Sinewave
	Measure.Power.AC.DigitalModulation
	Source.Power.AC.PulseModulation
	Source.Ratio.Power.AC.PulseModulation.Delta.Sinewave
	Source.Power.AC.DigitalModulation
11.1.6 EM/RF Power measurements in balanced lines	Measure.Ratio.Power.Transmission.AC.Sinewave Measure.Ratio.Power.Reflection.AC.Sinewave
11.2 EM/RF Scalar RF reflection coef. and attenuation	
11.2.1 EM/RF Reflection coefficient in coaxial line 11.2.2 EM/RF Reflection coefficient in waveguide	Measure.Ratio.Power.Reflection.AC.Sinewave
11.2.3 EM/RF Attenuation in coaxial line (values in dB) 11.2.4 EM/RF Attenuation in waveguide (values in dB)	Measure.Ratio.Power.Transmission.AC.Sinewave
11.2.5 EM/RF Directivity, effective source match	Measure.Ratio.Power.Directivity.AC.Sinewave
	Measure.Ratio.Power.SourceMatch.AC.Sinewave
11.2.6 EM/RF Reflection and attenuation measurements in balanced lines	Measure.Ratio.Power.Reflection.AC.Sinewave
	Measure.Ratio.Power.Transmission.AC.Sinewave
11.3 EM/RF Scattering parameters (vectors)	
11.3.1 EM/RF Reflection coefficient in coaxial line (real and imaginary) 11.3.2 EM/RF Reflection coefficient in waveguide (real and imaginary)	Measure.Ratio.Power.Reflection.AC.Sinewave
	Measure.Phase.Reflection.AC.Sinewave
11.3.3 EM/RF Transmission coefficient in coaxial line (real and imaginary) 11.3.4 EM/RF Transmission coefficient in waveguide (real and imaginary)	Measure.Ratio.Power.Transmission.AC.Sinewave
	Measure.Phase.Transmission.AC.Sinewave
11.3.5 EM/RF Directivity, effective source match	Measure.Ratio.Power.Directivity.AC.Sinewave
	Measure.Ratio.Power.SourceMatch.AC.Sinewave
11.3.6 EM/RF Reflection coefficient for common mode systems	Measure.Ratio.Power.Reflection.AC.Sinewave
	Measure.Phase.Reflection.AC.Sinewave
11.3.7 EM/RF Transmission coefficient for common mode systems	Measure.Ratio.Power.Transmission.AC.Sinewave
	Measure.Phase.Transmission.AC.Sinewave
11.3.8 EM/RF Reflection coefficient (Sii) in planar line systems	Measure.Ratio.Power.Reflection.AC.Sinewave
	Measure.Phase.Reflection.AC.Sinewave
11.3.9 EM/RF Transmission coefficient (Sij) in planar line	Measure.Ratio.Power.Transmission.AC.Sinewave

Classification	Taxon
systems	Measure.Phase.Transmission.AC.Sinewave
11.4 EM/RF Noise	
11.4.1 EM/RF Noise temperature or excess noise ratio in coaxial line	Measure.Noise.AC
11.4.2 EM/RF Noise temperature or excess noise ratio in waveguide	Measure.Ratio.Noise.AC
11.4.3 EM/RF Amplifier noise parameters	Measure.Ratio.Noise.AC.Delta.Power
11.4.4 EM/RF Phase noise	Measure.Ratio.Noise.Sideband
11.4.5 EM/RF Radio brightness temperature, spectral radiance in free space	Measure.Noise.AC
11.5 EM/RF Antenna properties	
11.5.1 EM/RF Antenna factor	Measure.Ratio.Power.AntennaFactor
11.5.2 EM/RF Antenna gain	Measure.Ratio.Power.AntennaGain
11.5.3 EM/RF Other properties (pattern, beam width, . . .)	TBD
11.6 EM/RF Signal and pulse characteristics	
11.6.1 EM/RF Pulse amplitude	Measure.Power.AC.PulseModulation
11.6.2 EM/RF Pulse time parameters	Measure.Time.Transition.PulsedRF
11.6.3 EM/RF Modulation, AM and FM	Measure.Ratio.AmplitudeModulation Measure.Frequency.FrequencyModulation.Deviation
11.6.4 EM/RF Distortion and harmonic content	Measure.Ratio.Power.AC.Sinewave.Harmonic Measure.Ratio.Distortion.AmplitudeModulation Measure.Ratio.Distortion.FrequencyModulation Measure.Ratio.Distortion.PhaseModulation
11.7 EM/RF RF voltage and current	
11.7.1 EM/RF RF-DC difference	Measure.Voltage.AC.Sinewave.Delta.Frequency
11.7.2 EM/RF RF voltage sources	Measure.Voltage.AC.Sinewave Measure.Power.AC.Sinewave
11.7.3 EM/RF RF voltage meters	Source.Voltage.AC.Sinewave Source.Power.AC.Sinewave
11.7.4 EM/RF RF current	Measure.Current.AC.Sinewave Source.Current.AC.Sinewave
11.7.5 EM/RF RF transfer impedance	TBD
11.7.6 EM/RF RF voltage division factor	Measure.Ratio.Current.AC.Sinewave
11.7.7 EM/RF RF coupling factor	Measure.Ratio.Power
11.7.8 EM/RF Flatness of RF voltage sources	Measure.Ratio.Power.Delta.Frequency
11.7.9 EM/RF Flatness of RF voltage meters	Source.Ratio.Power.Delta.Frequency
11.8 EM/RF Lumped impedance - admittance	
11.8.1 EM/RF Resistance or conductance	Measure.Resistance.AC Measure.Conductance
11.8.2 EM/RF Inductance	Measure.Inductance
11.8.3 EM/RF Capacitance	Measure.Capacitance
11.8.4 EM/RF Quality factor	Measure.Ratio.QualityFactor
11.9 EM/RF RF characteristic impedance	
11.9.1 EM/RF Mechanical dimensions	Measure.Length.Diameter.Inner Measure.Length.Diameter.Outer Measure.Length
11.9.2 EM/RF Electrical parameters	Measure.Impedence

8. Results and CMC Coverage

The KCDB contains nearly 26,000 CMCs, so the taxon-assignment process benefits from a standardized process and would further benefit from automation tools [6]. This section outlines the procedure we used and some issues discovered. The services covered in this paper include 3595 CMCs out of a total of 4575 CMCs in the "Electricity and Magnetism" metrology area. We reviewed these 3595 CMCs and assigned taxa to nearly all of them.

We downloaded the CMCs using the BIPM's application-programming interface (API) [9] and MII-specific code under development [6] on March 29, 2024. Developed and refined over many years, the KCDB provides a rich resource both for classifying measurements and for developing this taxonomy for digital measurement data. The API provides easy access to the data in digital form and greatly facilitated this project.

We opened the downloaded CMCs in a spreadsheet and managed the taxon assignments there. As previously mentioned, the software under development [6] will take over this function in the future. The KCDB classification scheme provides a good basis for applying taxa because it allows filtering by any field in the spreadsheet (branchValue, serviceValue, etc.), easy review of the unique entries in other columns to verify consistency, and mass assignment of taxa.

We found few CMCs in the wrong classification. We generally found it simple to apply the taxa to the CMCs because the taxa map to the existing classifications as one-to-one or two-to-one. It is relatively easy for someone with experience to identify the difference between services calibrating sources and measuring instruments. It is also relatively easy to identify the real and imaginary components in impedance services through interpretation of the quantity or units. Some CMCs apply to both sources and measuring instruments and therefore require two taxa for each CMC.

Applying taxa to AC-power services turned out more difficult because the individual services remain quite generic and the distinction between measured quantities only comes at the "quantity" level. Individual NMIs and DIs enter the quantity field values and therefore use many textual variations for the same quantity. For example, individual service 7.1.1, "Single phase power and energy at frequencies below or equal to 400 Hz", has 35 quantity entries as shown in Table 10. Many of these quantities only appear once, which makes searching difficult for both humans and machines. It would seem relatively simple to control these entries or to define more individual services to distinguish the measurands.

A service for DC Energy appears here. Though it clearly does not belong in "AC Power and Energy", we found no clear place where it would fit in the existing classification.

Table 10. Quantities in classification 7.1.1, "Single Phase Power" (taxon parameters not shown).

Quantity	Number of Entries
AC energy: single phase (frequency <= 400 Hz)	5
AC power and energy: single phase	7
AC power and energy: single phase (f <= 400 Hz), active power	10
AC power and energy: single phase (f <= 400 Hz), apparent power	3
AC power and energy: single phase (f <= 400 Hz), energy	1
AC power and energy: single phase (f <= 400 Hz), reactive power	4
AC power and energy: single phase (f<=400 Hz), active power	1
AC power and energy: single phase (frequencies below or equal to 400 Hz), active energy	1
AC power and energy: single phase (frequencies below or equal to 400 Hz), active power	3
AC power and energy: single phase (frequencies below or equal to 400 Hz), reactive energy	1
AC power and energy: single phase (frequencies below or equal to 400 Hz), reactive power	1
AC power and energy: single phase (frequency <= 400 Hz)	10
AC power and energy: single phase (frequency <= 400 Hz), active energy	18
AC power and energy: single phase (frequency <= 400 Hz), active power	31
AC power and energy: single phase (frequency <= 400 Hz), apparent energy	3
AC power and energy: single phase (frequency <= 400 Hz), apparent power	12
AC power and energy: single phase (frequency <= 400 Hz), reactive energy	10
AC power and energy: single phase (frequency <= 400 Hz), reactive power	18
AC power and energy: single phase (frequency >= 400 Hz), active energy	1
AC power and energy: single phase (frequency below or equal to 400 Hz), active power	1

Quantity	Number of Entries
AC power and energy: single phase (frequency below or equal to 400 Hz), apparent power	1
AC power and energy: single phase at frequencies below 400 Hz	2
AC power and energy: single phase, active energy	2
AC power and energy: single phase, active power	3
AC power and energy: single phase, apparent power	1
AC power and energy: single phase, distorted current	1
AC power and energy: single phase, power	2
AC power and energy: single phase, reactive power	2
AC power and energy: three phase, power loss	1
AC power: single phase (frequency <= 400 Hz)	6
DC energy	1
Power (sinusoidal)	2
Power and energy single phase. Power at frequencies <= 400 Hz	3
Power loss (in-phase)	3
Power loss (quadrature)	3
AC energy: single phase (frequency <= 400 Hz)	5

9. Summary

The review of the KCDB "Classification of Services in Electricity and Magnetism" has provided a valuable test of the MII taxonomy. This project will likely result in updates to the draft taxonomy specification document under development via the GitHub repository [5], such as clarifying the guidance and strategy for using tokens as opposed to parameters to distinguish similar measurands. The KCDB classification scheme provides a definitive list of the measurement services provided by NMIs and DIs and mapping this to the MII taxonomy provides a confidence check on the completeness of both classification systems. We have proposed updates to the MII taxonomy and will provide similar comments to the CCEM for their consideration.

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