Inaccuracy calculations for determining lamp power in dimming systems

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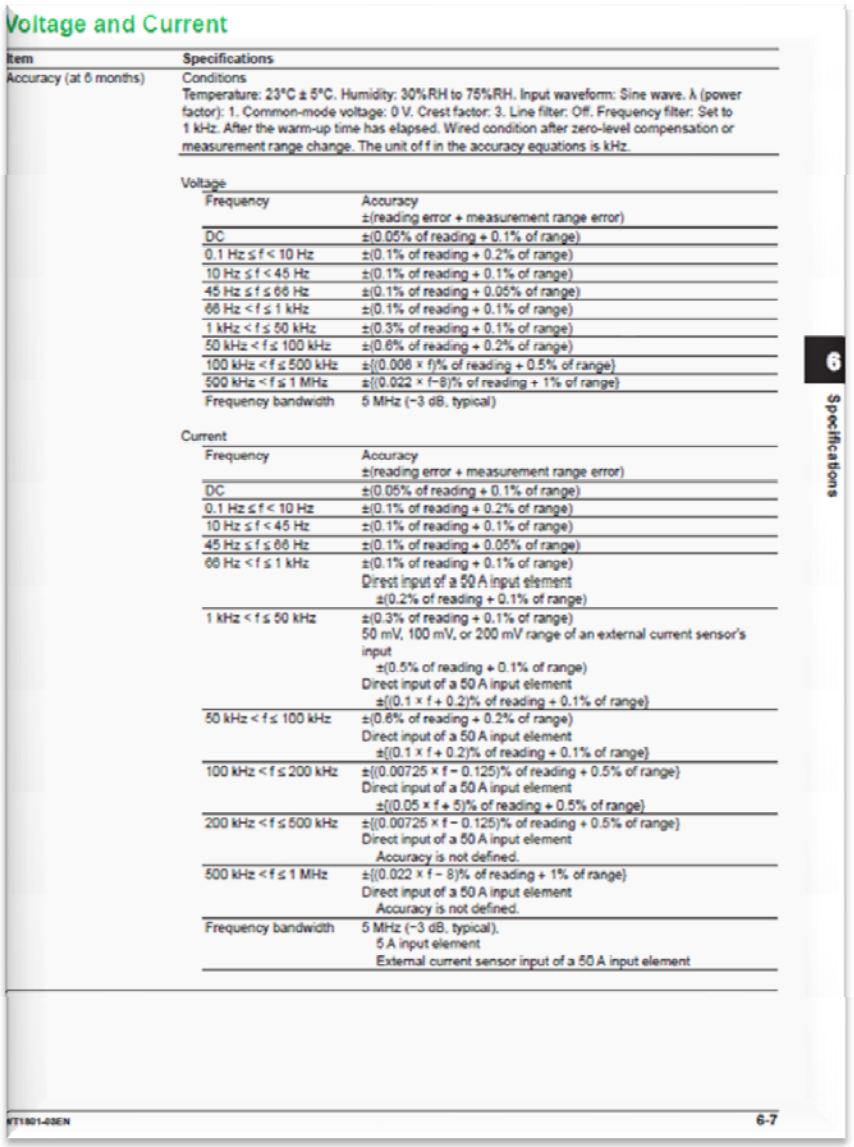
Sources of inaccuracy

- All testing systems are not perfect, some sources of inaccuracy are:
  - Calibrations uncertainty (See ANSI Guide for uncertainty measurements, named the “GUM).
  - ISO lab practices, repeatability and uncertainty (see ISO 17025)
  - Instrumentation tolerances and inaccuracy (see instrument manufacturer specifications)
  - Power supply stability and impedance (See ANSI C82.11)
  - Instruments and equipment under test means of interconnection
  - Lamp, ballast and other equipment variability
  - Environmental conditions (humidity, temperature, and other)

Instrument specification example

An accuracy analysis considering the manufacturer specifications for the instrumentation used for the measurements (Yokogawa WT 1800 Power Analyzer) and means of interconnection follows:



Voltage and Current

Item	Specifications
Accuracy (at 6 months)	Conditions Temperature: 23°C ± 5°C, Humidity: 30%RH to 75%RH, Input waveform: Sine wave, λ (power factor): 1, Common-mode voltage: 0 V, Crest factor: 3, Line filter: Off, Frequency filter: Set to 1 kHz, After the warm-up time has elapsed, Wired condition after zero-level compensation or measurement range change, The unit of f in the accuracy equations is kHz.

Voltage

Frequency	Accuracy ±(reading error + measurement range error)
DC	±(0.05% of reading + 0.1% of range)
0.1 Hz ≤ f < 10 Hz	±(0.1% of reading + 0.2% of range)
10 Hz ≤ f < 45 Hz	±(0.1% of reading + 0.1% of range)
45 Hz ≤ f ≤ 66 Hz	±(0.1% of reading + 0.05% of range)
66 Hz < f ≤ 1 kHz	±(0.1% of reading + 0.1% of range)
1 kHz < f ≤ 50 kHz	±(0.3% of reading + 0.1% of range)
50 kHz < f ≤ 100 kHz	±(0.6% of reading + 0.2% of range)
100 kHz < f ≤ 500 kHz	±{(0.006 × f)% of reading + 0.5% of range}
500 kHz < f ≤ 1 MHz	±{(0.022 × f−8)% of reading + 1% of range}
Frequency bandwidth	5 MHz (−3 dB, typical)

Current

Frequency	Accuracy ±(reading error + measurement range error)
DC	±(0.05% of reading + 0.1% of range)
0.1 Hz ≤ f < 10 Hz	±(0.1% of reading + 0.2% of range)
10 Hz ≤ f < 45 Hz	±(0.1% of reading + 0.1% of range)
45 Hz ≤ f ≤ 66 Hz	±(0.1% of reading + 0.05% of range)
66 Hz < f ≤ 1 kHz	±(0.1% of reading + 0.1% of range) Direct input of a 50 A input element ±(0.2% of reading + 0.1% of range)
1 kHz < f ≤ 50 kHz	±(0.3% of reading + 0.1% of range) 50 mV, 100 mV, or 200 mV range of an external current sensor's input ±(0.5% of reading + 0.1% of range) Direct input of a 50 A input element ±{(0.1 × f + 0.2)% of reading + 0.1% of range}
50 kHz < f ≤ 100 kHz	±(0.6% of reading + 0.2% of range) Direct input of a 50 A input element ±{(0.1 × f + 0.2)% of reading + 0.1% of range}
100 kHz < f ≤ 200 kHz	±{(0.00725 × f − 0.125)% of reading + 0.5% of range} Direct input of a 50 A input element ±{(0.05 × f + 5)% of reading + 0.5% of range}
200 kHz < f ≤ 500 kHz	±{(0.00725 × f − 0.125)% of reading + 0.5% of range} Direct input of a 50 A input element Accuracy is not defined.
500 kHz < f ≤ 1 MHz	±{(0.022 × f − 8)% of reading + 1% of range} Direct input of a 50 A input element Accuracy is not defined.
Frequency bandwidth	5 MHz (−3 dB, typical), 5 A input element External current sensor input of a 50 A input element

6 Specifications

What this means

Consider the measurements from a calibration circuit consisting of a power supply and a resistor. Different voltages, with different frequencies are applied to a variable resistor.

The instrument ranges are selected concurrently to the testing needs as described in the table.

The 50 kHz thru 100 kHz ranges highlighted correspond to typical dimming ballast measurements from 100% to fully dimmed light output respectively. The proposed arc power levels of 80% & 50% are also highlighted for reference.

The following slides represent measurements made directly with the power analyzer.

Arc		RANGES		
Pwr	Freq	V range	I range	P range
%	KHz	Vrms	Arms	W
	10	150	0.25	37.5
	20	150	0.25	37.5
	30	150	0.25	37.5
	40	150	0.25	37.5
100	50	300	0.1	30
80	60	300	0.1	30
60	70	300	0.1	30
50	75	300	0.1	30
40	80	300	0.1	30
20	90	300	0.1	30
0	100	300	0.1	30

What this means

	READINGS		
PF	Lamp V	Lamp I	Lamp P
	Vrms	A rms	W
1	135	0.16	21.6
1	130	0.12	15.6
1	140	0.1	14
1	145	0.08	11.6
0.999	150	0.06	8.991
0.99	160	0.04	6.336
0.9	170	0.03	4.59
0.85	175	0.025	3.71875
0.8	180	0.02	2.88
0.7	190	0.015	1.995
0.6	175	0.01	1.05

The voltages and current readings are also typical of dimming ballast measurements. Note the displacement effect from the parasitic capacitances above 50 kHz.

What this means

The voltage inaccuracy calculations per the instrument manufacturer specifications.

The high voltage, high frequency measurements at the proposed dimming levels yield an instrument inaccuracy of about 1%

VOLTAGE		
reading Error	range Error	Meas. Error
Vrms	Vrms	Vrms
0.405	0.15	0.555
0.39	0.15	0.54
0.42	0.15	0.57
0.435	0.15	0.585
0.9	0.6	1.5
0.96	0.6	1.56
1.02	0.6	1.62
1.05	0.6	1.65
1.08	0.6	1.68
1.14	0.6	1.74
1.05	0.6	1.65

What this means

CURRENT		
Range Error	Reading Error	Meas. Error
Arms	Arms	Arms
0.00025	0.00048	0.00073
0.00025	0.00036	0.00061
0.00025	0.0003	0.00055
0.00025	0.00024	0.00049
0.0002	0.00036	0.00056
0.0002	0.00024	0.00044
0.0002	0.00018	0.00038
0.0002	0.00015	0.00035
0.0002	0.00012	0.00032
0.0002	0.00009	0.00029
0.0002	0.00006	0.00026

The current inaccuracy calculations per the instrument manufacturer specifications.

The low current, high frequency measurements at the proposed dimming levels yield an instrument inaccuracy of about 0.03%

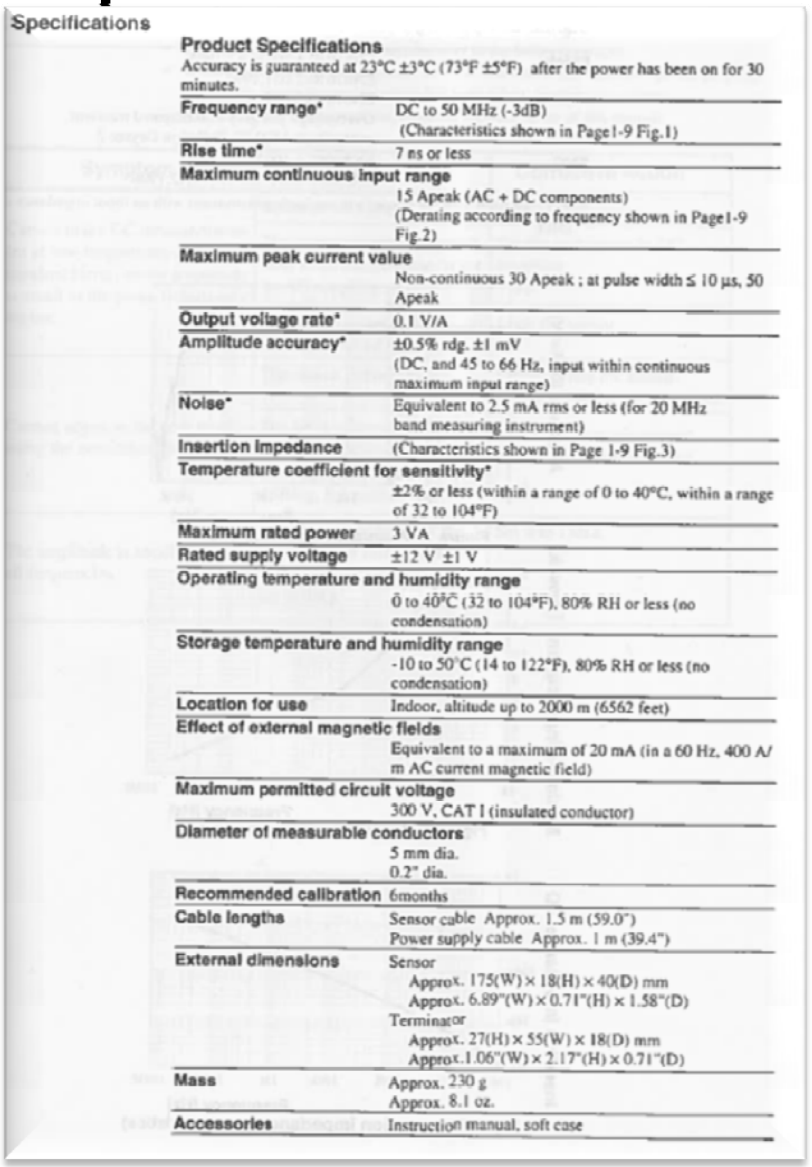
What this means

The power inaccuracy calculations per the instrument manufacturer specifications.

The high voltage, low current, high frequency measurements at the proposed dimming levels yield an instrument inaccuracy of about 3% from the measurement inaccuracy, and about 17% from the displacement inaccuracy at 50% dimming level.

POWER			
reading Error	range Error	Meas. Error	Displ Error
W	W	W	W
0.108	0.075	0.183	0
0.078	0.075	0.153	0
0.07	0.075	0.145	0
0.058	0.075	0.133	0
0.062937	0.09	0.152937	-0.009
0.044352	0.09	0.134352	-0.064
0.03213	0.09	0.12213	-0.51
0.02603125	0.09	0.11603125	-0.65625
0.02016	0.09	0.11016	-0.72
0.013965	0.09	0.103965	-0.855
0.00735	0.09	0.09735	-0.7

Probe specification example



Specifications

Product Specifications

Accuracy is guaranteed at 23°C ±3°C (73°F ±5°F) after the power has been on for 30 minutes.

Frequency range*	DC to 50 MHz (-3dB) (Characteristics shown in Page1-9 Fig.1)
Rise time*	7 ns or less
Maximum continuous input range	15 Apeak (AC + DC components) (Derating according to frequency shown in Page1-9 Fig.2)
Maximum peak current value	Non-continuous 30 Apeak ; at pulse width ≤ 10 µs, 50 Apeak
Output voltage rate*	0.1 V/A
Amplitude accuracy*	±0.5% rdg. ±1 mV (DC, and 45 to 66 Hz, input within continuous maximum input range)
Noise*	Equivalent to 2.5 mA rms or less (for 20 MHz band measuring instrument)
Insertion impedance	(Characteristics shown in Page 1-9 Fig.3)
Temperature coefficient for sensitivity*	±2% or less (within a range of 0 to 40°C, within a range of 32 to 104°F)
Maximum rated power	3 VA
Rated supply voltage	±12 V ±1 V
Operating temperature and humidity range	0 to 40°C (32 to 104°F), 80% RH or less (no condensation)
Storage temperature and humidity range	-10 to 50°C (14 to 122°F), 80% RH or less (no condensation)
Location for use	Indoor, altitude up to 2000 m (6562 feet)
Effect of external magnetic fields	Equivalent to a maximum of 20 mA (in a 60 Hz, 400 A/m AC current magnetic field)
Maximum permitted circuit voltage	300 V, CAT I (insulated conductor)
Diameter of measurable conductors	5 mm dia. 0.2" dia.
Recommended calibration	6months
Cable lengths	Sensor cable Approx. 1.5 m (59.0") Power supply cable Approx. 1 m (39.4")
External dimensions	Sensor Approx. 175(W) × 18(H) × 40(D) mm Approx. 6.89"(W) × 0.71"(H) × 1.58"(D) Terminator Approx. 27(H) × 55(W) × 18(D) mm Approx.1.06"(W) × 2.17"(H) × 0.71"(D)
Mass	Approx. 230 g Approx. 8.1 oz.
Accessories	Instruction manual, soft case

What this means

CURRENT PROBE 700937				
Probe	reading Error	range Error	Noise Error	Meas. Error
mA	mA	mA	mA	mA
0.016	0.00008	10	2.5	12.50008
0.012	0.00006	10	2.5	12.50006
0.01	0.00005	10	2.5	12.50005
0.008	0.00004	10	2.5	12.50004
0.006	0.00003	10	2.5	12.50003
0.004	0.00002	10	2.5	12.50002
0.003	0.000015	10	2.5	12.500015
0.0025	0.0000125	10	2.5	12.5000125
0.002	0.00001	10	2.5	12.50001
0.0015	0.0000075	10	2.5	12.5000075
0.001	0.000005	10	2.5	12.500005

The current inaccuracy calculations are per the instrument manufacturer specifications.

The low current, high frequency measurements yield an instrument inaccuracy of about 100%

Note: The reference numbers shown are for a Yokogawa 700937 current probe, which is similar to the Fluke i50s current probe, for which this information was not available at the time of this presentation.

Inaccuracy due to calculations - Subtracting input arc power from the input power

Consider a input power measurement of 100W and a arc power measurement of 80W

Assume that the total inaccuracy is 5%

If any power reading in the +/- 5% tolerance has the same probability to be captured in the measurement process, then the input power subtracted by the arc power may be any number from 11 to 29 or about 40% range

	-5%		5%
	Min		Max
Input Power	95	100	105
Arc Power	76	80	84
Input - Arc power	29	20	11

Summary

- Dimming systems may be measured with higher accuracy close to their full power

- A metric based on BLE will yield higher accuracy, and repeatability lab to lab