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Are we there yet? Using NEMA SSL-7A to improve LED dimming

April 25, 2013 10:30am-12:00pm

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IES IALD AMC

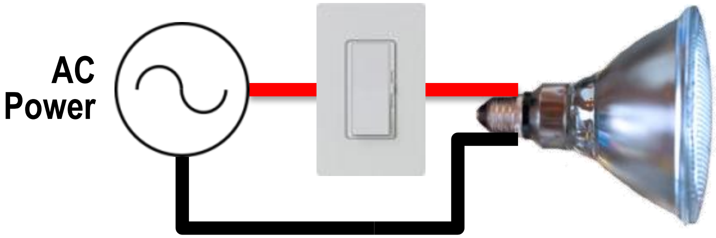
Agenda

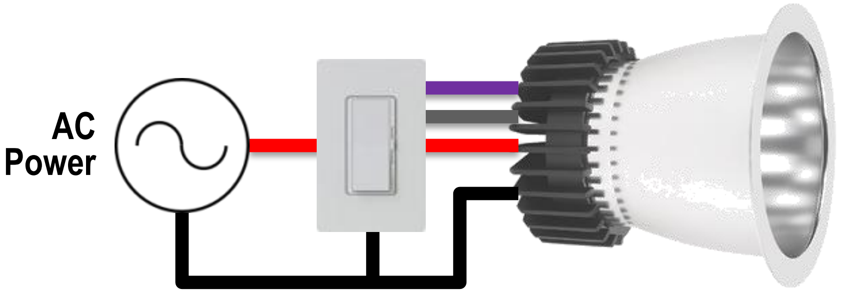
- Where are we today?
  - Dimming background
  - User problems
  - Technical challenges
- What will SSL-7A deliver?
  - History
  - Goals, Approach
  - Summary of tests
  - Status
- What comes next?
  - Market adoption
  - Specification agents
  - Other paths to improved dimming

WHERE ARE WE AT TODAY?

Two approaches to dimming

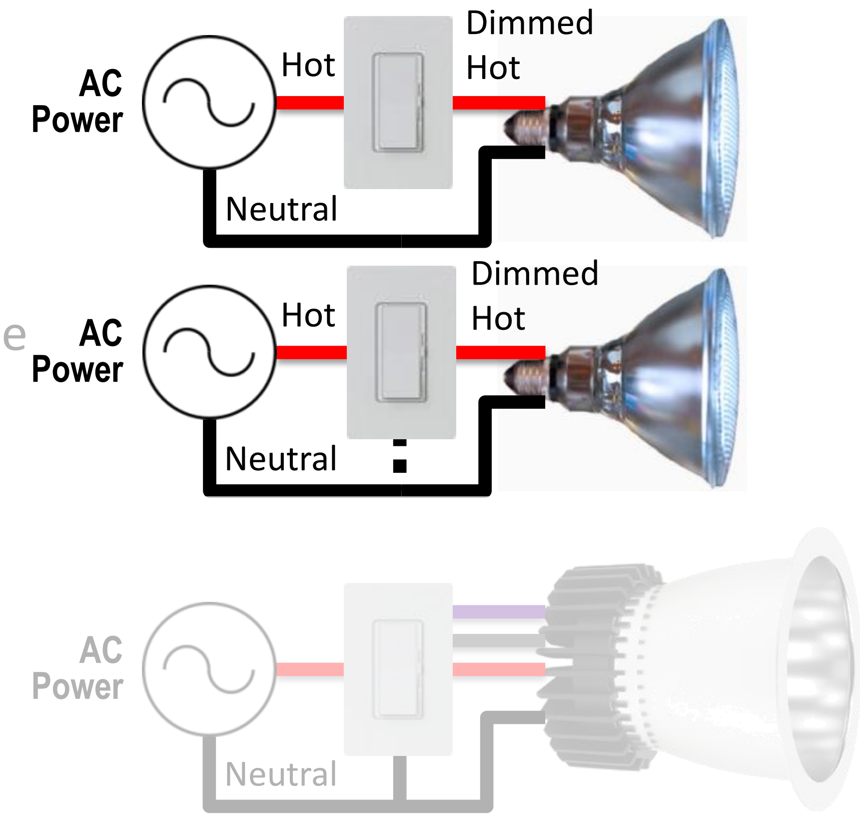
- Coincident AC power and control signal
  - Reduce amplitude of AC sine wave
  - Phase-cut AC sine wave
- Separate AC power and control signal
  - Wiring requirements
  - Degree of device-level control
  - One or two-way communication





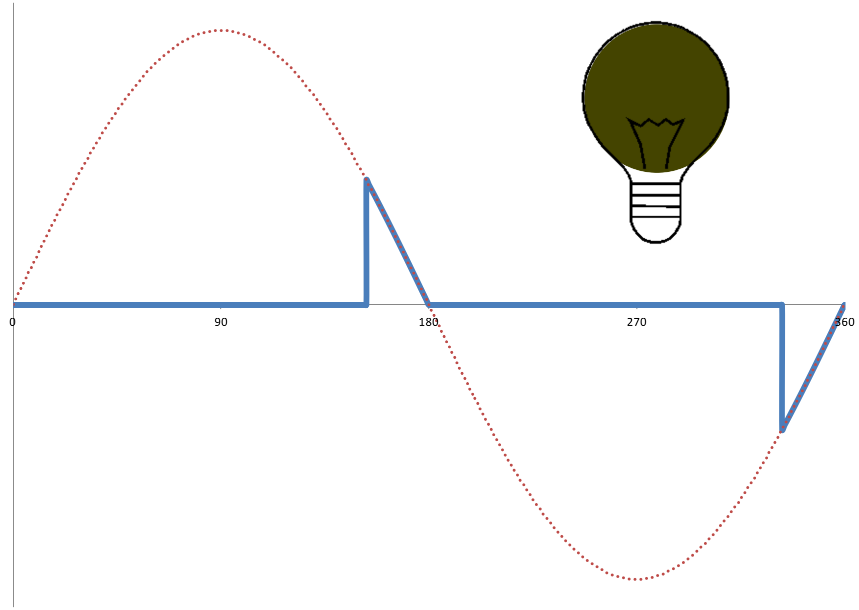
Common dimming technologies

- Coincident AC power and control signal
  - Sine wave (long obsolete)
  - Phase-Cut
    - Forward phase or reverse phase
    - 2-Wire or 3-Wire
- Separate AC power and control signal
  - Fluorescent 3-Wire
  - 0-10V
  - DALI
  - DMX512

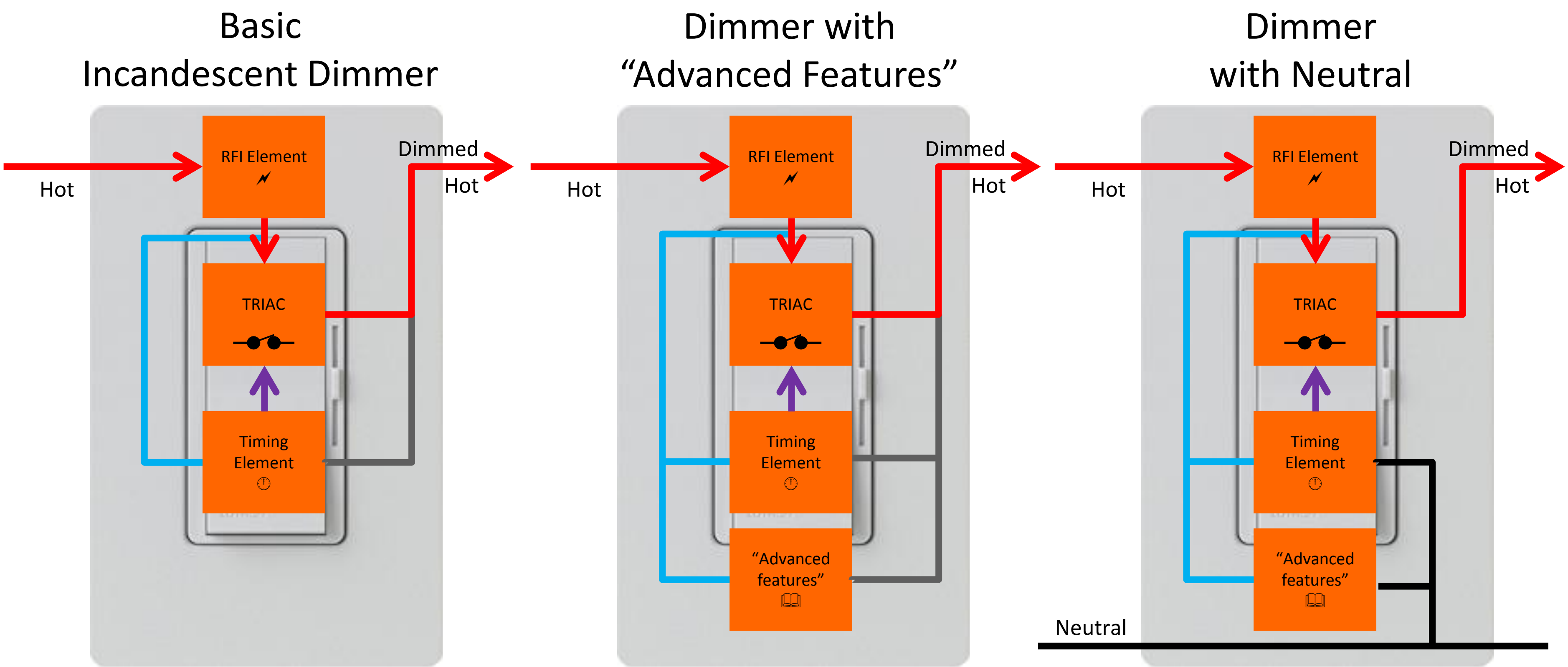


Forward phase-cut dimming

- Most common dimming method
- Largest (by far) installed base
- Designed for resistive (incandescent, halogen) or magnetic low-voltage (MLV) loads
- Typically a TRIAC switching device, but may use Field-Effect Transistors (FETs)
- Low cost, simple designs

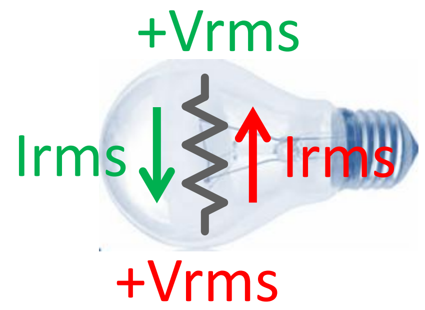


Forward phase-cut dimmer examples



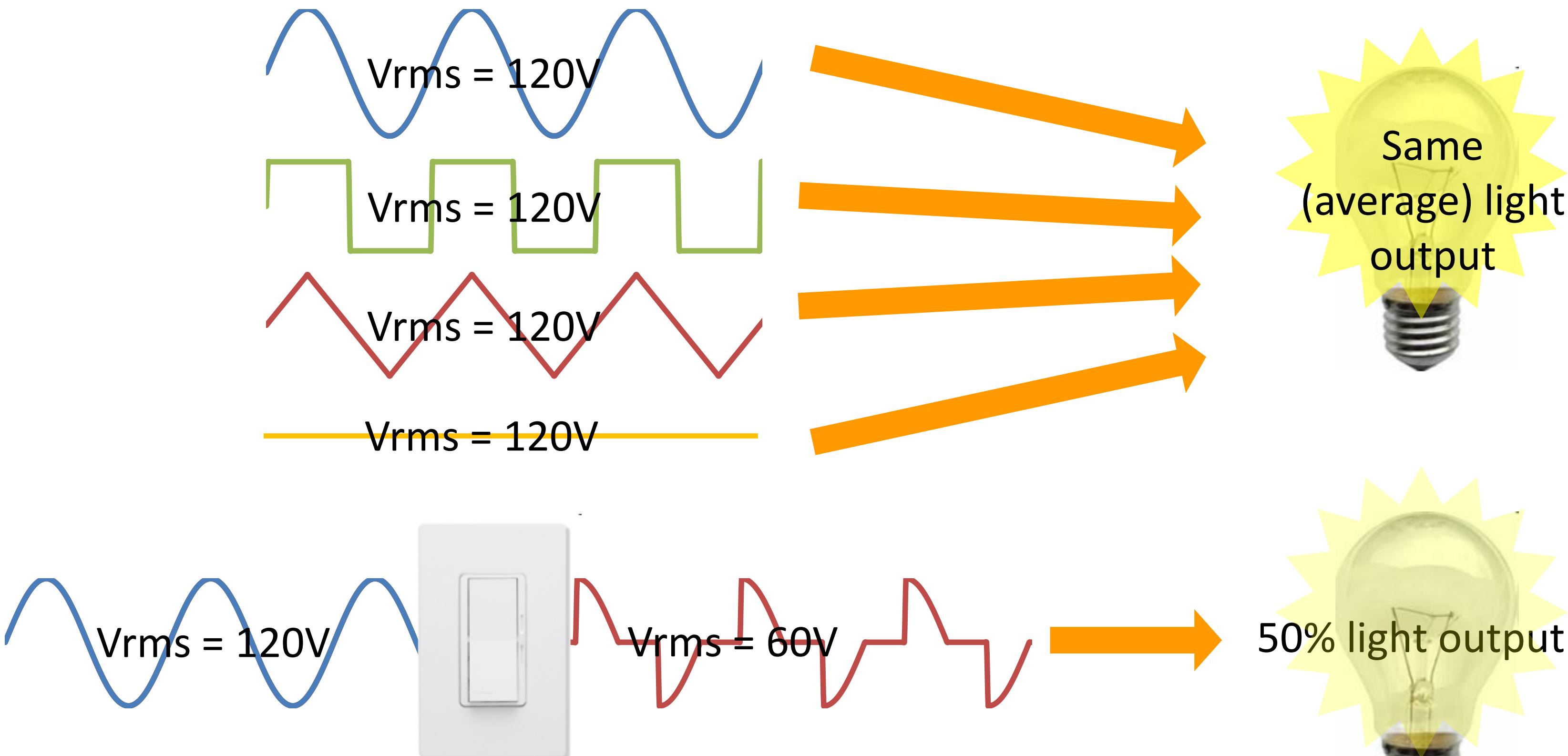
Incandescent sources are simple loads

- Incandescent sources electrically behave like resistors (unlike pretty much every other lighting technology)
- Incandescent sources effectively only care about Vrms
  - Constant R at steady state
  - R is a function of filament temperature
- Incandescent sources are bidirectional
  - Applying ±Vrms results in the same Irms
  - Irms = (1/R) x |Vrms|



- Important caveat: thermal persistence
  - If I(t>0)→0 in resistor, no power consumption
  - If I(t>0)→0 in incandescent source, light output continues as long as filament is hot (10s to 100s of milliseconds)

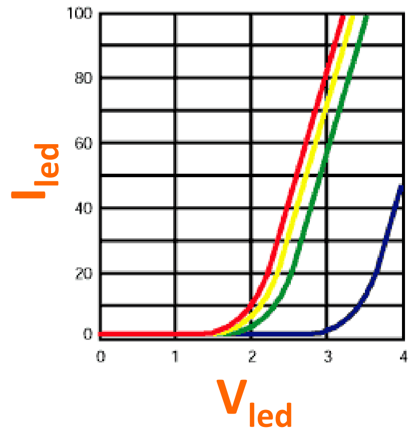
Controlling incandescent light output

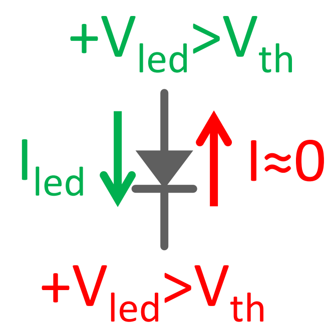


High performance
Inexpensive
Vrms adjuster
Determines dimming performance!

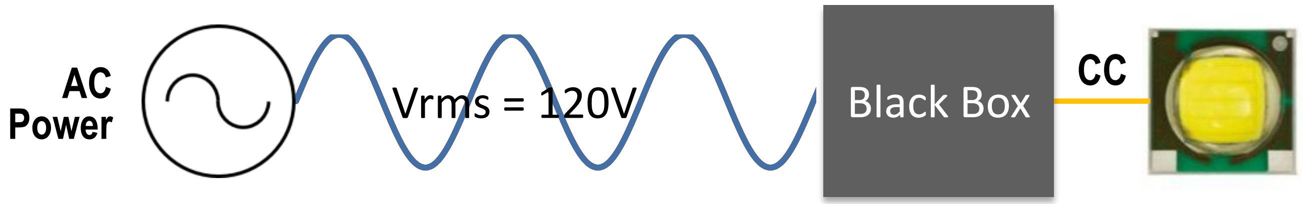
LEDs are complex loads

- LEDs are non-linear devices
  - Different current-voltage relationships in different regions of operation
  - Small change in voltage can equal large change in current
  - (Average) current must (typically) be controlled
- LEDs are unidirectional
  - (Forward) current only flows in one direction
  - Light output only produced for forward current
- Important caveat: fast response
  - If I(t>0)→0 in diode, no power consumption
  - If I(t>0)→0 in LED, no light output
  - Careful attention to time where I≈0



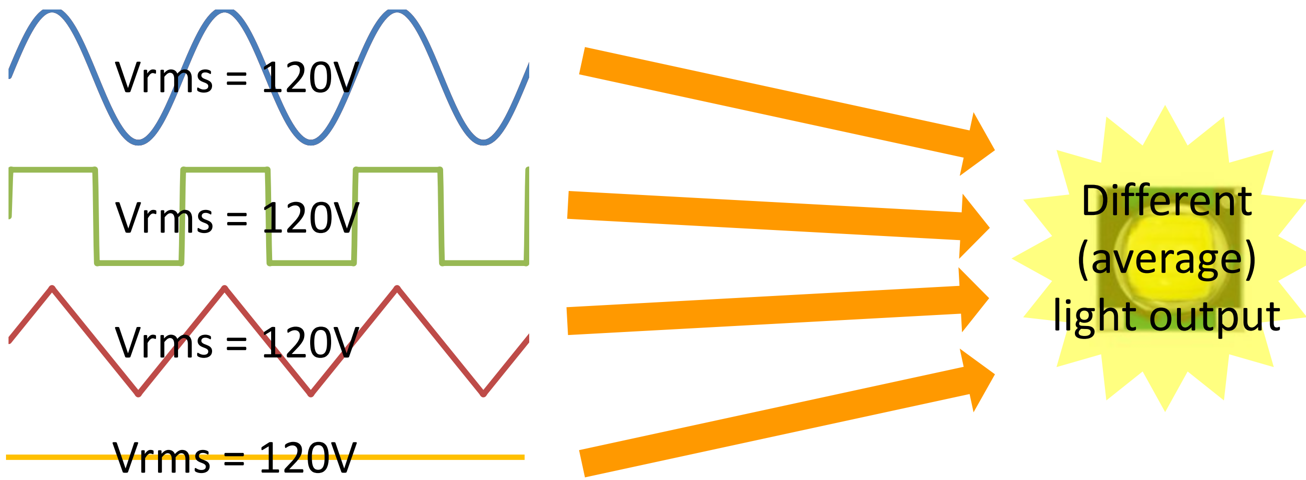


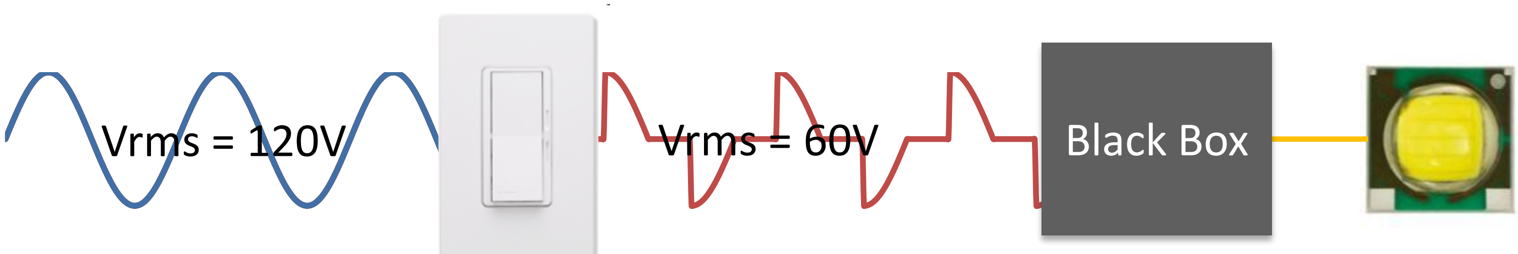
LEDs (typically) need a Driver



- Non-linear I_{led} vs. V_{led} relationship, together with manufacturing variation in V_f, mean LEDs are best regulated by controlling their current
- Typically, LEDs are operated (or "Driven") such that their (average) current is constant (Constant Current)
- Typically, power electronics components are used to create circuits which convert AC voltage into regulated LED constant (average) current

Controlling LED light output





High performance
Inexpensive
Vrms adjuster

Controls current to LED
Determines dimming performance!

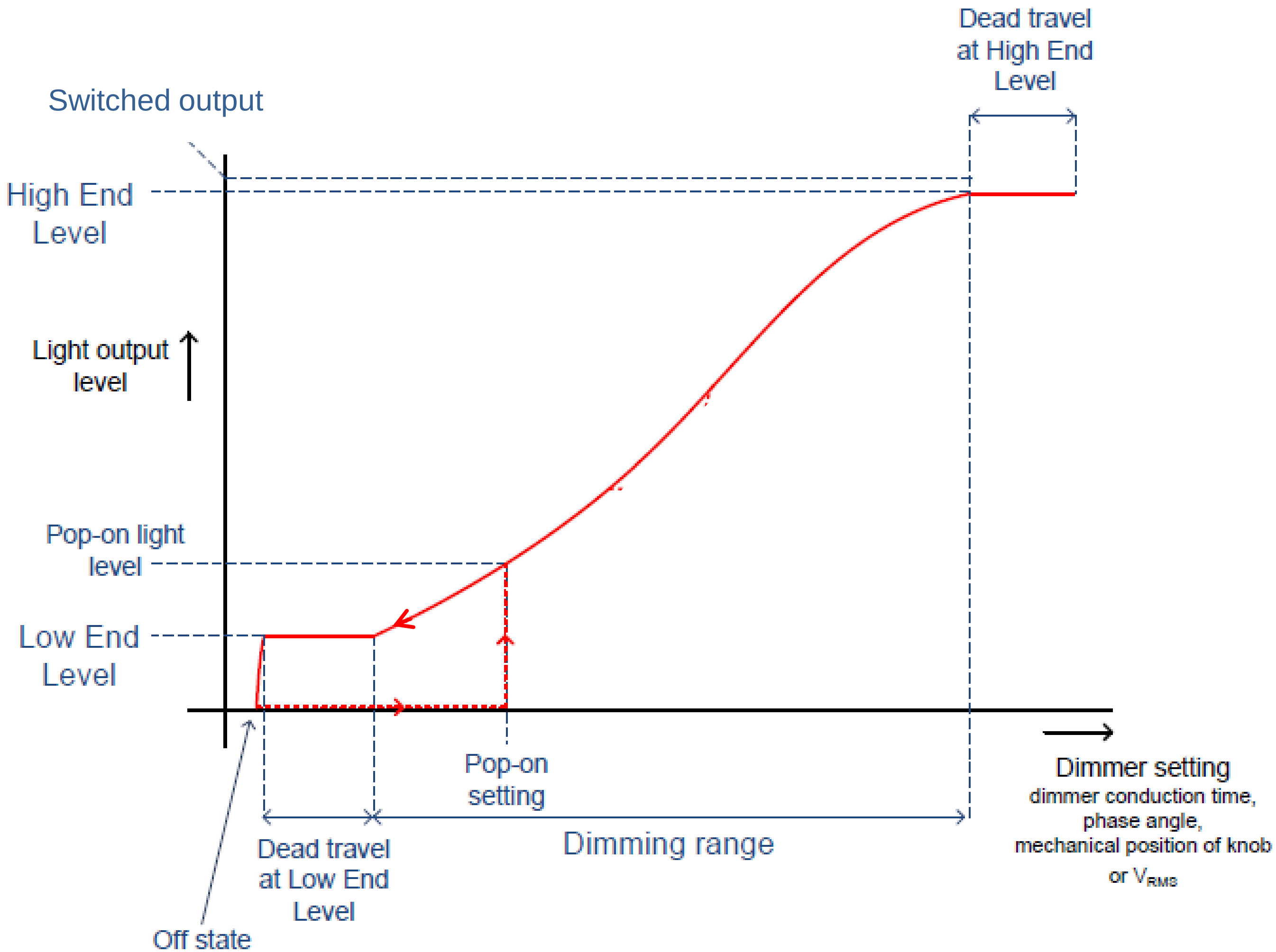
Shouldn't LED dimming be easy?

- Variation in LED system architecture, driver design matter
  - LED lighting is still very much an emerging technology
  - Significant market variation today, likely for the foreseeable future
  - Lagging focus on dimmability (dimmable or designed to dim?)
- Variation in dimmer architecture, circuit design matter
  - Existing infrastructure was predominantly designed to dim incandescent sources
  - Cost, expectation barrier to replacing dimming controls
- No standards for ensuring LED dimming compatibility or predictable performance
  - Standard measurement procedures or metrics for dimming compatibility or dimming performance have never existed
  - Some existing standards are not as "standard" as one would expect or desire

Phase-cut dimming user problems

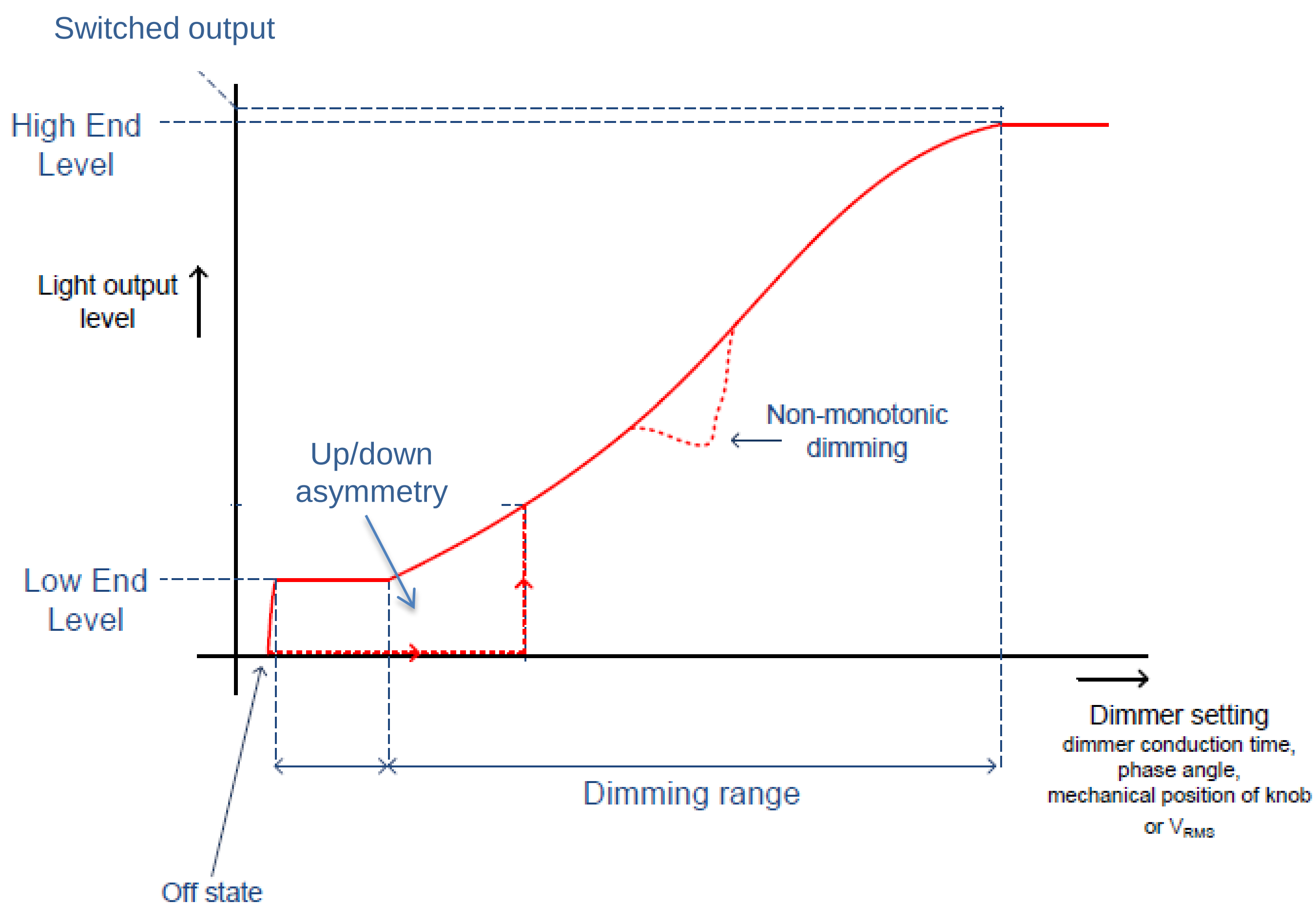
- ❑ Dimming range
- ❑ Dead travel
- ❑ Pop-on
- ❑ Drop-out
- ❑ Popcorn
- ❑ Ghosting
- ❑ Flashing/Strobing
- ❑ Induced Flicker
- ❑ Audible noise
- ❑ Dimming smoothness
- ❑ Dimming monotonicity
- ❑ Dimming up/down symmetry
- ❑ Dimmer loading
- ❑ LED load - dimmer inoperability
- ❑ Premature failure of dimmer and/or LED load

Dimming range, dead travel, pop-on



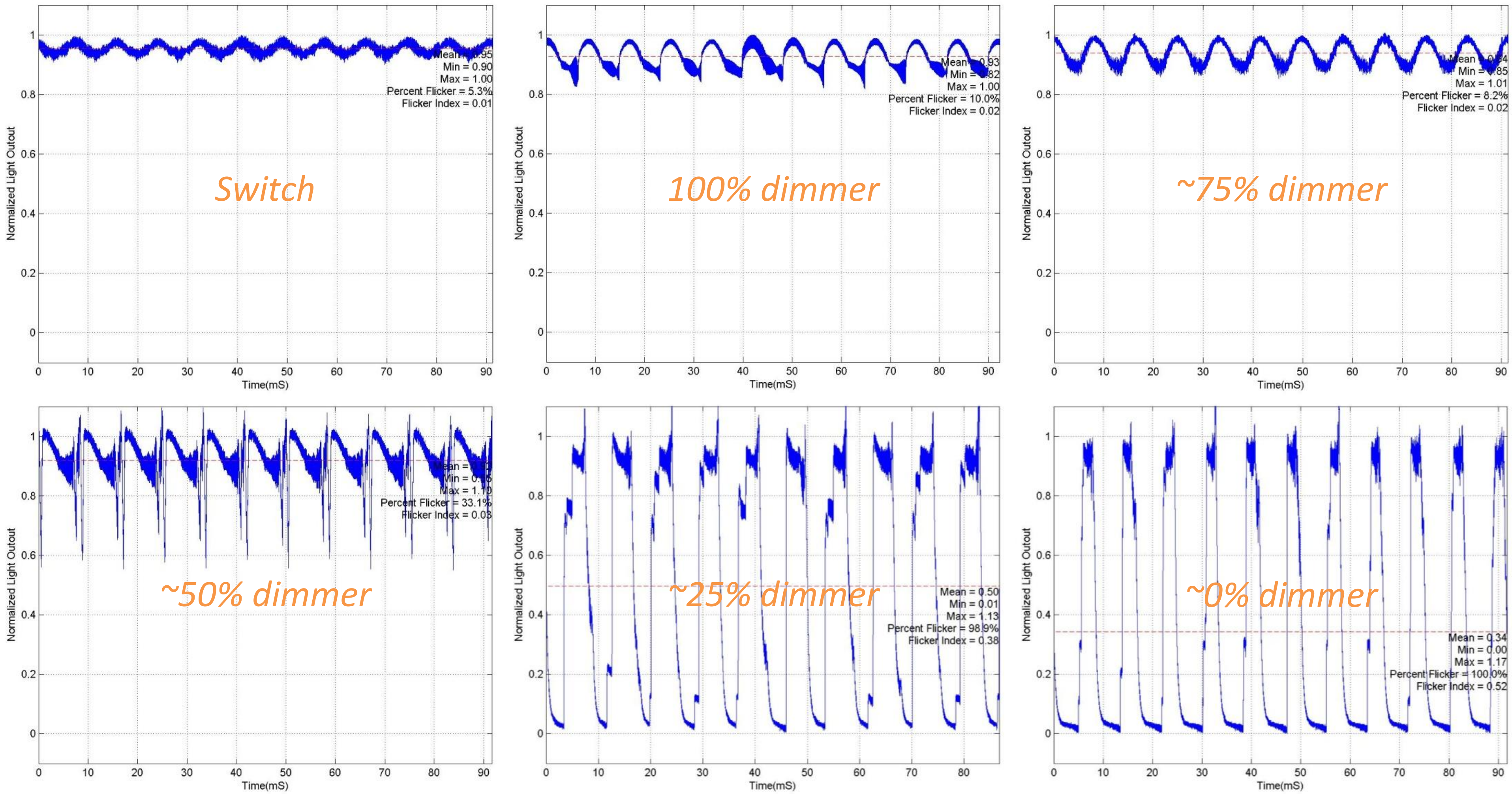
Source: Modified from NEMA SSL-6

Dimming smoothness, monotonicity, up/down symmetry



Source: Modified from NEMA SSL-6

Induced flicker



Dimmer loading

- Minimum load varies by dimmer
- Maximum load varies by dimmer and LED load

Dimmer	Light Source	Possible loading
600W incandescent	60W incandescent 	1-10
600W incandescent	12W LED 	~~1-50?~~ 3-10*
600W ELV	50W halogen 	1-12
600W ELV	10W LED 	~~1-60?~~ 2-30*

*Example; varies by LED load

Other problems

- Drop-out
  - No light output at the bottom of the dimming range
  - The light source turns off when the switch is still on
- Popcorn
  - Different turn-on times for different light sources on a dimmed circuit
- Ghosting
  - The light source is at a low-level on state when it should be off
- Flashing/Strobing
  - The light source is intermittently on when it should be off

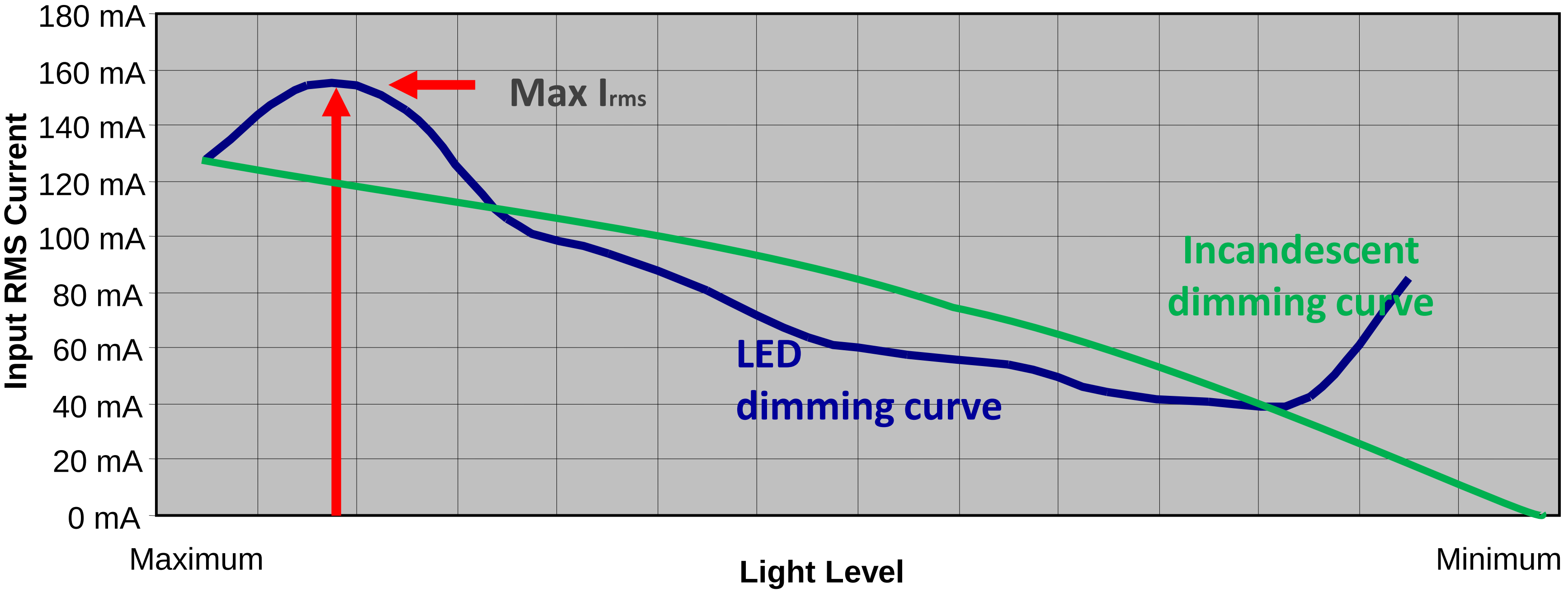
Not the desired effect

Phase-cut dimming technical challenges

- LED load RMS current
- LED load inrush current
- LED load repetitive peak current
- Repetitive ring-up voltage
- Dimmer switching element current requirements
- Dimmer timing element series impedance requirements
- Dimmer on-state and/or off-state operating current requirements

LED load RMS current

- RMS current of an LED load may not immediately decrease as it is dimmed; a 20%-50% increase is not uncommon

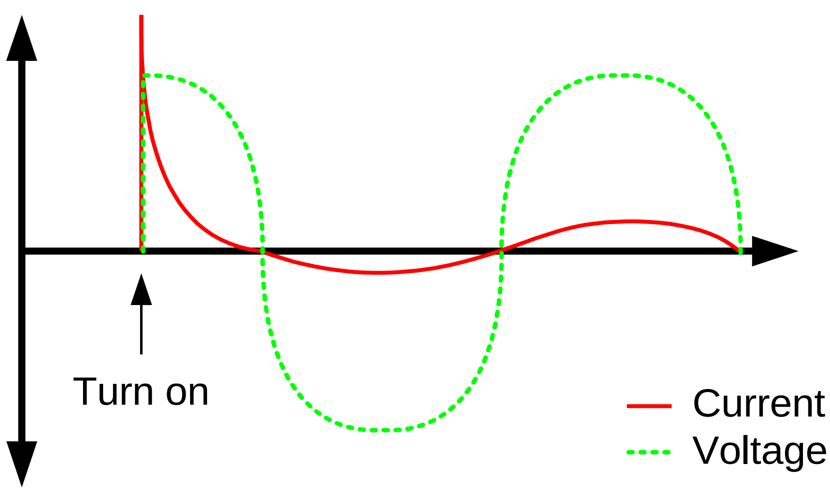


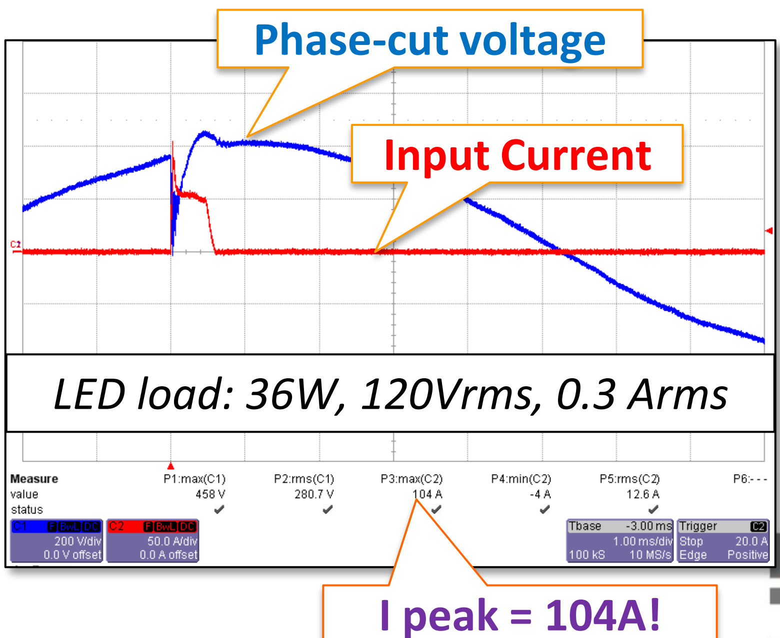
LED load RMS current

- Higher current in control can cause excessive (unexpected) heating of components in control or LED load
- Excessive heating can cause component stress and premature failure
- Increased power and energy consumption
  – If at any point during dimming Irms has gone up more than Vrms has gone down …
  – Then Pave = Irms x Vrms can go up!

LED load inrush current

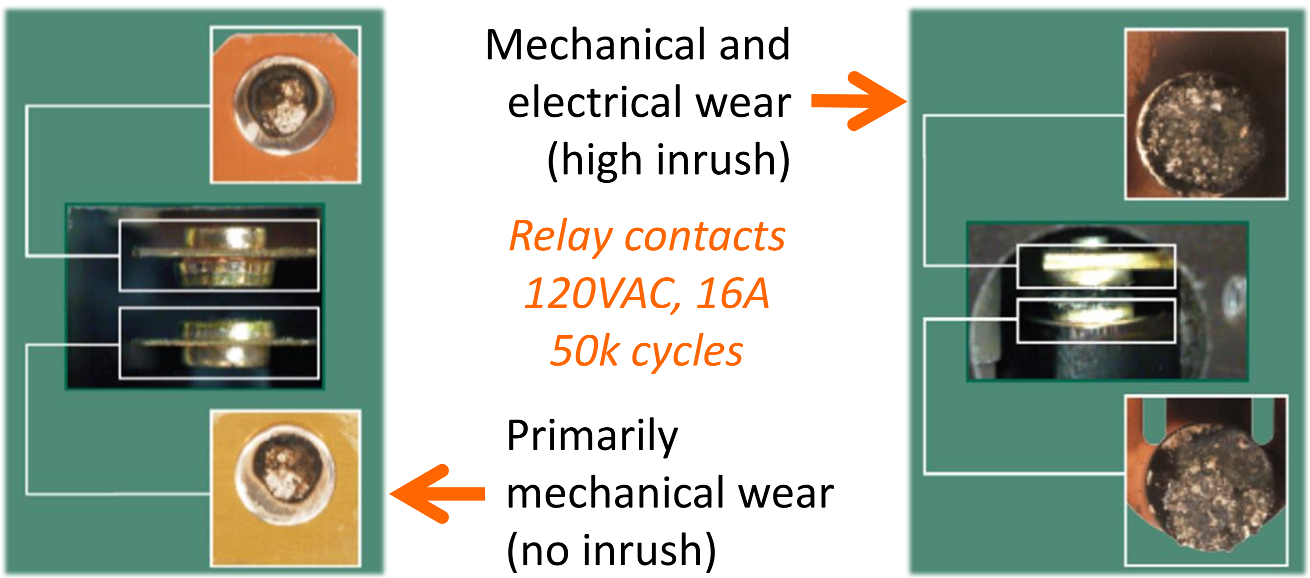
- Created by connection to power
- Occurs once per power-up





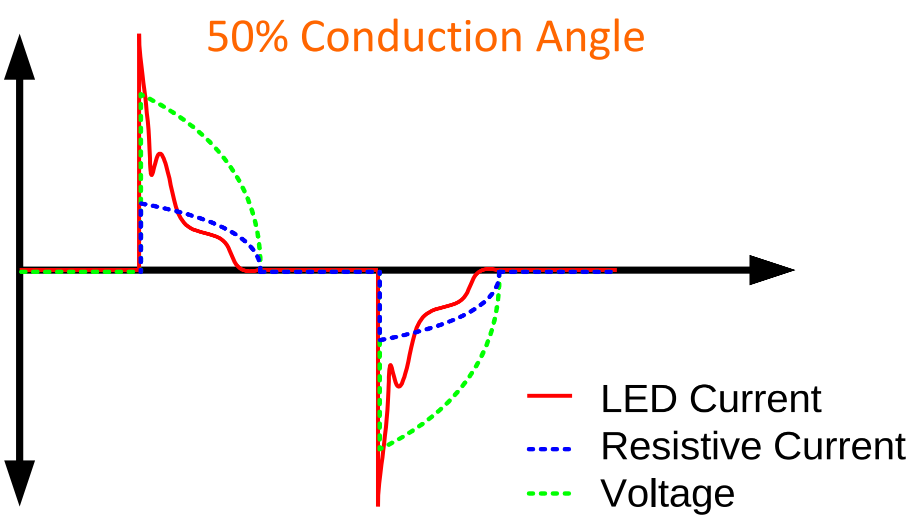
LED load inrush current

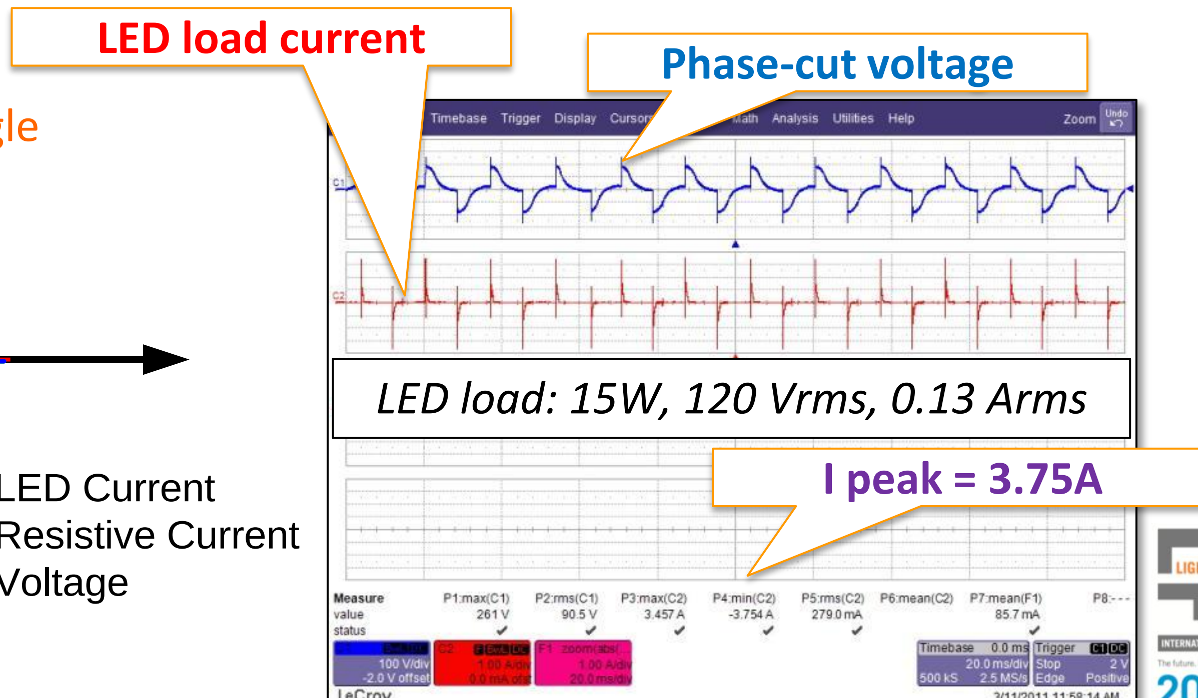
- Excessive wear on switch or relay contacts
- Premature failure (welding) of switch or relay
- Large chokes can be designed into dimmer to minimize inrush to dimmer, but may create issues of their own



LED load repetitive peak current

- Created by forward phase-cut, occurs every half-cycle
- Commonly 5-10x Irms; can be much higher



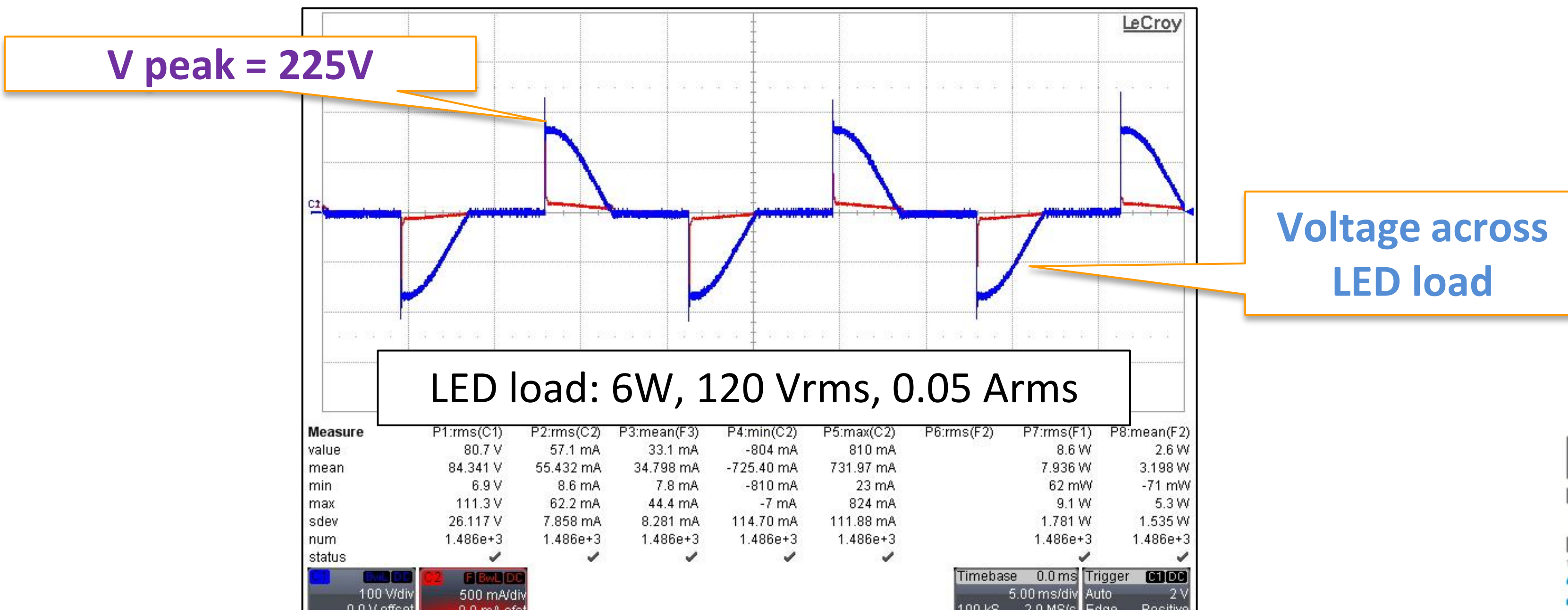


LED load repetitive peak current

- Varies significantly across LED products
- Often major factor determining maximum dimmer loading
- Major contributor to audible noise in light sources and controls
- Major contributor to RFI noise and interference with other electronics
- Major contributor to potentially reduced control lifetime

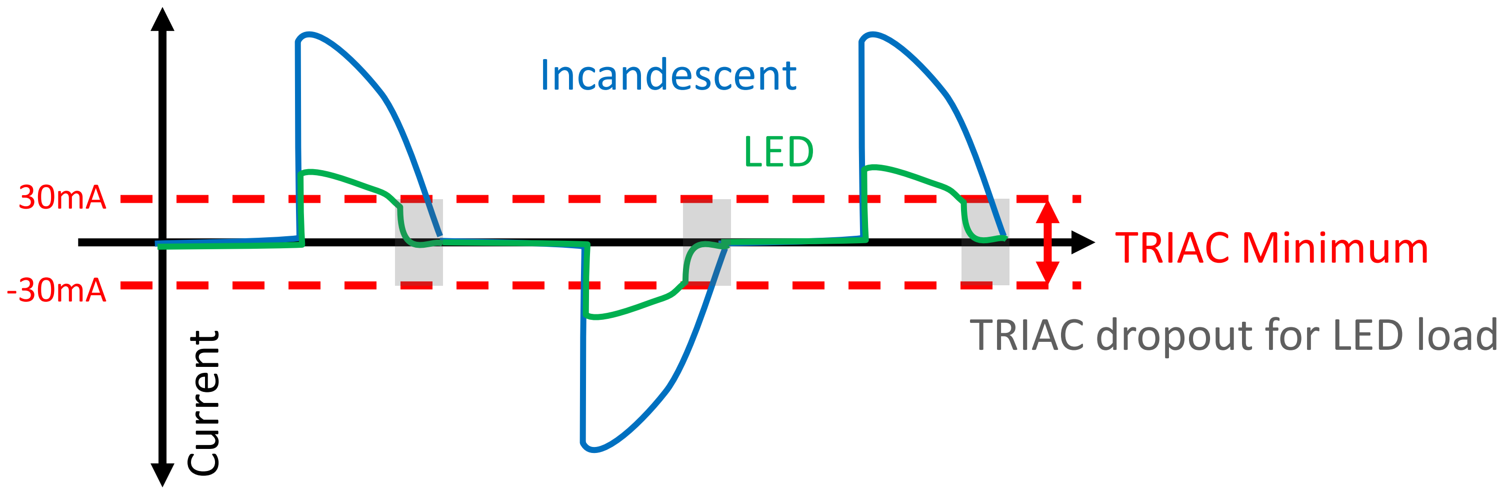
Repetitive ring-up voltage

- A very brief spike in voltage (above the instantaneous line voltage) caused by the discharge of energy-storage elements
- Can cause long-term damage to voltage-sensitive components in the dimmer or lamp
- Caused by *interaction* between dimmer and lamp



Measure	P1:rms(C1)	P2:rms(C2)	P3:mean(F3)	P4:min(C2)	P5:max(C2)	P6:rms(F2)	P7:rms(F1)	P8:mean(F2)
value	80.7 V	57.1 mA	33.1 mA	-804 mA	810 mA		8.6 W	2.6 W
mean	84.341 V	55.432 mA	34.798 mA	-725.40 mA	731.97 mA		7.936 W	3.198 W
min	6.9 V	8.6 mA	7.8 mA	-810 mA	23 mA		62 mW	-71 mW
max	111.3 V	62.2 mA	44.4 mA	-7 mA	824 mA		9.1 W	5.3 W
sdev	26.117 V	7.858 mA	8.281 mA	114.70 mA	111.88 mA		1.781 W	1.535 W
num	1.486e+3	1.486e+3	1.486e+3	1.486e+3	1.486e+3		1.486e+3	1.486e+3
status	✔	✔	✔	✔	✔		✔	✔

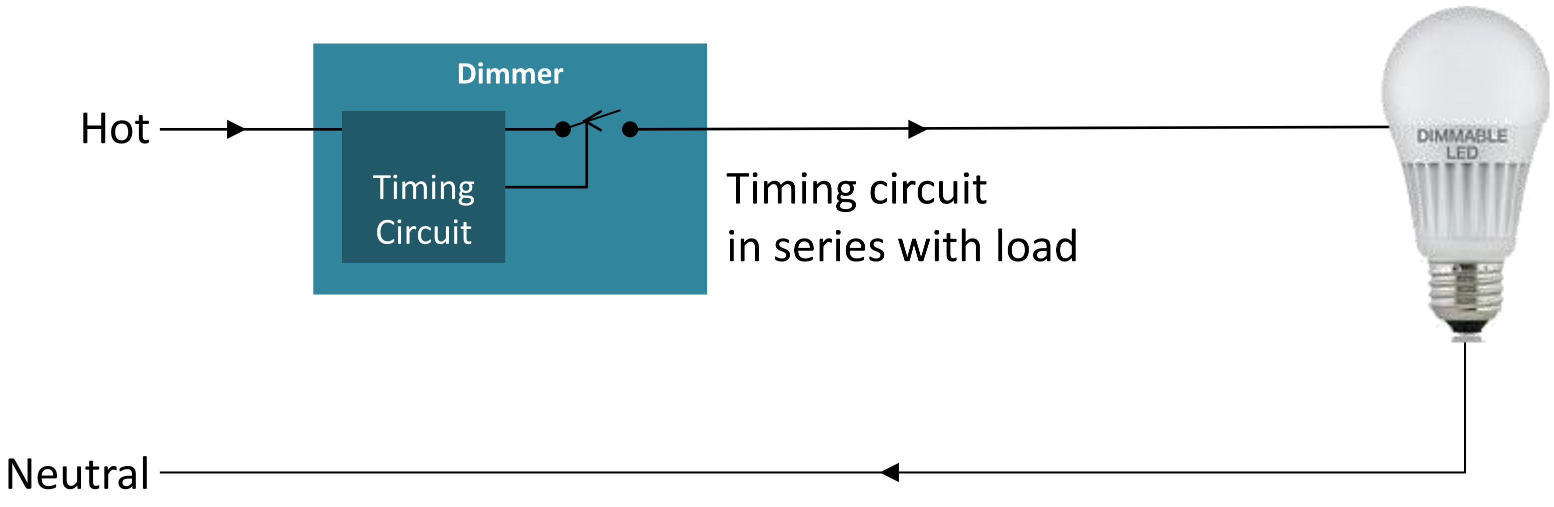
Dimmer switching element requirements



Symbol	Test Conditions	Quadrant		BTA10 / BTB10		Unit
				C	B	
I_{GT} (1)	$V_D = 12$ V $R_L = 33\ \Omega$	I - II - III IV	MAX.	25 50	50 100	mA
V_{GT}		ALL	MAX.	1.3		V
V_{GD}	$V_D = V_{DRM}$ $R_L = 3.3\ k\Omega$ $T_j = 125°C$	ALL	MIN.	0.2		V
I_H (2)	$I_T = 500$ mA		MAX.	25	50	mA

Dimmer timing element requirements

- The timing element for phase-cut dimmers without neutral are designed to operate through the load, and expect "resistive" load characteristics
- LED load input impedance characteristics are typically not resistive, and may change as it is dimmed.

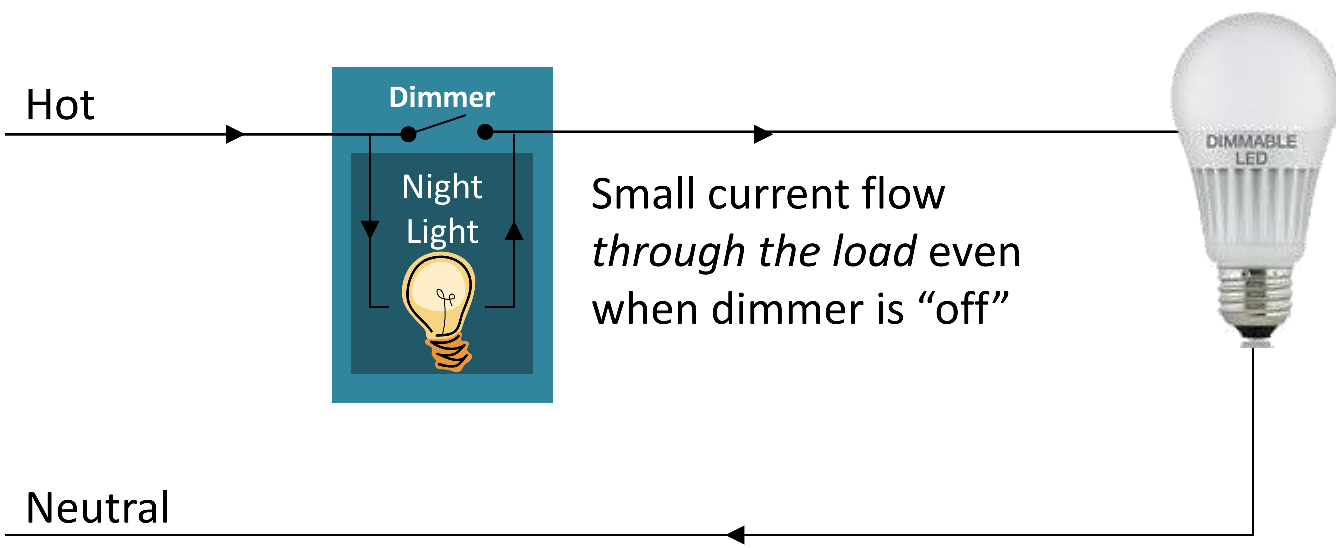


Dimmer timing element requirements

- Timing element problems cause the switching element to turn on or off at the wrong time, aperiodically (not at consistent intervals), or both
- Any change in the switching element behavior directly affects light output
  - Turning on or off at wrong time will raise or lower light level
  - Turning on or off aperiodically causes the light level to change from cycle to cycle, likely resulting in objectionable flicker

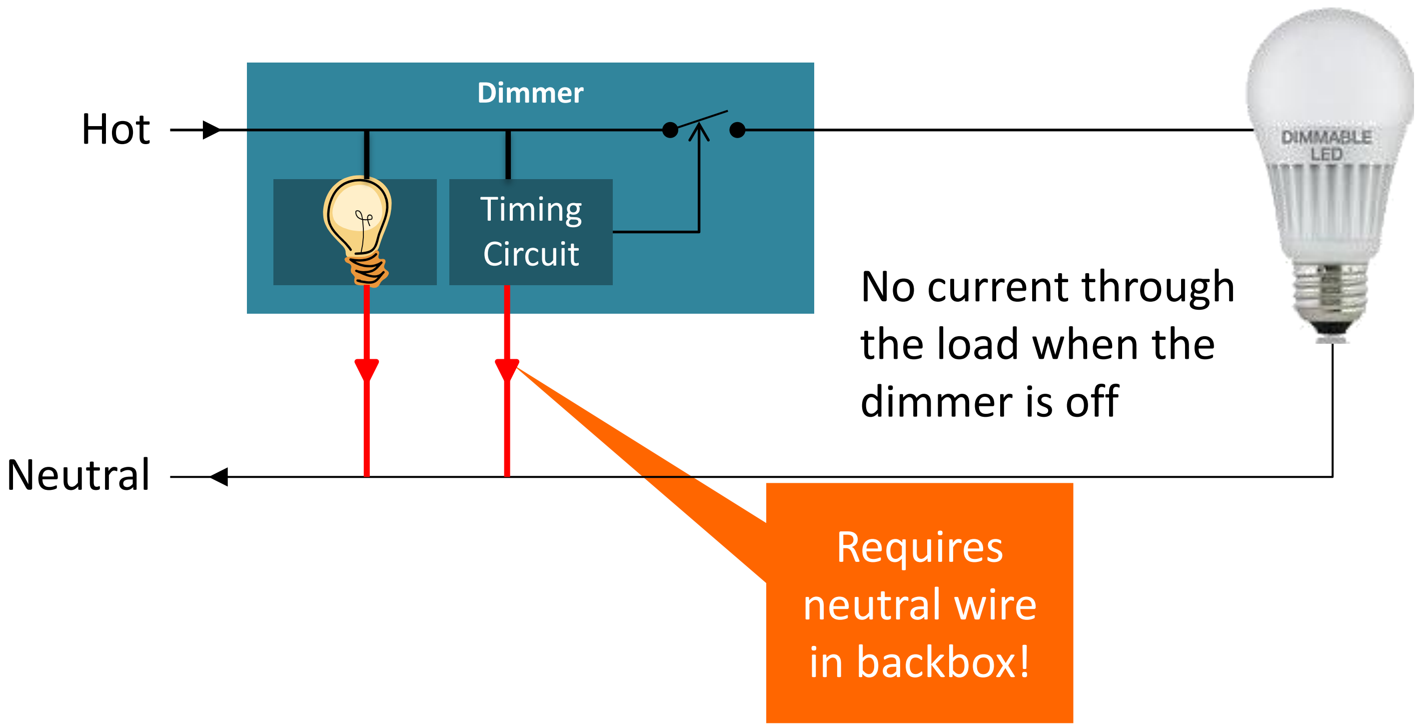
Dimmer "advanced features" requirements

- Dimmers without neutral need to use LED load for return path to keep "advanced features" circuitry running
- Most LED loads can not pass standby current required by dimmers with advanced features



Neutral benefits

- Dimmers with neutral have a path other than through the load for timing circuit or "advanced features" current



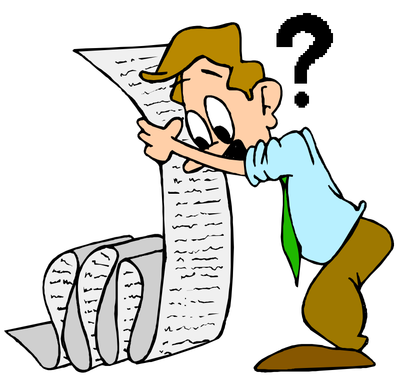
Dimmer operating current requirements

- Can lead to LED source flashing/strobing
  - LED source gets/accepts enough current to start, but not maintain operation
- Can lead to LED source ghosting
  - LED source gets/accepts enough current to start, and maintain (low light level) operation
- Can lead to dimmer inoperability or malfunction
  - LED source does not accept enough current to maintain proper operation of the dimmer control
  - Most problematic for advanced dimmers

Today's solutions

Hope for the best/get lucky

Mock-up entire circuits



Follow compatibility lists

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WHAT WILL SSL-7A DELIVER?

Inception of SSL-7

- Market demand by lamp and control manufacturers and sales channels
- Demand from industry forces
- Work by other standards bodies
- Frustrating user experiences

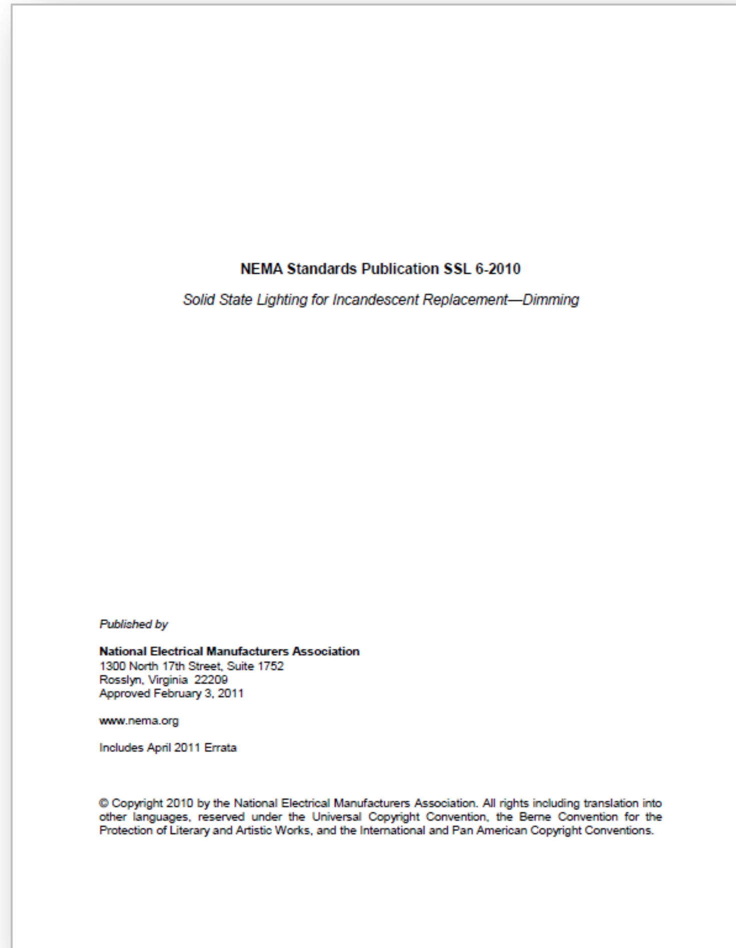
Inception of SSL-7

- Zhaga's goal of "interchangeable LED Light Engines" required control compatibility
- No common standardization of control type (forward/reverse phase) or specification existed
- NEMA was chosen as the administrative body for developing a phase-control specification
- SSL-7 is expected to be required by Zhaga-compliant products which use phase-cut dimming

Zhaga

Inception of SSL-7

- Existing SSL 6 (2010) described installed base of phase-cut dimmers
- Latent demand for a tighter specification
- A forward-looking strategy was adopted to bound the problem:
  - NOT concerned with existing products (variation is too wide)
  - Expected to be used on *new* products going forward



NEMA Standards Publication SSL 6-2010

Solid State Lighting for Incandescent Replacement—Dimming

Published by

National Electrical Manufacturers Association
1300 North 17th Street, Suite 1752
Rosslyn, Virginia 22209
Approved February 3, 2011

www.nema.org

Includes April 2011 Errata

Source: http://www.nema.org/standards/Pages/Solid-State-Lighting-for-Incandescent-Replacement-Dimming.aspx

Who was involved

- A consortium open to many interested companies
- NEMA Lighting Section members
  - American lamp and control manufacturers
- Plus other members
  - Standards bodies, European manufacturers, IC manufactures (invited through Zhaga)
- Multi-national group targeted a global scope
  - 100, 120, 230, 277V specifications

SSL-7 requirements

- In late 2011, work began within NEMA on SSL-7, using basic requirements defined by Zhaga as a starting point
- Scope of work and existing obstacles were identified in order to achieve a rapid specification
- Goal is that the NEMA document will be accepted as a whole or in part by standards-enforcement bodies (Zhaga, UL, Energy Star, IEC, etc.)
  - NEMA does not enforce standards

SSL7 Overview

- SSL7 is an *interface* standard: it specifies the *interaction* between lamps and dimmers

- The problem is very complicated! So, the strategy was to break it into two aspects:

Basic definitions

- <u>Dimmer</u>
  - A device (with or without a neutral wire) which creates a forward-phase waveform
- <u>LLE (LED Light Engine)</u>
  - A combination of an LED module plus driver, either combined (lamp) or separate (fixture)
- <u>Compatible</u>
  - Reliability of the dimmer and LLE are not affected by combining them
  - Dimming behavior meets or exceeds specified functionality

Structure of SSL7

- Addresses it as a system components:
  - Dimmer section
  - LLE section
- Two unknown black boxes need to work together, each which has wide variation

SSL7 Test philosophy

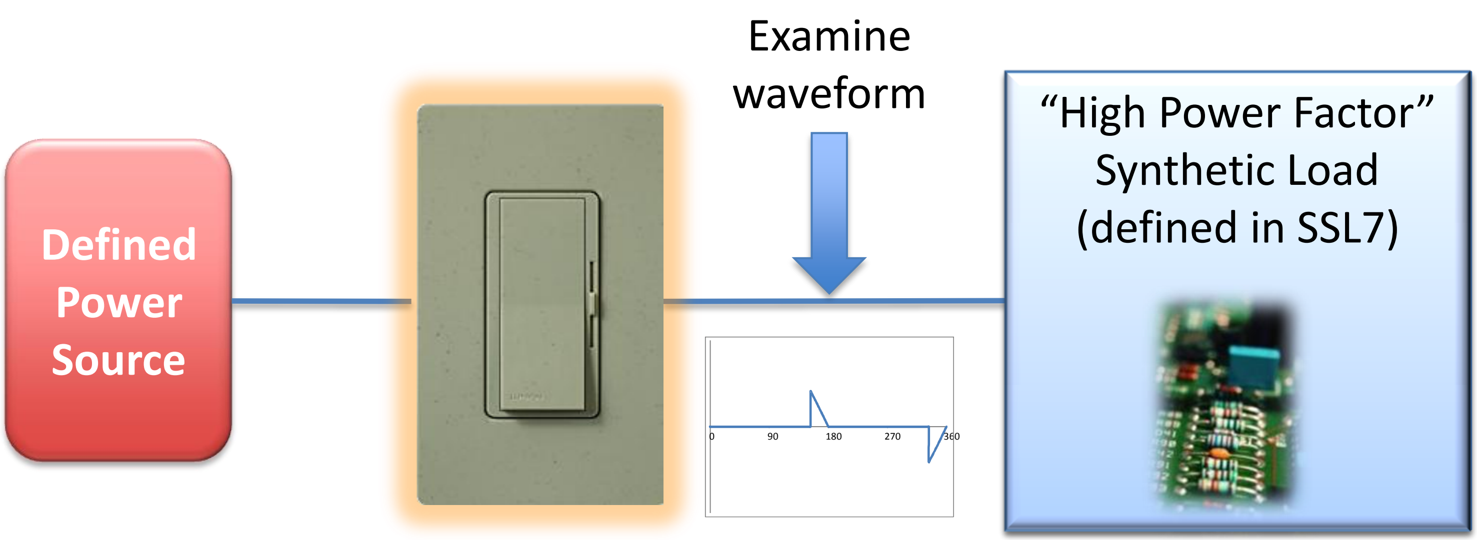
- Synthetic test circuits are used to generate proper characteristics or waveforms for testing the Device Under Test (DUT: LLE or Dimmer)
- Components in Test Circuits are usually adjusted for:
  - Power rating of Dimmer/LLE being tested
  - Mains voltage of DUT
- If the DUT works with the synthetic circuit, representing a worst-case scenario, it will work with any device whose characteristics do not exceed that worst-case

Summary of tests

Dimmer Tests	**LLE Tests**
Waveform stability	
Inrush	⇨ Inrush
Repetitive Peak Current	⇨ Repetitive Peak Current
Overload	⇨ Maximum RMS Current
Repetitive Ringup Voltage	⇨ Repetitive Ringup Voltage
Min. Conduction Angle	⇨ Minimum Light Level
Max. Conduction Angle	⇨ Maximum Light Level
Off-state Current	⇨ Off-state Current
On-state Current	⇨ On-state Current

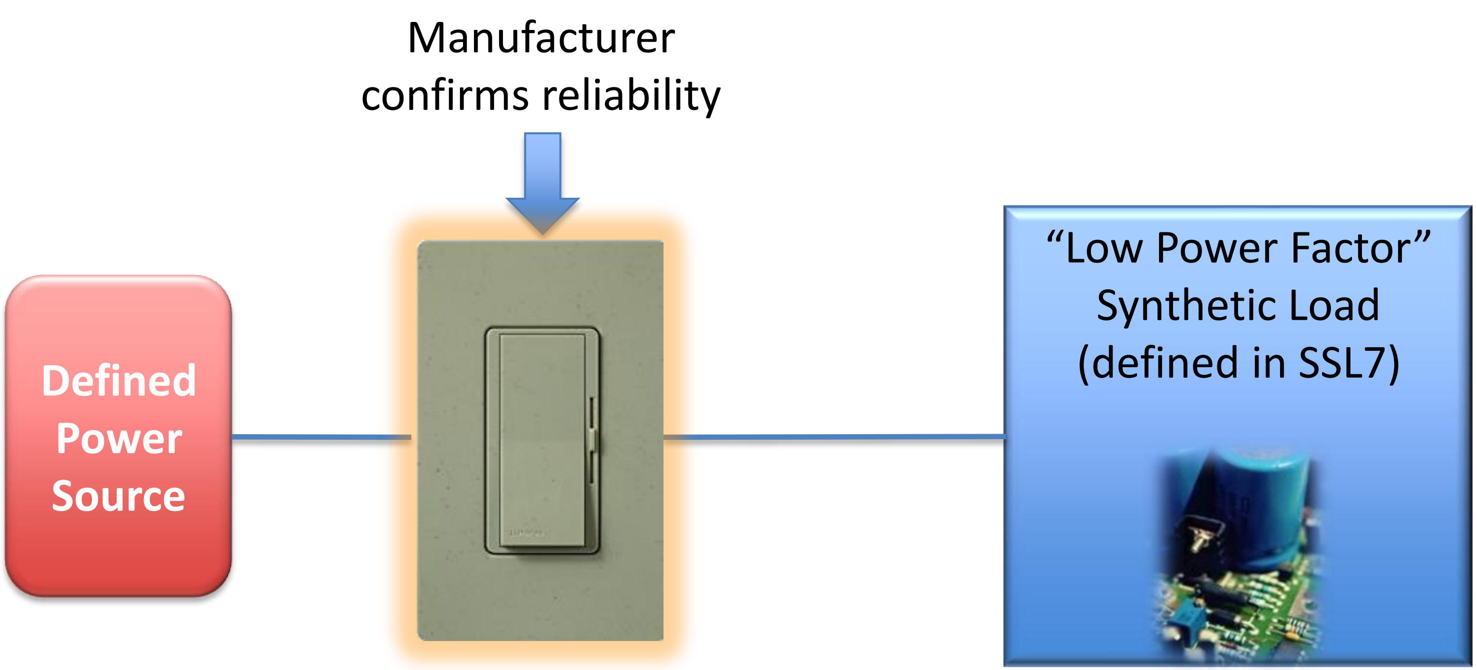
Dimmer section:
Stability

- *Purpose*: ensure Dimmer provides a proper (stable) forward-phase-cut waveform
- *Test*: connect Dimmer to two Synthetic Loads, representing high-power factor and low-power factor LLE (two different kinds of worst-case scenarios)



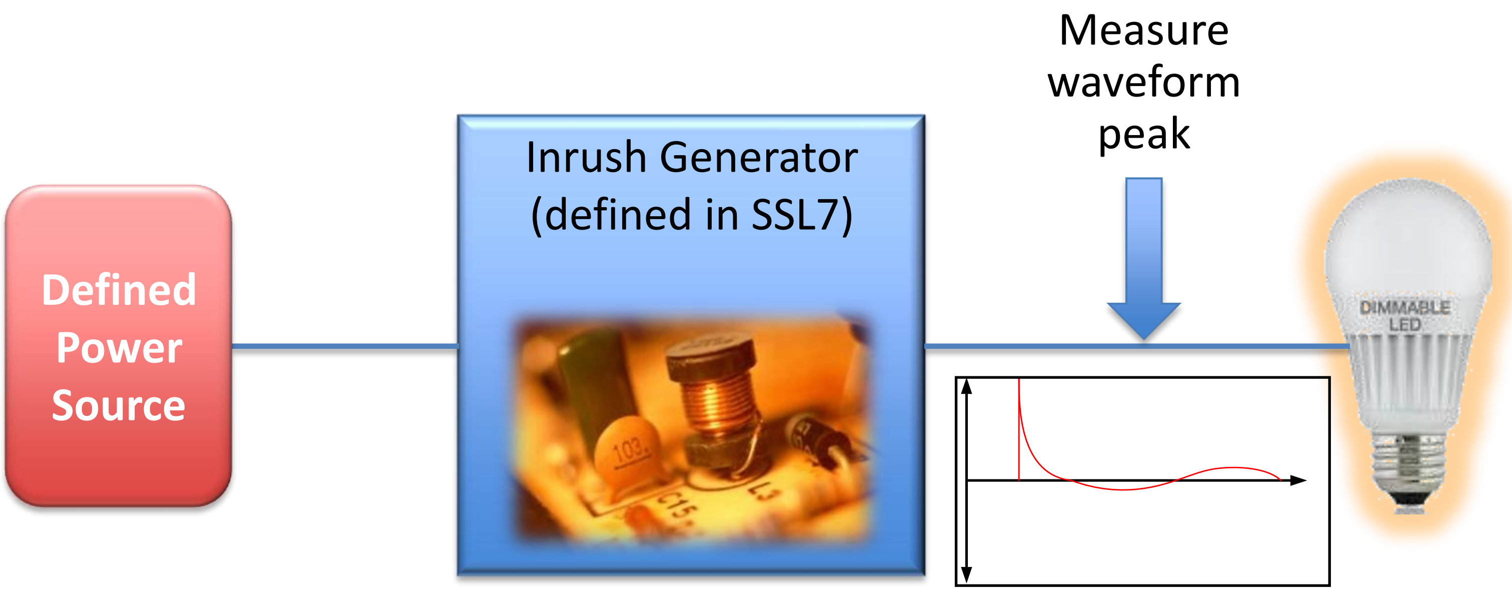
Dimmer section: Inrush

- *Purpose*: ensure Dimmer can handle high-inrush loads well
- *Test*: connect Dimmer to Low Power Factor Synthetic Load, representing worst-case LLE



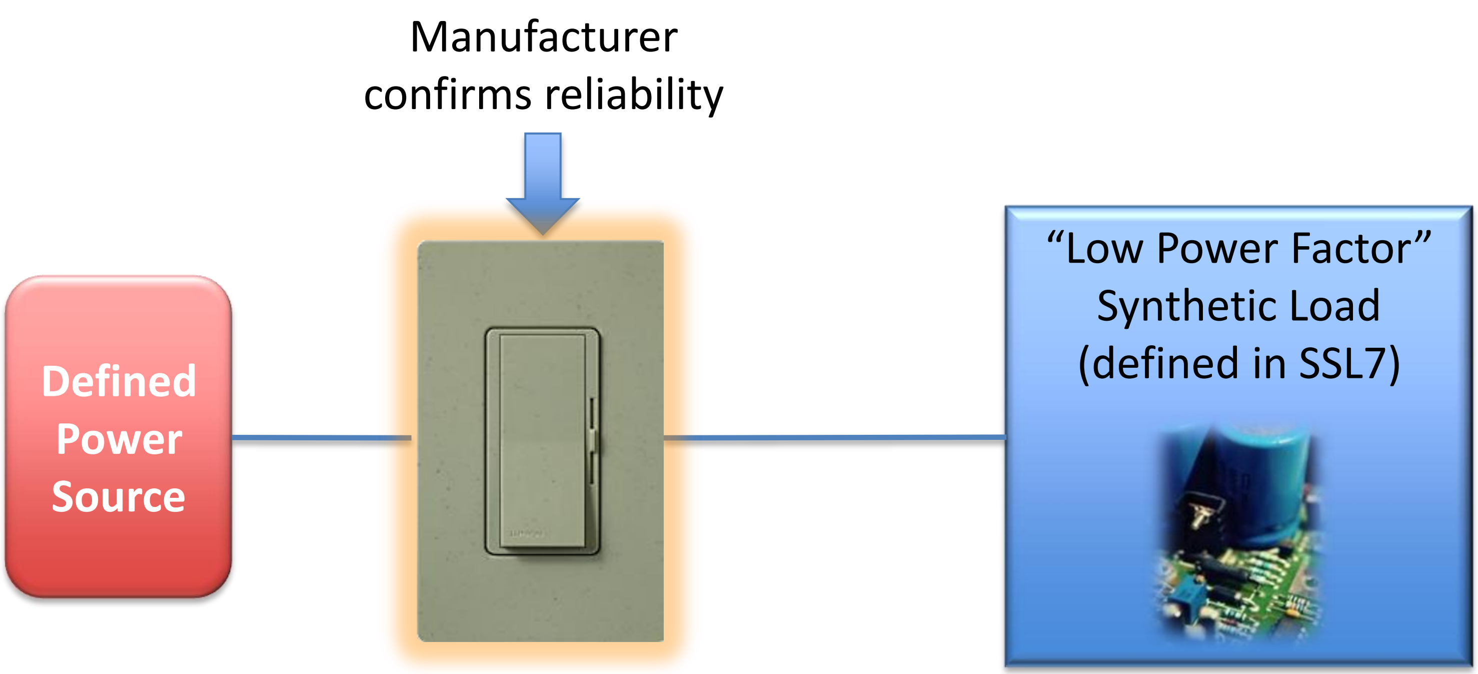
LLE section: Inrush

- *Purpose*: ensure LLE does not generate excessive inrush current
- *Test*: connect LLE to Inrush Generator, representing worst-case switch-on scenario



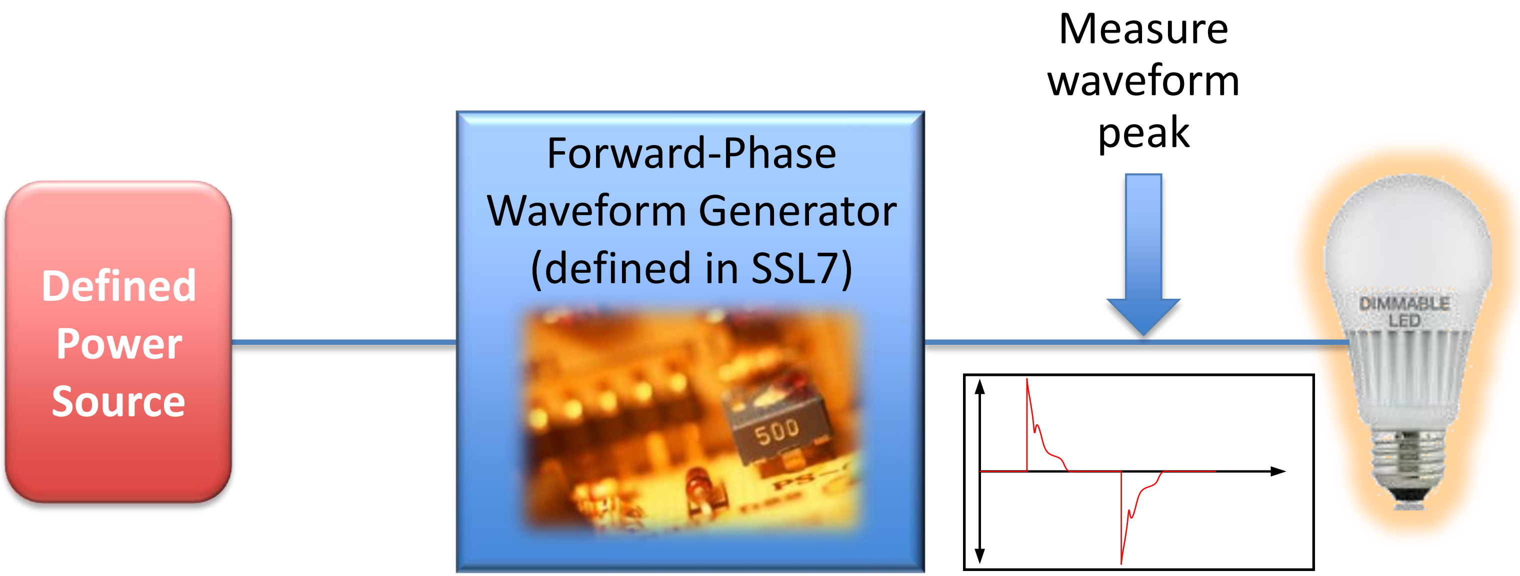
Dimmer section: Repetitive peak current

- ***Purpose***: ensure Dimmer can handle high repetitive peak current
- ***Test***: connect Dimmer to Low Power Factor Synthetic Load, representing worst-case LLE



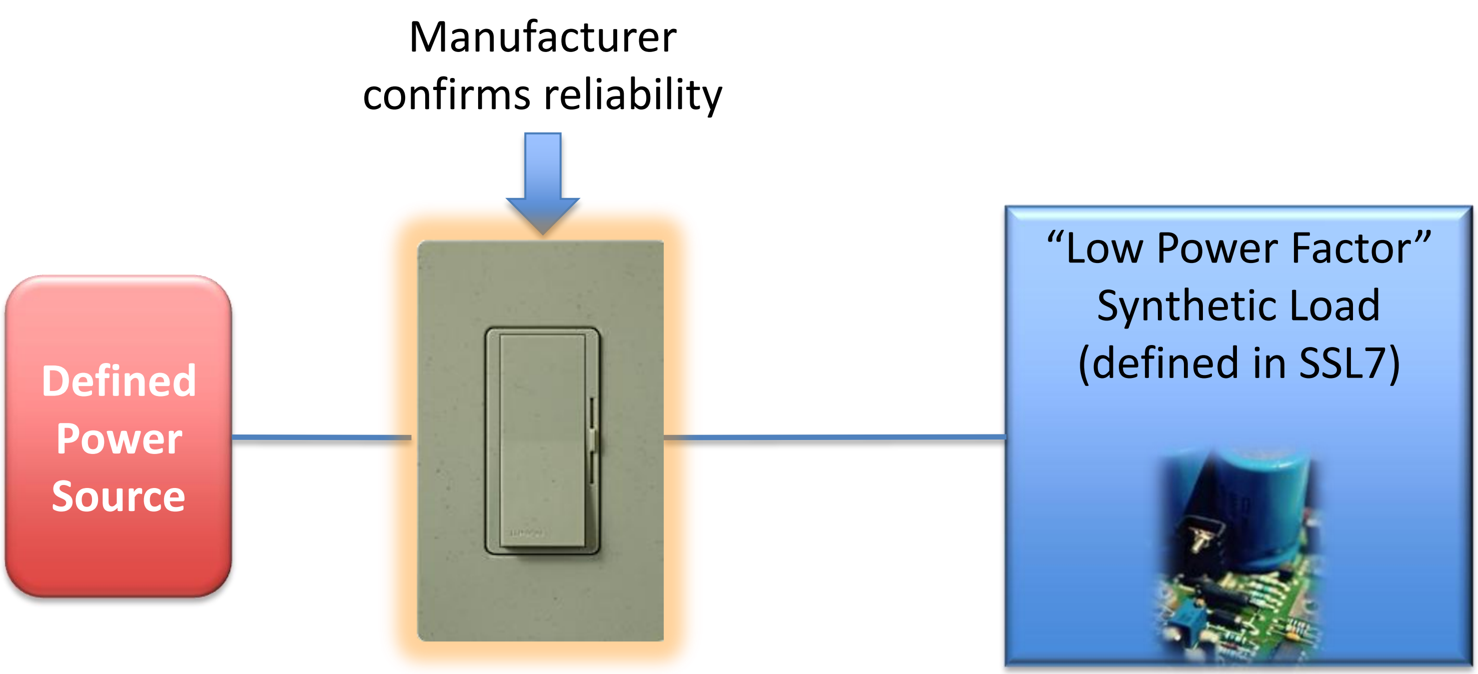
LLE section:
Repetitive peak current

- *Purpose*: ensure LLE does not generate excessive repetitive peak current
- *Test*: connect LLE to Synthetic Waveform Generator, simulating a forward-phase dimmer



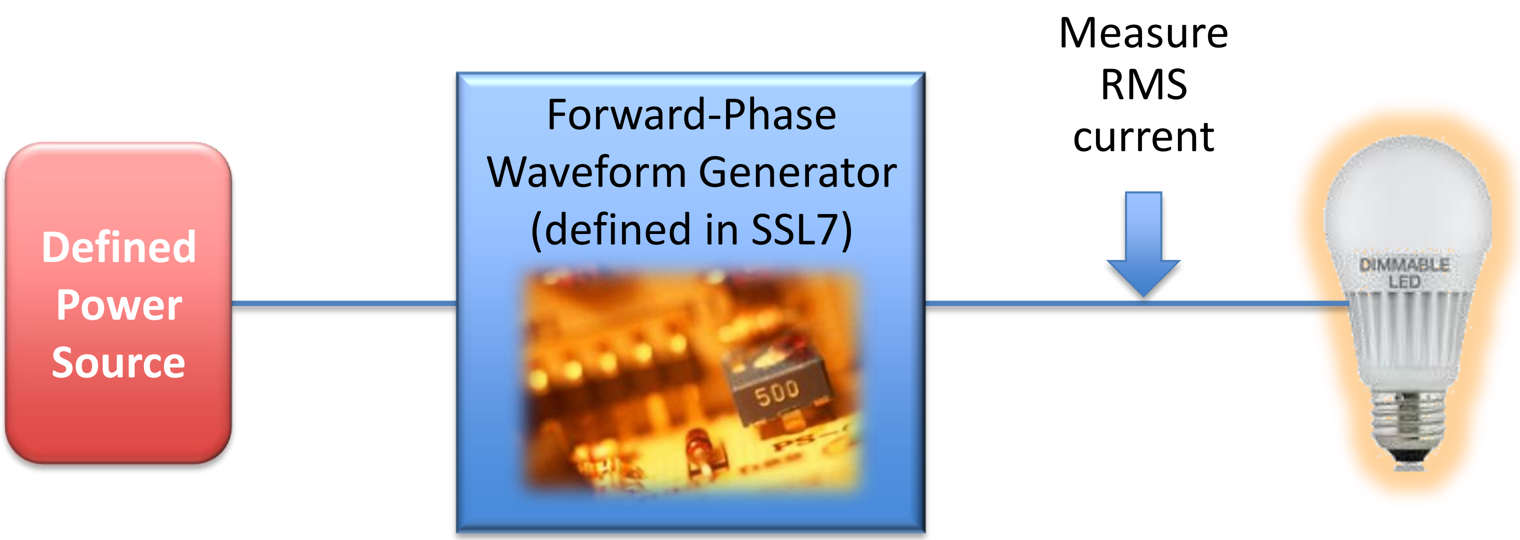
Dimmer section: Overload

- *Purpose*: ensure Dimmer can handle increased RMS current that may occur when dimming some LLEs
- *Test*: connect Dimmer to Low Power Factor Synthetic Load, representing worst-case LLE



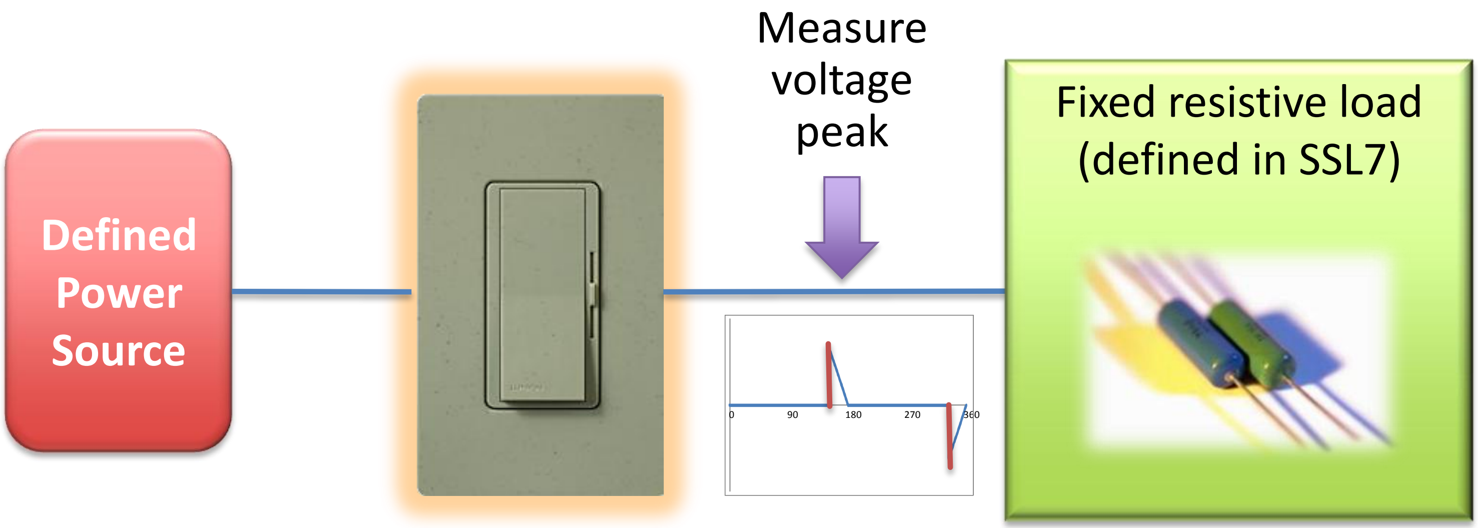
LLE section: Maximum RMS current

- *Purpose*: ensure LLE does not draw excessive RMS current when dimmed
- *Test*: connect LLE to Synthetic Waveform Generator, representing a standard forward-phase dimmer



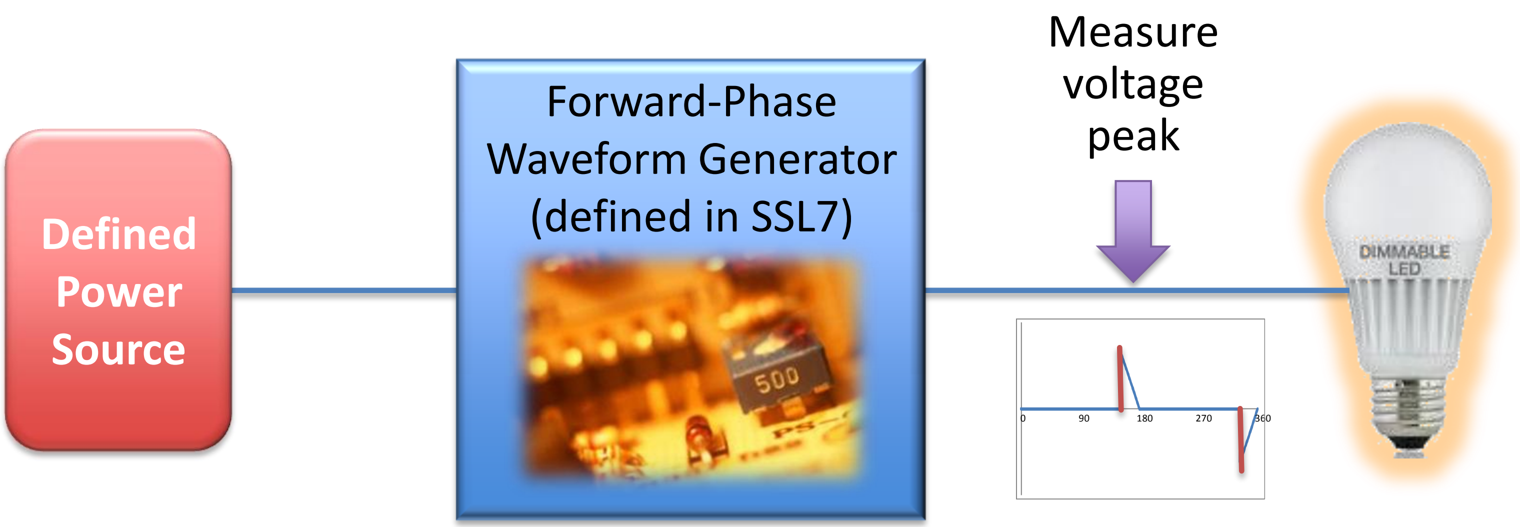
Dimmer section: Repetitive peak voltage

- ***Purpose***: ensure Dimmer does not cause excessive voltage ring-up
- ***Test***: connect Dimmer to small resistor, which represents the load which causes the highest ring-up voltage (least damping)



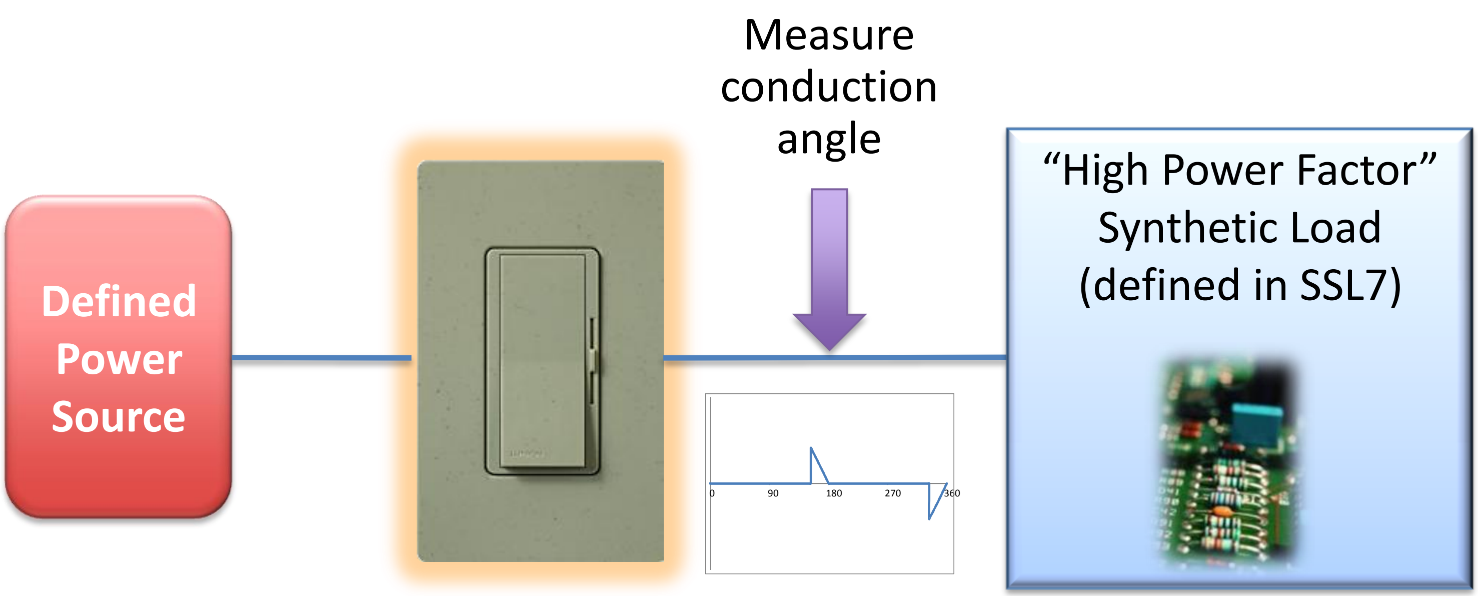
LLE section: Repetitive peak voltage

- *Purpose*: ensure LLE does not cause excessive voltage ring-up
- *Test*: connect LLE to Synthetic Waveform Generator, representing a standard forward-phase dimmer



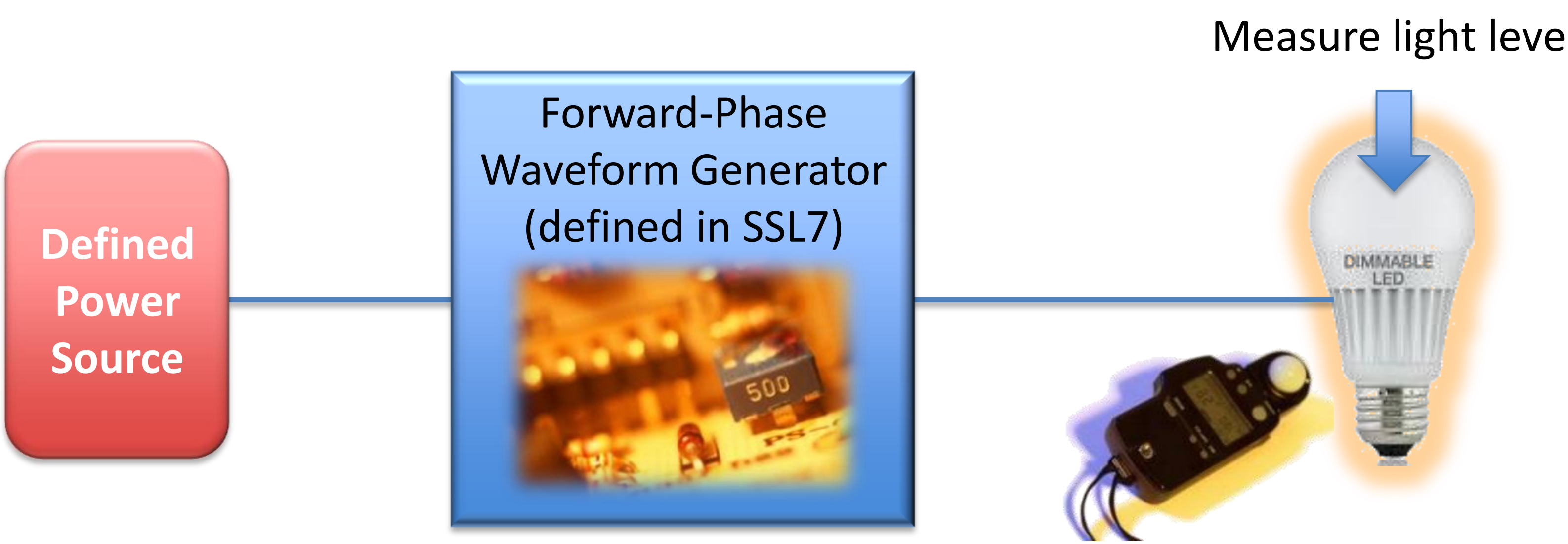
Dimmer section:
Min/Max conduction angle

- *Purpose*: ensure Dimmer can produce the proper expected range of conduction angles under all conditions
- *Test*: connect Dimmer to High Power Factor Synthetic Load, representing a worst-case LLE



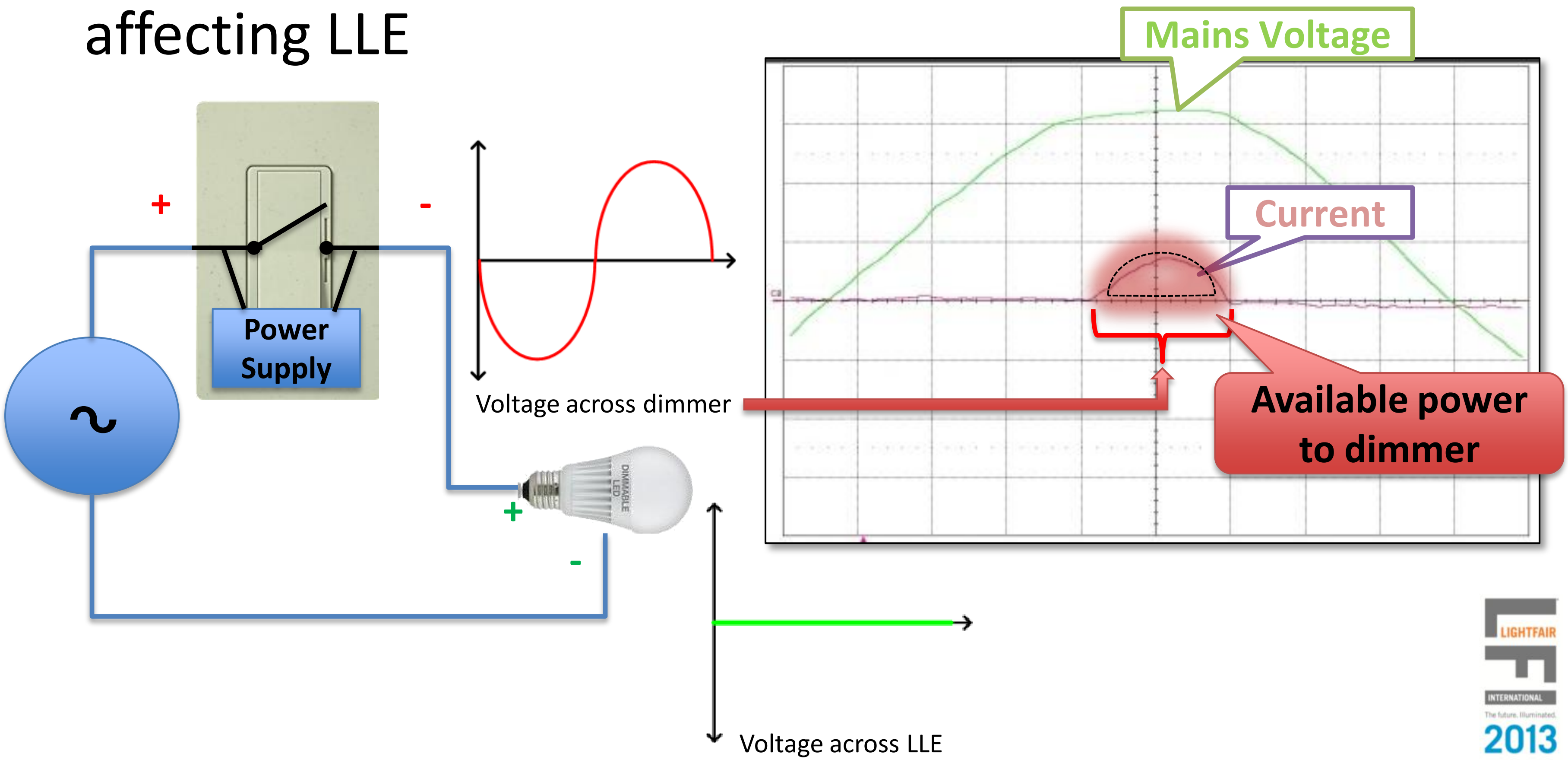
LLE section:
Min/Max light level

- *Purpose*: ensure LLE goes to expected light level when given waveforms that represent high end and low end
- *Test*: connect LLE to Synthetic Waveform Generator, representing a standard forward-phase dimmer



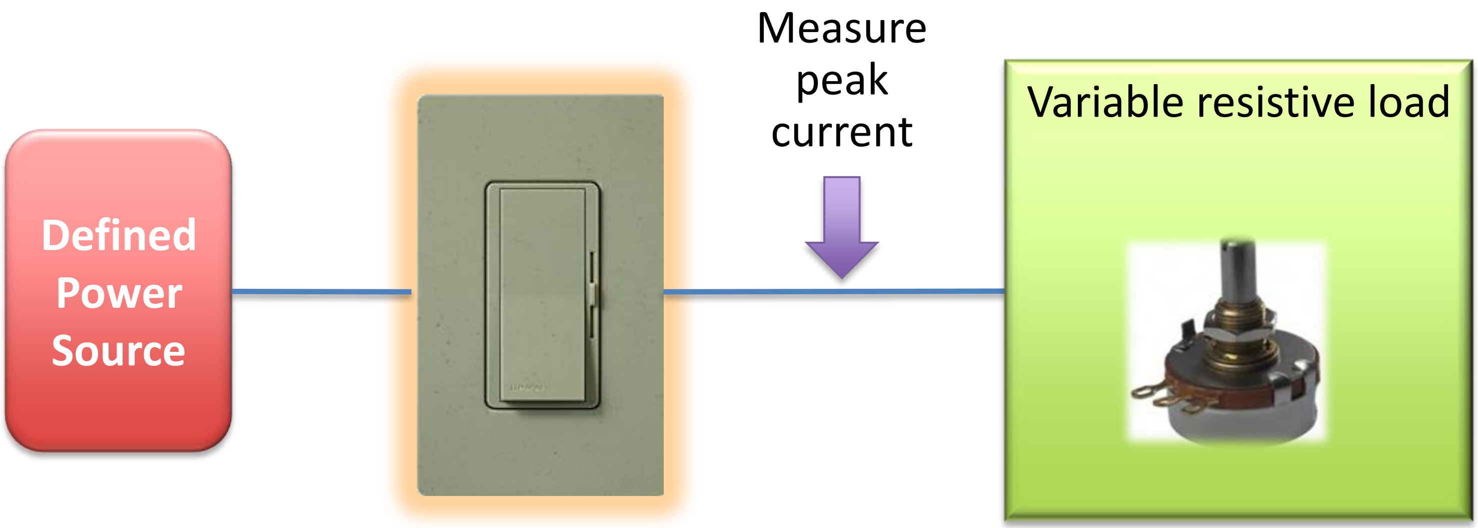
Dimmer supply current in the off-state

- Test must confirm Dimmer can get enough current through LLE in order to operate, without adversely affecting LLE



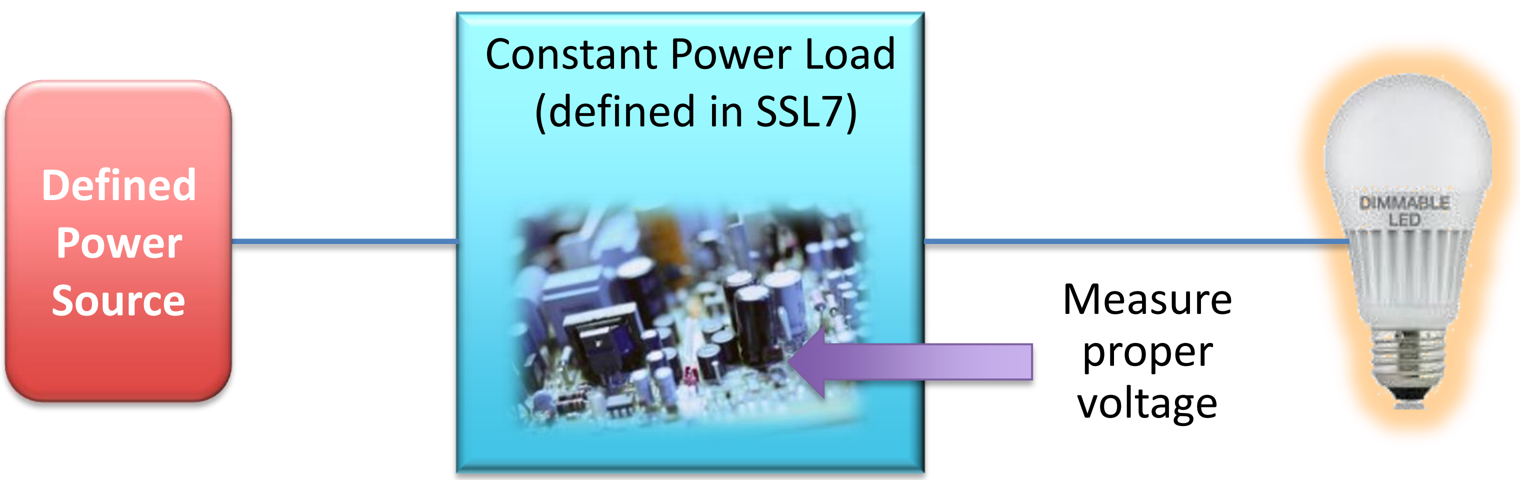
Dimmer section: Off-state current

- *Purpose*: ensure Dimmer power supply can operate without drawing excessively high peak currents over a defined LLE impedance range
- *Test*: connect Dimmer to variable resistive load, representing a range of possible LLE designs



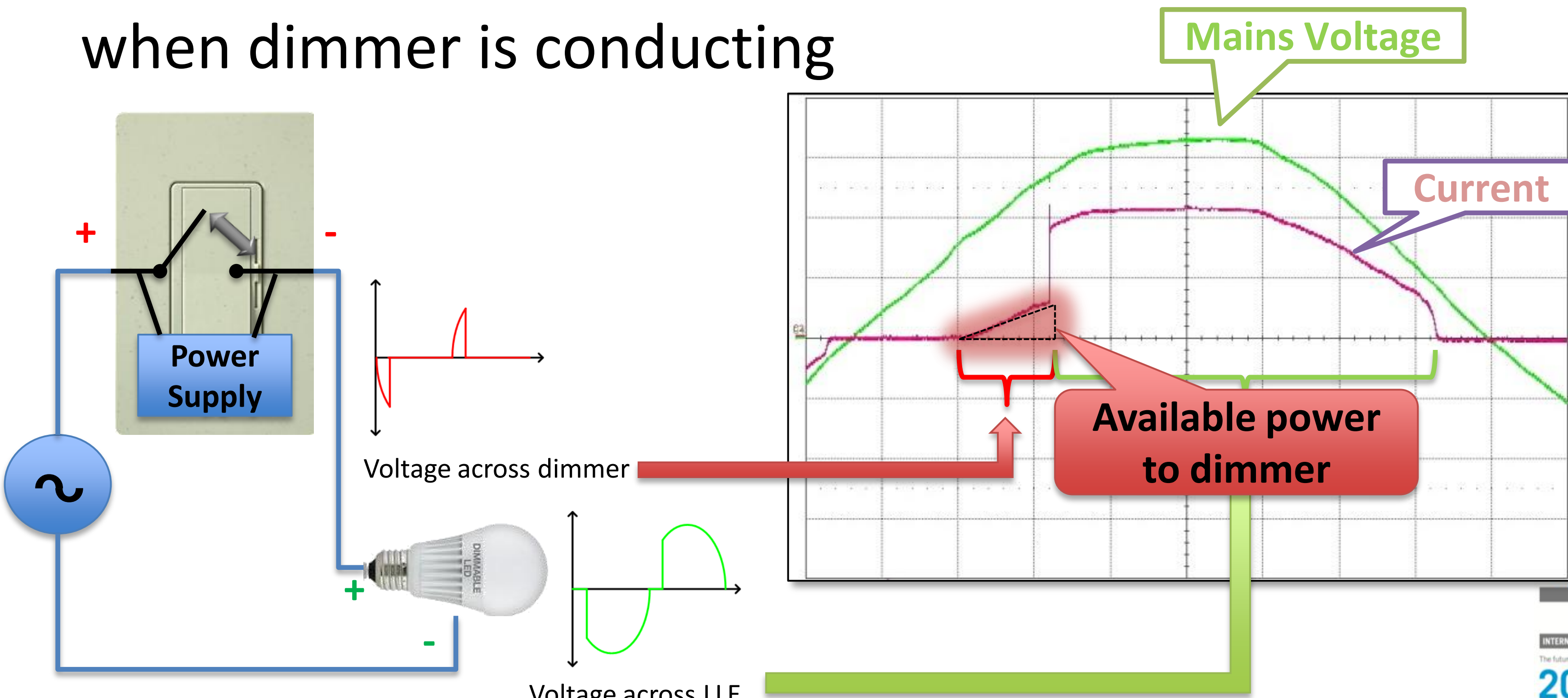
LLE section: Off-state current

- *Purpose*: ensure LLE can allow required amount of current for Dimmer power supply to operate
- *Test*: connect LLE to Synthetic Power Supply representing a worst-case (constant power) power supply; power supply must generate specified voltage (draw sufficient power)



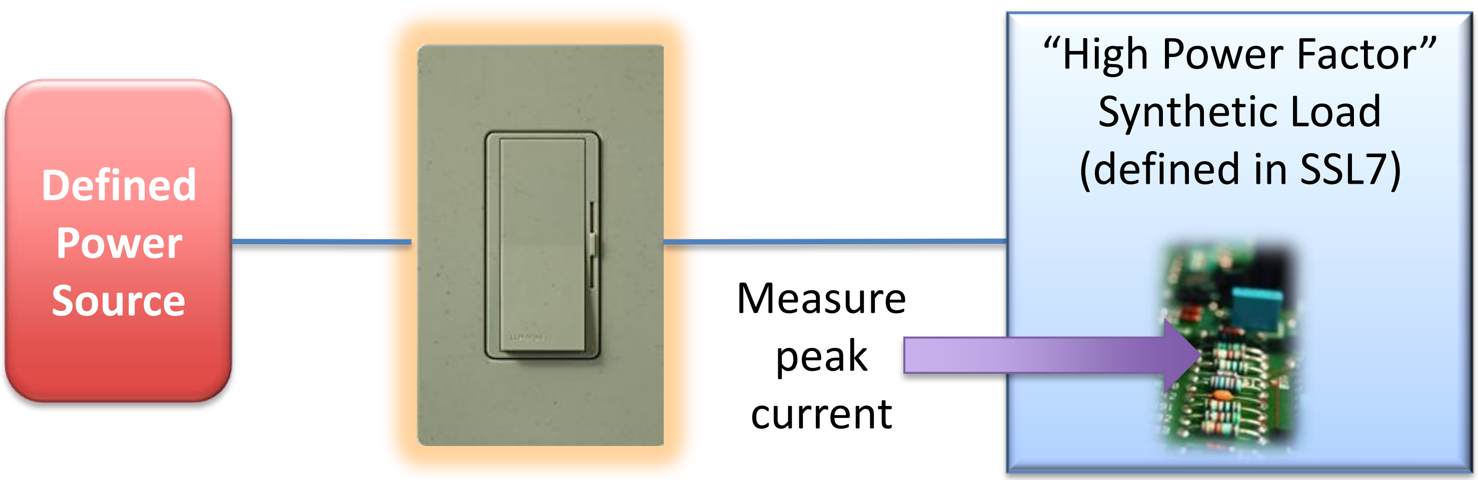
Dimmer supply current in the on-state

- Dimmer can only get power when its switching device (triac, etc.) is not conducting
- Hardest to do at high end: least amount of time when dimmer is conducting



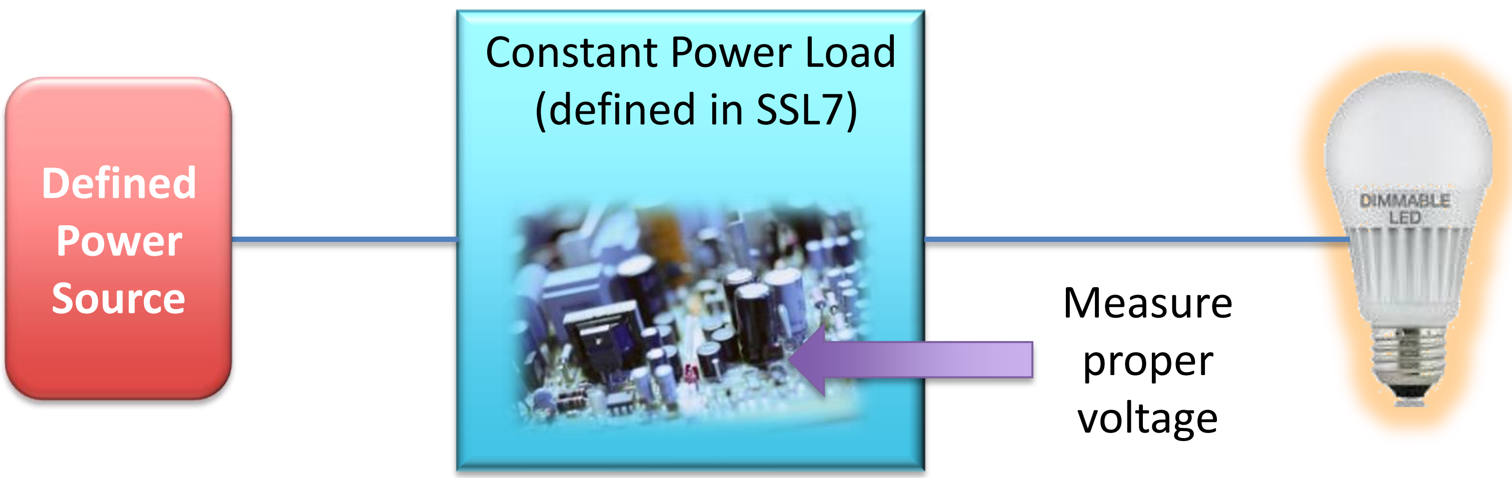
Dimmer section:
On-state current

- *Purpose*: ensure Dimmer power supply can operate without drawing excessive current in the on-state
- *Test*: connect Dimmer to High Power Factor Synthetic Load, representing worst-case LLE



LLE section:
On-state current

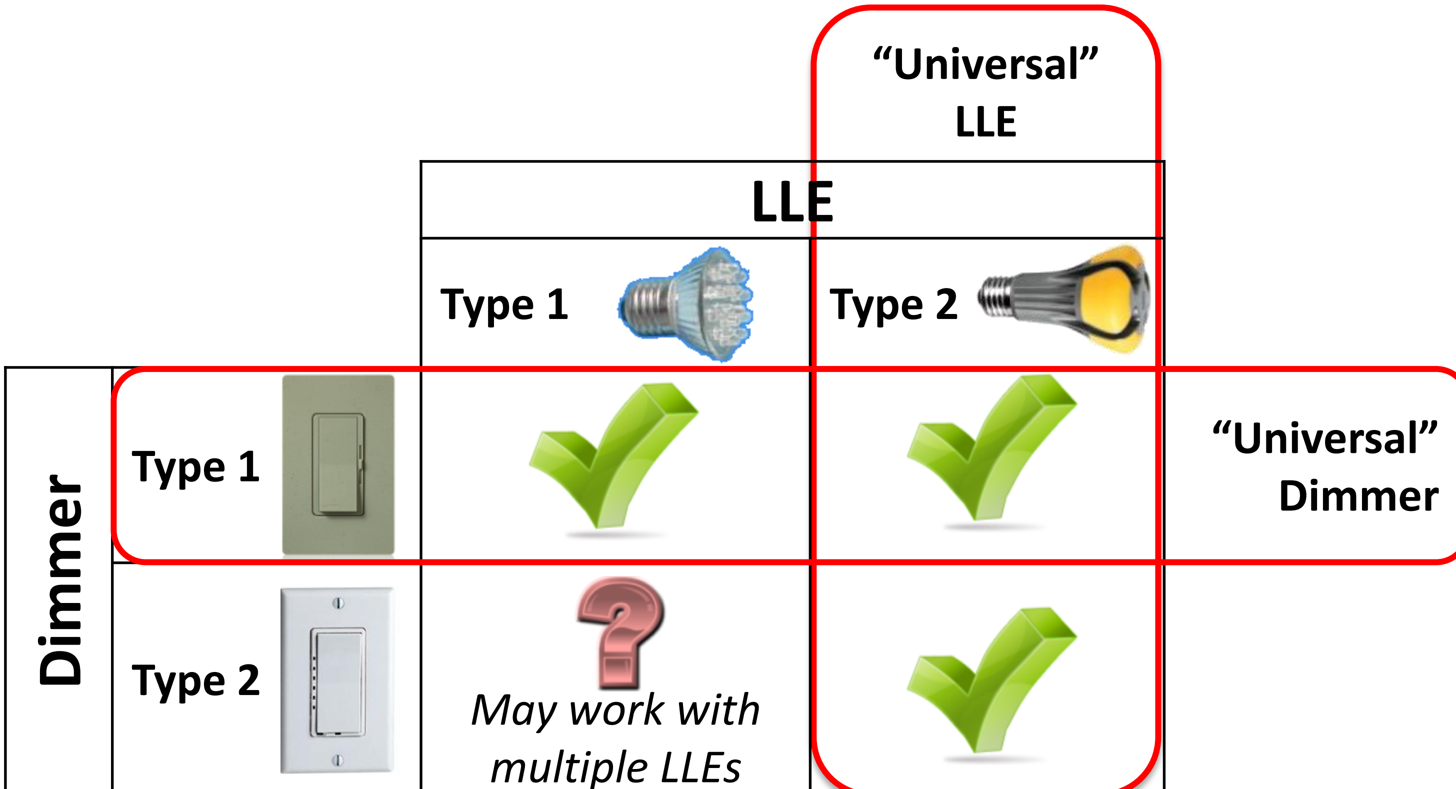
- *Purpose*: ensure LLE allows sufficient current for Dimmer power supply to operate
- *Test*: connect LLE to Synthetic Power Supply representing a worst-case (constant power) power supply; power supply must generate specified voltage (draw sufficient power)



On and off-state current challenges

- Not all dimmers need a large amount of current for on- and off-state operation
- Not all lamps want to include the additional complexity for dimmers whose power supply requires high current

Type 1 and Type 2 Dimmers and LLEs



Marking requirements

Dimmer

- Maximum rated wattage
- Minimum load
- Type 1/Type 2 compliance
- How to set SSL-7A load type

LLE

- Minimum light output
- Type 1/Type 2 compliance

So how did we do?
User problems:

- ✓ Dimming range
- ✓ Dead travel
- ✓ Pop-on
- ✓ Drop-out
- ■ Popcorn
- ✓ Ghosting
- ■ Flashing/Strobing
- ✘ Induced Flicker
- ✘ Audible noise

- ✘ Dimming smoothness
- ✘ Dimming monotonicity
- ✘ Dimming up/down symmetry
- ✓ Dimmer loading
- ■ LED load - dimmer inoperability
- ✓ Premature failure of dimmer and/or LED load

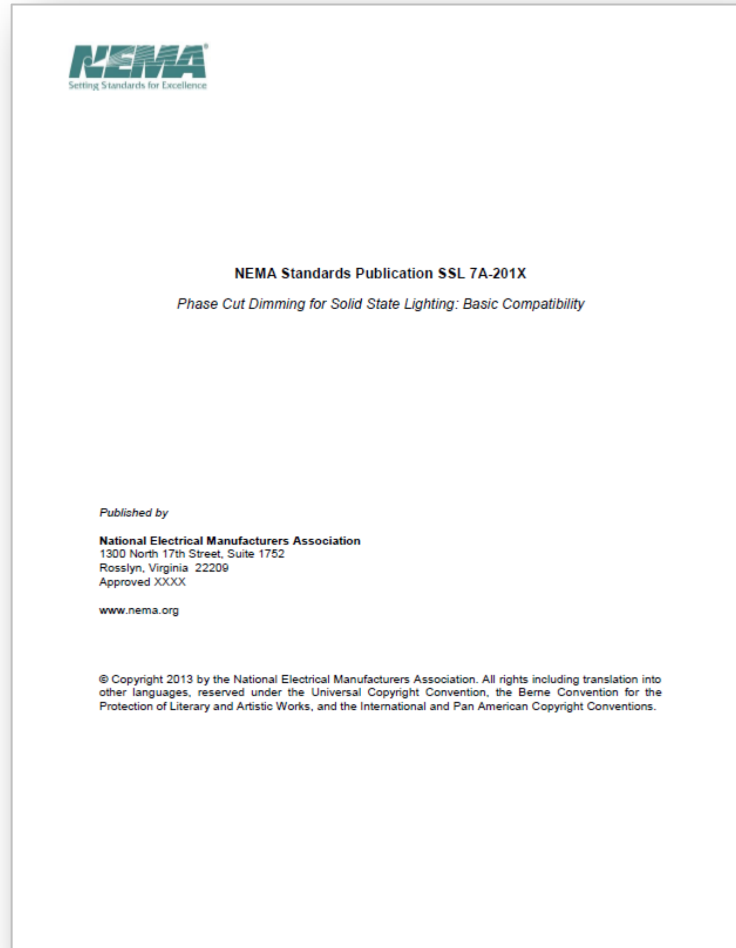
So how did we do?
Technical challenges

- ✓ LED load RMS Current
- ✓ LED load inrush Current
- ✓ LED load repetitive peak current
- ✓ Repetitive ring-up voltage
- ■ Dimmer switching element current requirements
- ✓ Dimmer timing element series impedance requirements
- ✓ Dimmer on-state and/or off-state operating current requirements

Status

- Published on 4/22/2013
- Available for purchase: http://global.ihs.com

  (search for SSL7)



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Setting Standards for Excellence

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Phase Cut Dimming for Solid State Lighting: Basic Compatibility

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WHAT COMES NEXT?

Commercial adoption

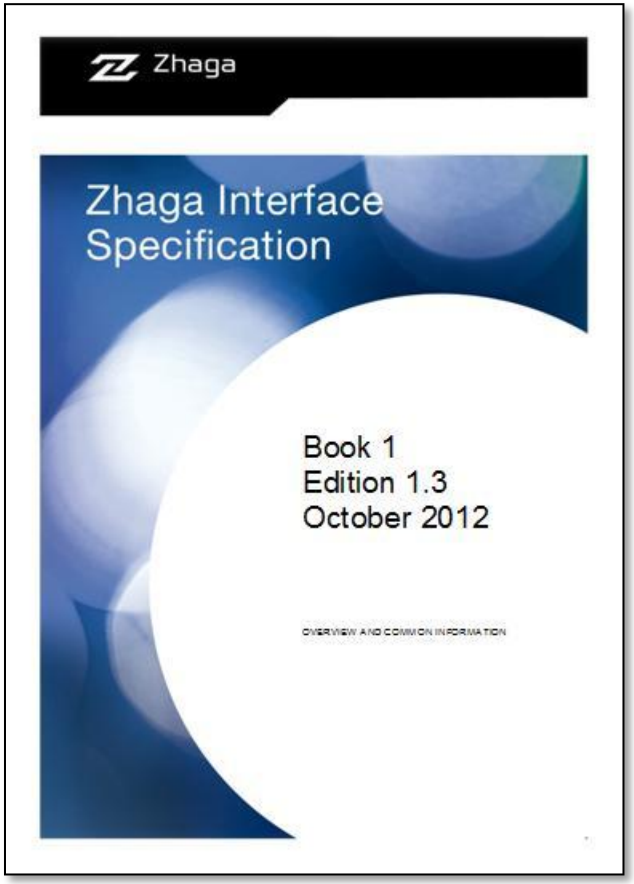
Specification agents

- Zhaga
  - Book 1
- EPA ENERGYSTAR
  - Lamps Specification
  - Luminaire Specification
- California Energy Commission
  - Title 20 (CEC-140-2012-002)
  - Voluntary California Quality LED Lamp Specification (CEC-400-2012-016-SF)

Zhaga

"…Whereas this edition of Book does not define a specific technology to realize such dimming functionality, the Product Data Set shall provide at least the following information if the product is to be considered dimmable:

- The required dimming technology, such as forward phase, reverse phase, 0-10V, DALI, etc.
- The expected ratio of the minimum to maximum total luminous flux when dimmed—i.e. a low-end dimming percentage such as 10%, 20%, etc."



Source: http://www.zhagastandard.org/specifications/book-1.html

EPA ENERGYSTAR

Proposed language included in Lamps Specification Draft 4 Version 1.0 (published 4/19/2013; comment period closes 5/17/2013)

12. DIMMING PERFORMANCE: ALL LAMPS MARKETED AS DIMMABLE

If lamp is designed for phase cut dimming operation (alterations to the line voltage to the lamp), select 10 dimmers for testing. The 10 dimmers shall meet the following conditions:

1. From at least 2 different manufacturers
2. At least one dimmer must be specified as compatible use with energy efficient lighting (such as CFL or LED lamps)
3. At least one dimmer must be of one of the following types: Single (Forward) Phase Shift; Double Phase Shift, or Electronic Low Voltage/ Reverse Phase
4. At least one dimmer must have one of the following features: Microprocessor with Power Supply, Voltage Compensation, or Pre-set levels

If lamp is compatible with a non-phase cut control device (dimmer that does not alter the line voltage to the lamp), the controls must be listed on the packaging and be tested with the lamp against all dimming performance requirements. An asterisk next to “dimmable” on lamp packaging/online product listing marketing materials must be included and point to an “only compatible with …” statement.

The tested minimum light level on dimmers or controls shall be the minimum light level claimed by the manufacturer (or 20% if no minimum is claimed), and the lamp shall meet flicker and audible noise requirements at this level.

For purposes of third-party certification, maximum lighting output, minimum lamp output, flicker and noise levels shall be reported by the partner to the certification body however documentation shall not be reviewed when products are certified or during verification testing.

Dimming performance testing for certification is not required to be performed by a third party laboratory, but the performance data must be submitted to the certification body. EPA is continuously monitoring progress that industry and others are making towards the measurement of dimming, flicker, and audible noise and may refine the methods and requirements in the future as research and additional data becomes available.

EPA ENERGYSTAR

Proposed language included in Lamps Specification Draft 4 Version 1.0 (published 4/19/2013; comment period closes 5/17/2013)

12. DIMMING PERFORMANCE: ALL LAMPS MARKETED AS DIMMABLE

12.1. Maximum Light Output:

Lamp Type	ENERGY STAR Requirements	Methods of Measurement and/or Reference Documents	Supplemental Testing Guidance
All Lamps Marketed As Dimmable	Lamp light output on the maximum setting of a dimmer/control shall not exceed the lamp's rated light output by more than 10% or fall below the light output of the lamp by more than 20%. 80% of tested lamp/dimmer combinations must meet the requirement.	**Measurement:** ENERGY STAR Recommended Practice for evaluating Light Output on a Dimmer	**Sample Size**: 1 lamp per dimmer and 4 lamps per dimmer. See Section 8 of the Recommended Practice for Evaluating Light Output on a Dimmer for reporting information.

12.2. Minimum Light Output:

Lamp Type	ENERGY STAR Requirements	Methods of Measurement and/or Reference Documents	Supplemental Testing Guidance
All Lamps Marketed As Dimmable	Lamp light output on a dimmer/control shall be no more than 20% of the maximum light output of the lamp on each tested dimmer/control. 80% of tested lamp/dimmer combinations must meet the requirement.	**Measurement:** ENERGY STAR Recommended Practice for evaluating Light Output on a Dimmer	**Sample Size**: 1 lamp per dimmer and 4 lamps per dimmer. See Section 8 of the Recommended Practice for Light Output on a Dimmer for reporting information.

EPA ENERGYSTAR

Proposed language included in Lamps Specification Draft 4 Version 1.0 (published 4/19/2013; comment period closes 5/17/2013)

12. DIMMING PERFORMANCE: ALL LAMPS MARKETED AS DIMMABLE

15.2. Lamp Packaging: All Lamps Except as Noted[1]

Criteria	ENERGY STAR Requirement
Model Number	Lamp packaging shall include model number and retail SKU number (as applicable) as will appear on the ENERGY STAR qualifying product list.
Controls Compatibility	Lamp packaging exterior shall display on the front panel in ≥ 8 point type an indication of the lamp's dimming capability: "dimmable", "for dimmers", "non-dimmable", "do not use with dimmers" or the like. Dimmable lamp packaging shall indicate that the lamp may not be compatible with all dimmers, and shall reference a website providing regularly updated dimmer compatibility information for the lamp model. Lamps that are dimmable with a limited set of controls that elect to test and list compatibility with the limited set of controls must list all compatible controls on packaging. See Dimming Section 12. Packaging for lamps not designed for operation with photosensors, motion sensors or timing devices shall

[1] Packaging requirements must appear on the exterior of lamp packaging and not on the bottom of lamp packaging. The outermost package of bulk packaged (i.e. multi-pack) lamps facing the intended end user shall meet these requirements.

California Energy Commission

California Code of Regulations, Title 20. Public Utilities and Energy, November 2012 (CEC-140-2012-002)

Chapter 3. Energy Conservation, Article 4 Appliance Efficiency Regulations

- Does not contain any dimming requirements

California Energy Commission

Voluntary California Quality Light-Emitting Diode (LED) Lamp Specification, December 2012 (CED-400-2012-016-SF)

Chapter 2: Attributes of the Voluntary California Quality LED Lamp Specification

The California Specification requires LED replacement lamps to be dimmable, using the dimmability requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (See Appendix A). Note that although there is a requirement for lamps to be dimmable without visual flicker there is, as yet, no quantitative test procedure to quantify visual flicker.

Chapter 3: Voluntary California Quality LED Lamp Specification

Dimmability

To meet the specification, LED lamps shall be capable of continuous dimming, without flicker or noise, from 10-100 percent. For these lamps, the *California-Quality LED Lamp Specification* will use the test procedures (e.g., for flicker and noise) cited in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (see Appendix A). The test procedures used in the California Specification will update in line with future revisions to ENERGY STAR, but the requirement for dimming down to 10% will not update .

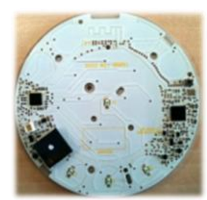
NEMA National Electrical Manufacturers Association Working Group

- Tracking and correcting errata
- Multiple possibilities for further work
  - SSL7-A:Compatibility → SSL7-B: Performance?
  - Reverse Phase?
- Decision TBD

Other paths to improved dimming?

- Zigbee Lightlink ZigBee Alliance Light Smart, easy-to-use lighting control designed for consumers.
  - Wireless mesh communication built on IEEE 802.15.4 PHY and MAC
  - Separate AC power and control signal
  - Digital, two-way communication






Other paths to improved dimming?

- DLT / IEC 62756-1
  - Digital Load Line Transmission
  - Coincident AC power and control signal (powerline carrier, NOT phase-cut)
  - Digital, one-way communication
- Connected Lighting Alliance
  - New (8/2012) manufacturer consortium (like Zhaga)
  - Promotes wireless lighting solutions by supporting open standards
  - Ensure interoperability
  - Initial focus on residential/consumer applications

Please remember to complete the course evaluations.
Thank you.

We hope you enjoy the trade show and conference!

We hope to see you at LFI 2014!
www.lightfair.com