

The Impact of Low Frequency Ripple Current on LEDs and LED drivers

OSRAM LED Light For You
San Diego, California
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The Impact of Low Frequency Ripple Current on LEDs and LED drivers

Abstract

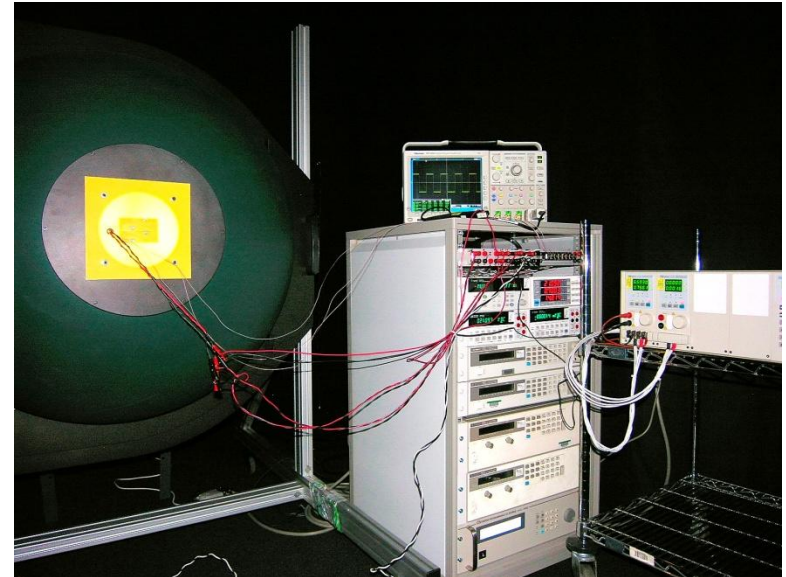
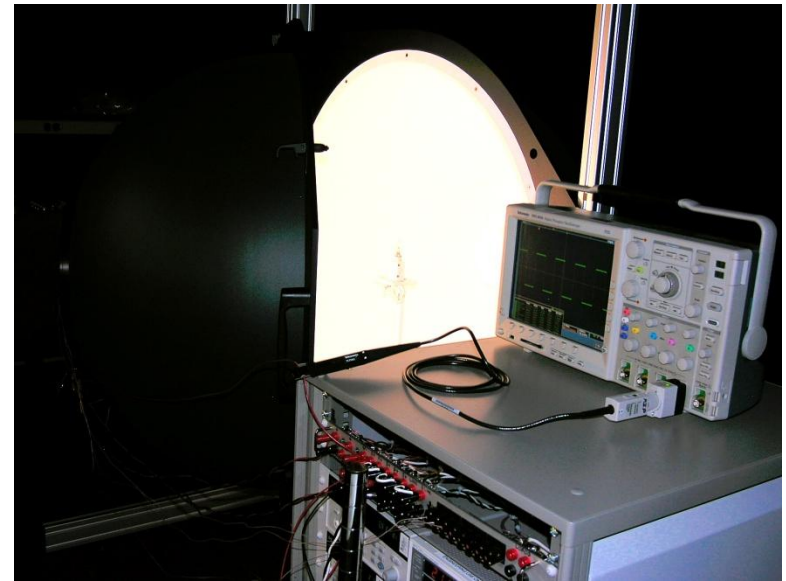
- The effect of LED ripple current on chromaticity, color shift, spectral radiance and efficacy is analyzed and related to dimmable AC-DC LED driver solutions. Traditional wall dimmers are based on TRIAC (triodes for alternating currents). The TRIAC has been used extensively in residential lighting applications with incandescent lamps. Since LED lighting consumes much less power for the same amount of light compared with incandescent sources, the current through the TRIAC wall dimmer is much less. This training will discuss the basic circuits and operation of a TRIAC. The pros and cons of several LED lighting TRIAC interface solutions will be presented. The solutions will include solutions based on TI's TPS92001, TPS92010 and TPS92210 LED lighting driver controllers.

Agenda

- LED characteristics with DC current
- LED characteristics with DC and AC current
 - 120 Hz sine wave ripple (60 Hz rectified)
- CFL vs. LED
- Basic TRIAC dimmers
- TRIAC Dimmer Practical Considerations
- TPS92001 Reference Design
- TPS92010 EVM
- TPS92210 Reference Design
- Summary

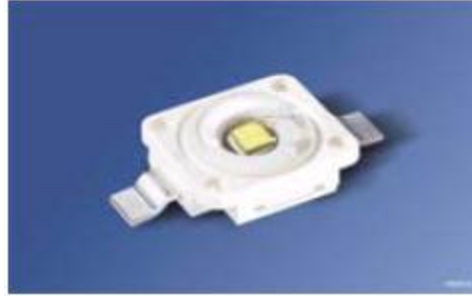
Lighting Equipment

- Small Luminaires & LEDs
 - Integrating Sphere & Spectroradiometer
 - Color, CCT, Lumens, Efficacy
 - Spectral Radiance
 - NIST traceability
- Large Luminaires
 - Color, lux, spatial distribution



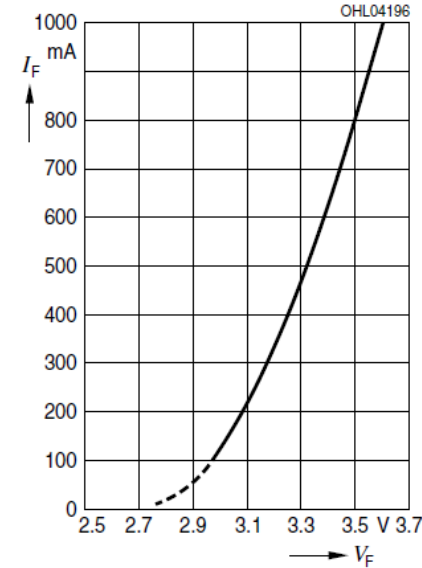
LED Specifications

- LED datasheets specify:
 - V_F vs. I_F
 - Color Coordinates
 - CCT
 - Lumens vs. **constant** I_F
 - Relative luminous flux vs. T_J @ **constant current**

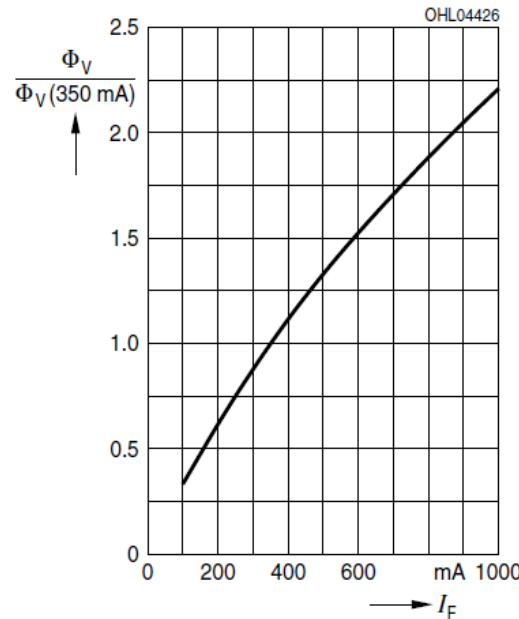


LUW W5AM

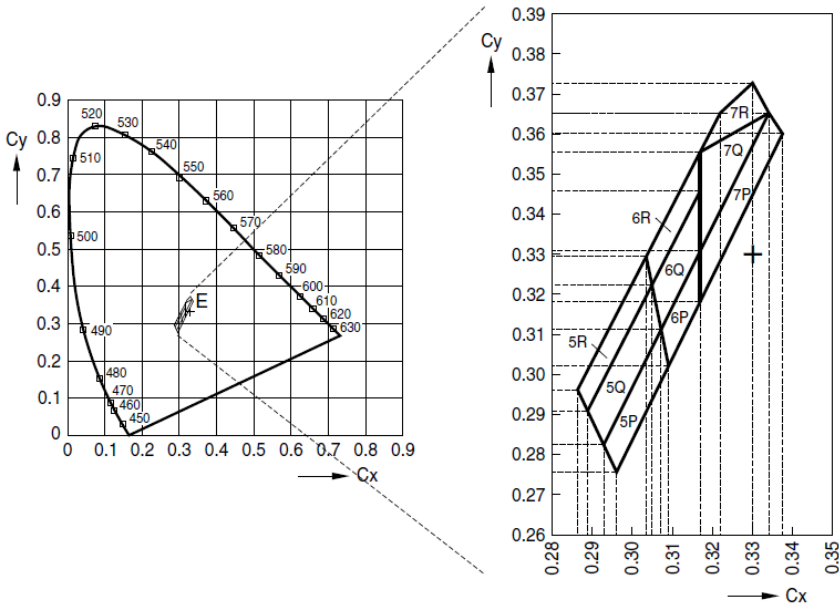
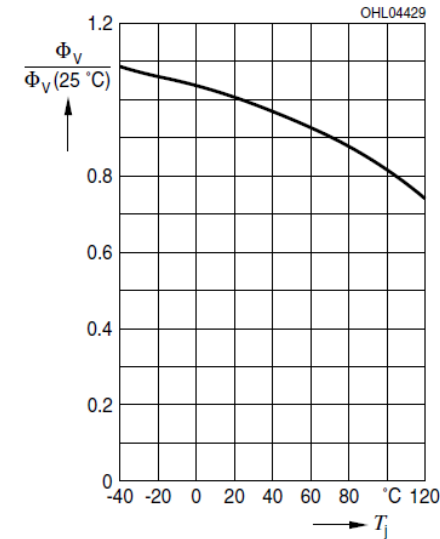
Durchlassstrom²⁾⁴⁾ Seite 21
 Forward Current²⁾⁴⁾ page 21
 $I_F = f(V_F); T_S = 25^\circ\text{C}$



Relative Lichtstrom²⁾ Seite 21
 Relative Luminous Flux²⁾ page 21
 $\Phi_V/\Phi_V(350\text{ mA}) = f(I_F); T_S = 25^\circ\text{C}$

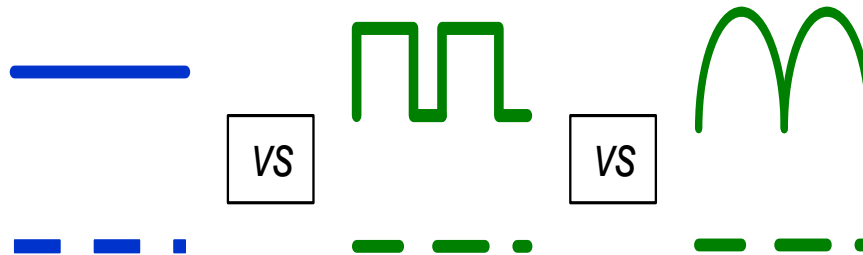


Relativer Lichtstrom²⁾ Seite 21
 Relative Luminous Flux²⁾ page 21
 $\Phi_V/\Phi_V(25^\circ\text{C}) = f(T_J); I_F = 350\text{ mA}$



LED Drivers

- Linear – constant current
- Switching – constant current + some % ripple

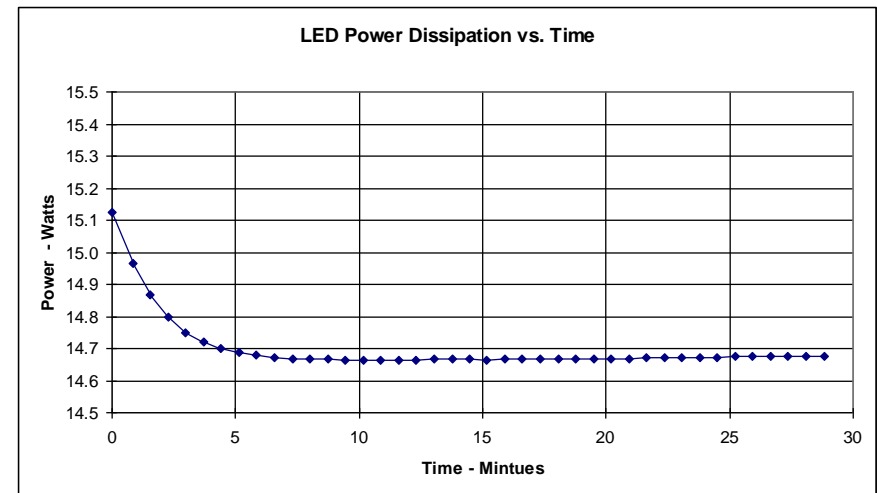


- How do the LEDs perform with modulated current?
- What characteristics change?
- What amount of change is acceptable?

Baseline: Constant Current

- Set $I_F = 700\text{mA}$
- Allow 30 minutes for thermal settling
- Measure T_A and T_{SP}
- $\Delta T_{DC} = T_{SP} - T_A$
- ΔT_{DC} is crucial because it is proportional to P_{DIS} of LED

- Measure:
 - P_{DIS} , Spectral Radiance
CCT, color coordinates
- Calculate:
 - Lumens, efficacy

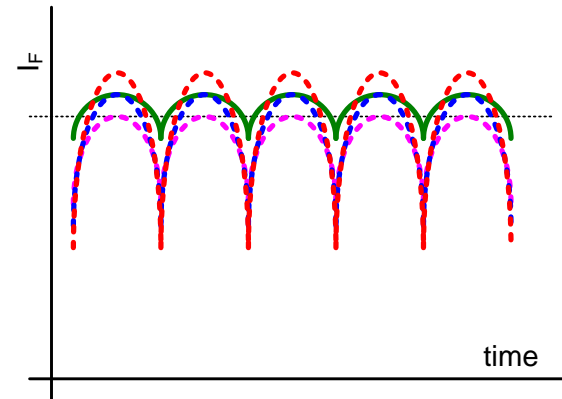


Baseline: Constant Current Results

- $T_A = 27.5^\circ\text{C}$, $T_{SP} = 105^\circ\text{C}$
- $\Delta T_{DC} = 77.5^\circ\text{C}$
- CCT = 3780 K (neutral white)
- $x = 0.3935$, $y = 0.3919$
- Lumens = 604.6 lm (6 LEDs ~ 100 lm each)
- $P_{DIS} = 14.68\text{W}$
- Efficacy = 41.2 lm/W

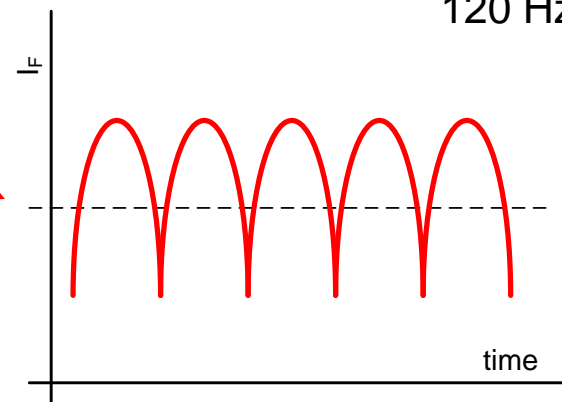
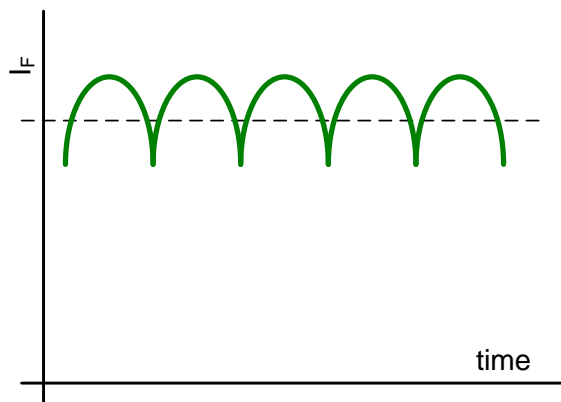
Modulated Current Test: Sine Wave

- Rectified Sine Wave
- Maintain $\Delta T_{\text{MOD}} = \Delta T_{\text{DC}}$
- How?
- As % Modulation $\uparrow I_{\text{AVG}} \downarrow$
- Why?

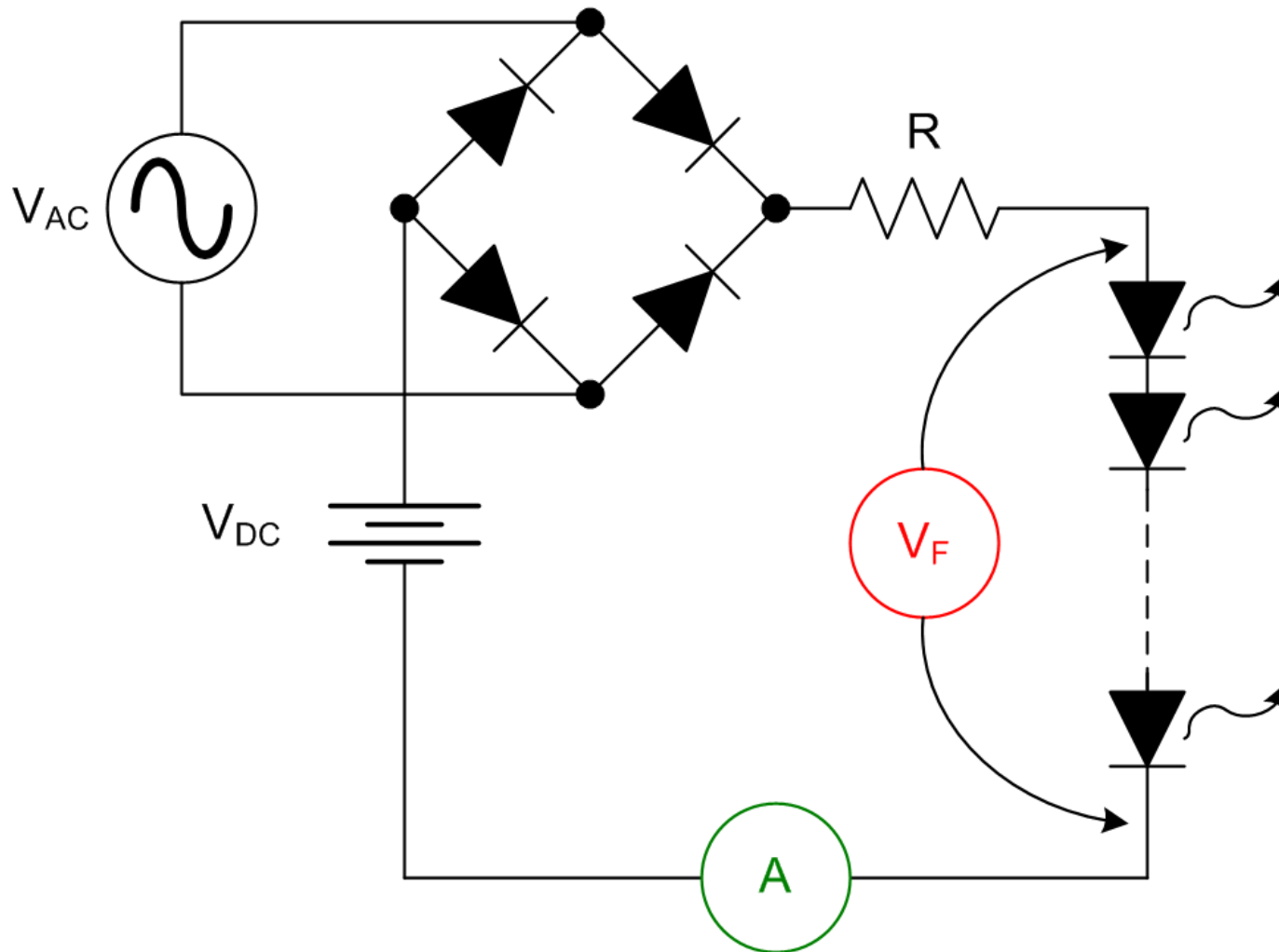


50% duty cycle

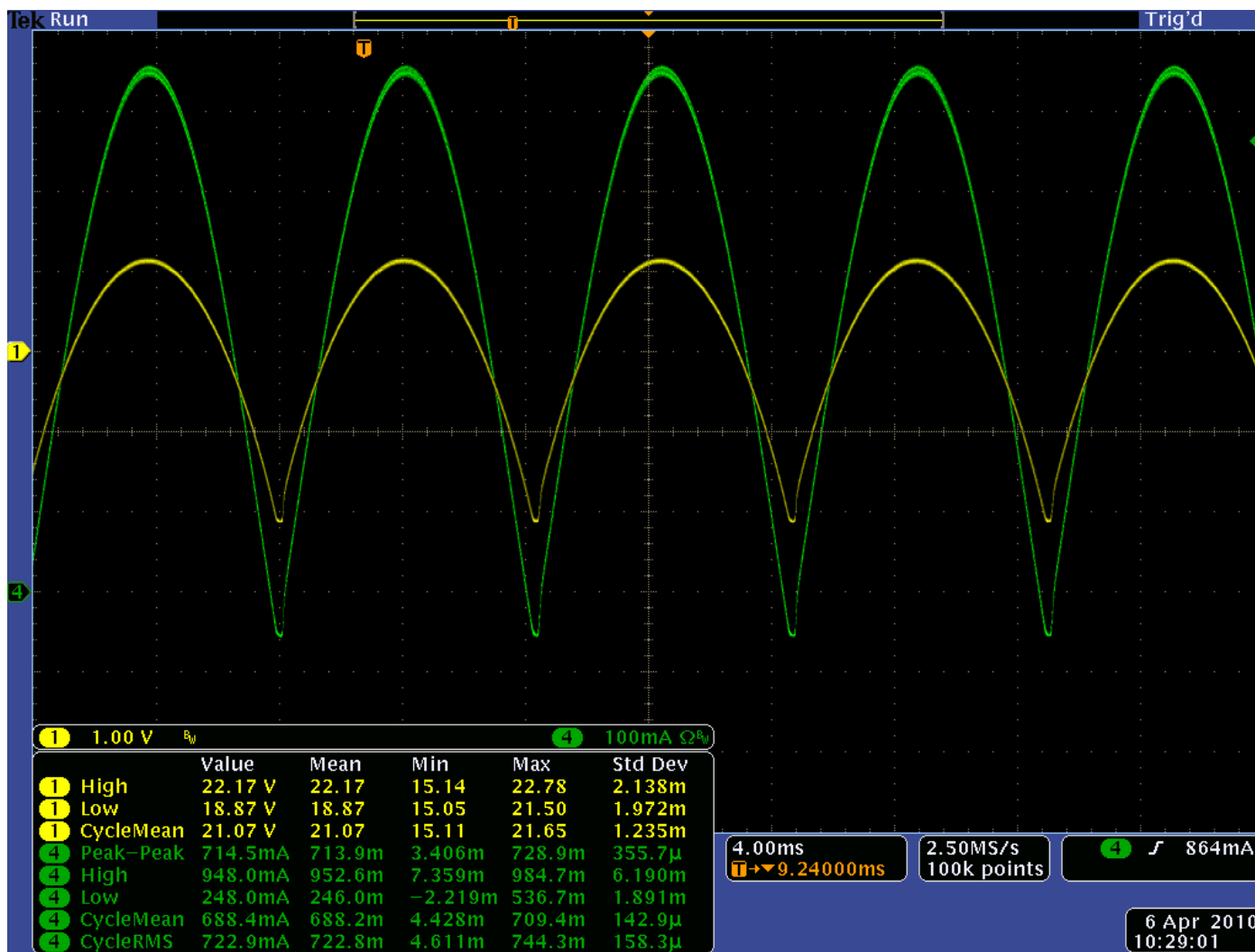
120 Hz ripple



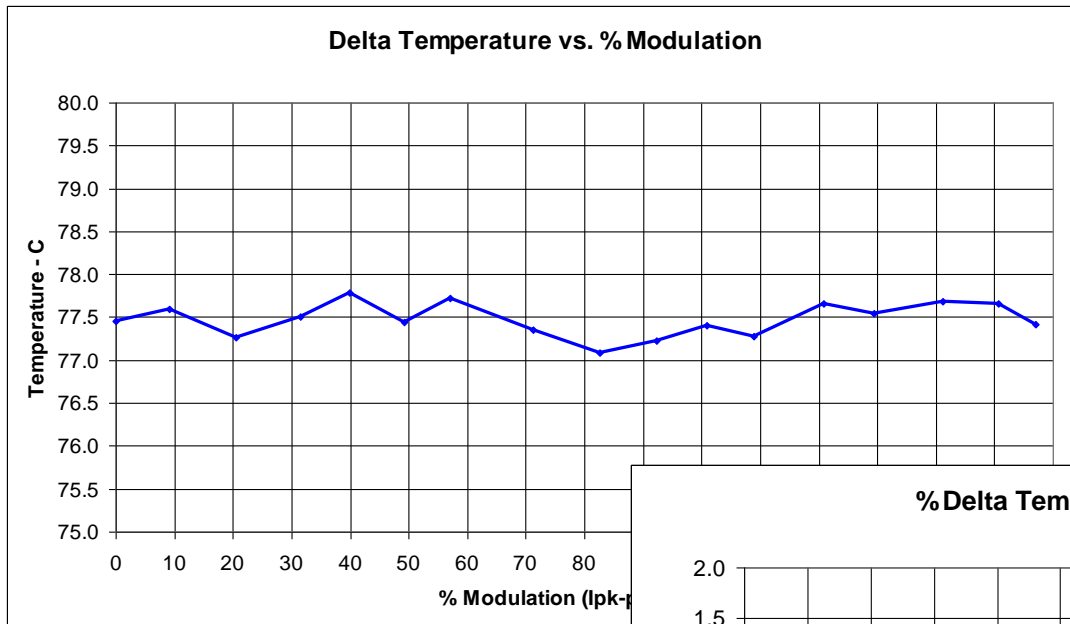
Modulated Current Test Circuit



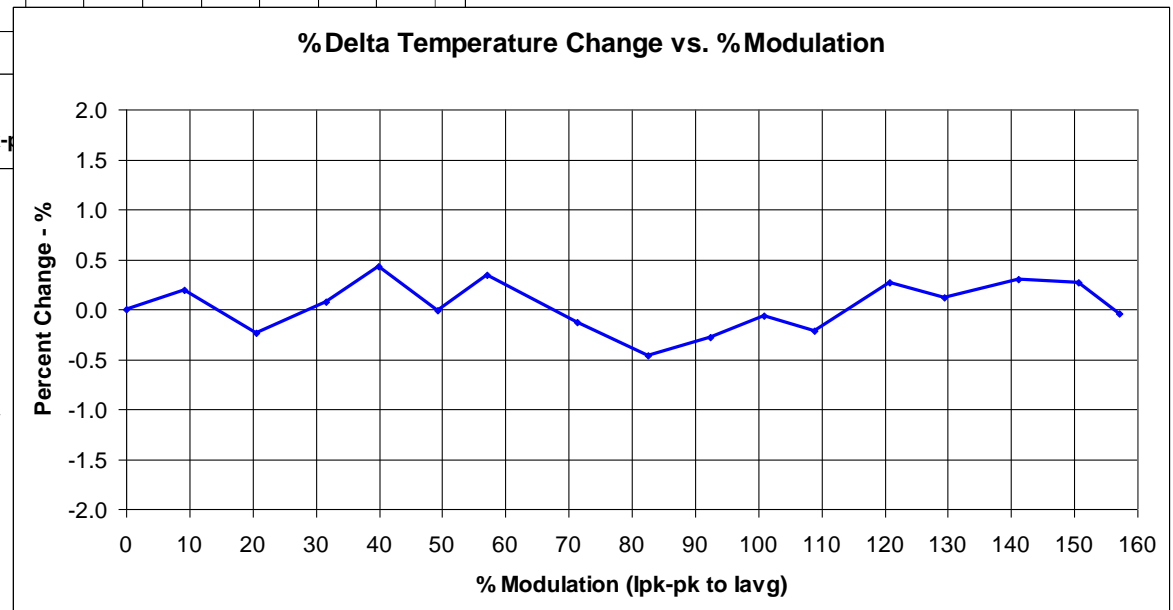
Modulated Current Test Waveform



Sine Wave Results

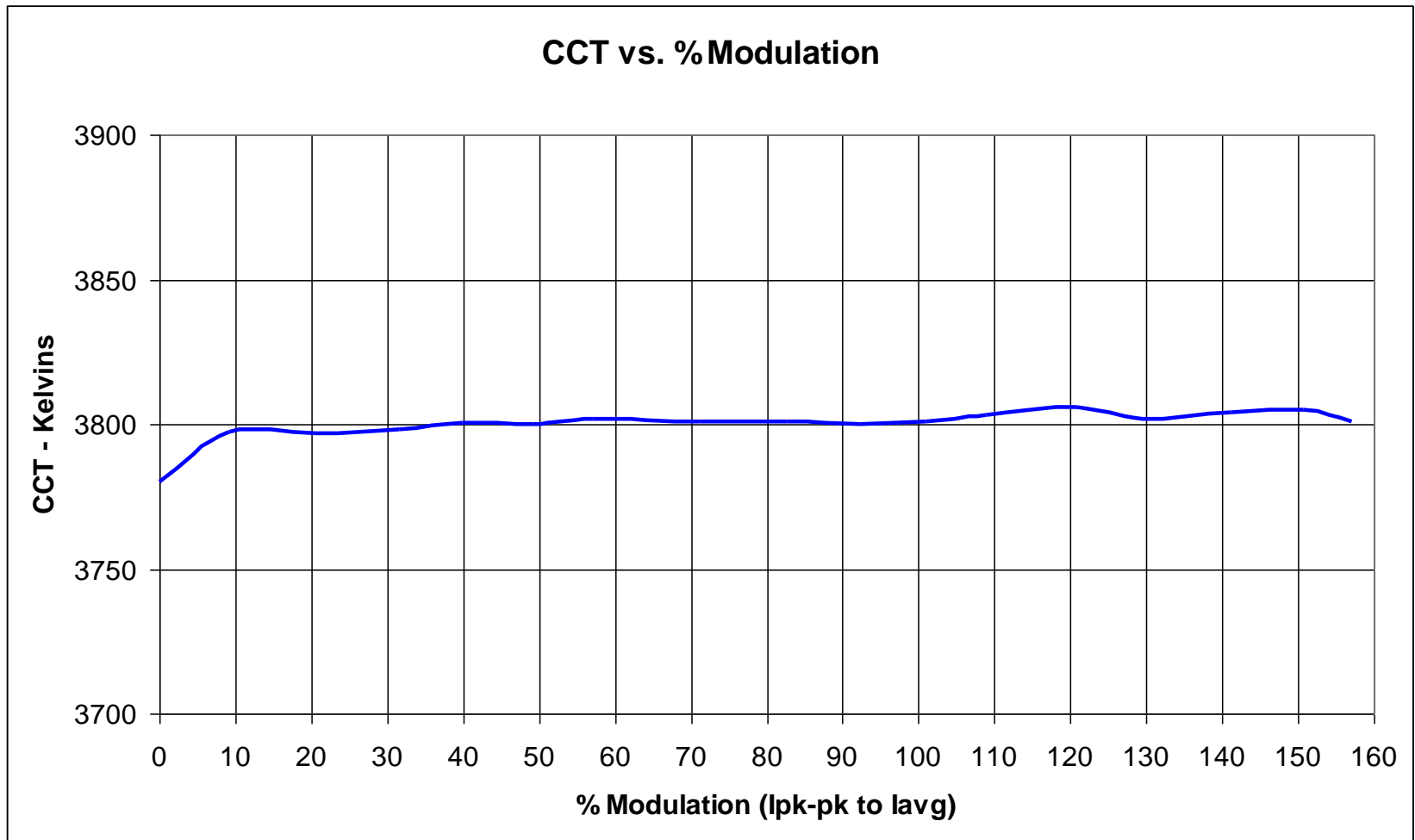


← Absolute Temperature

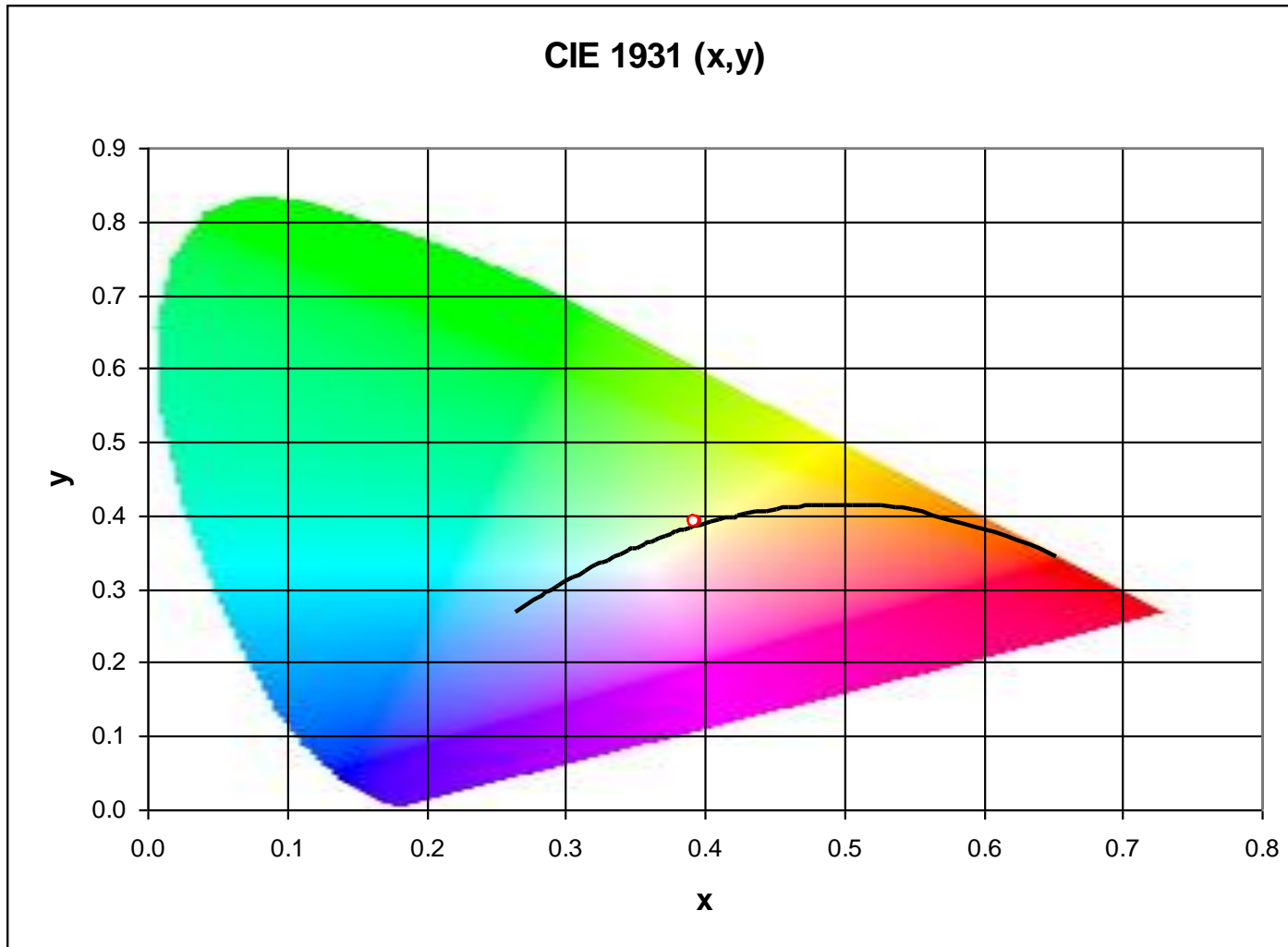


Normalized Change →

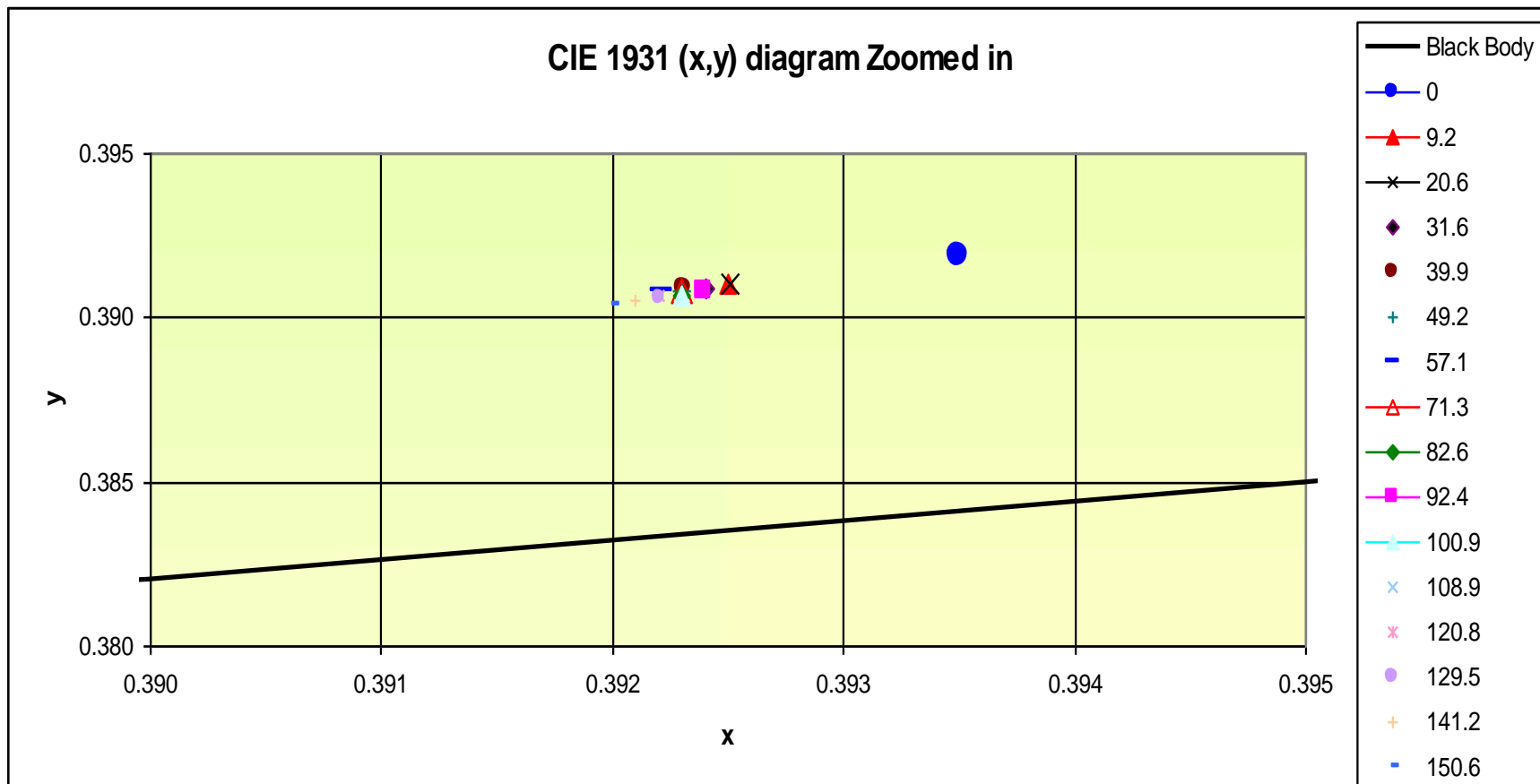
Sine Wave Results



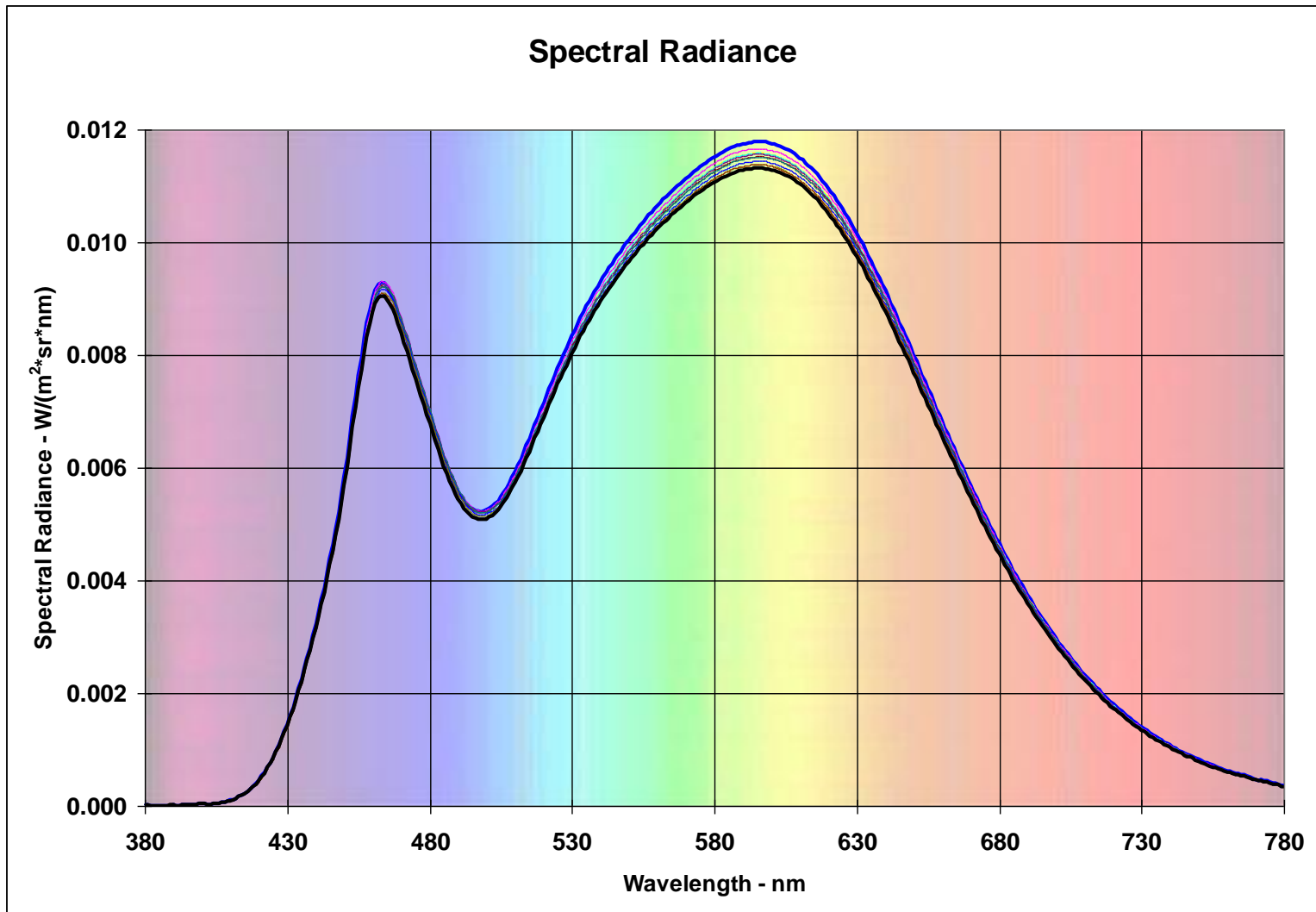
Results



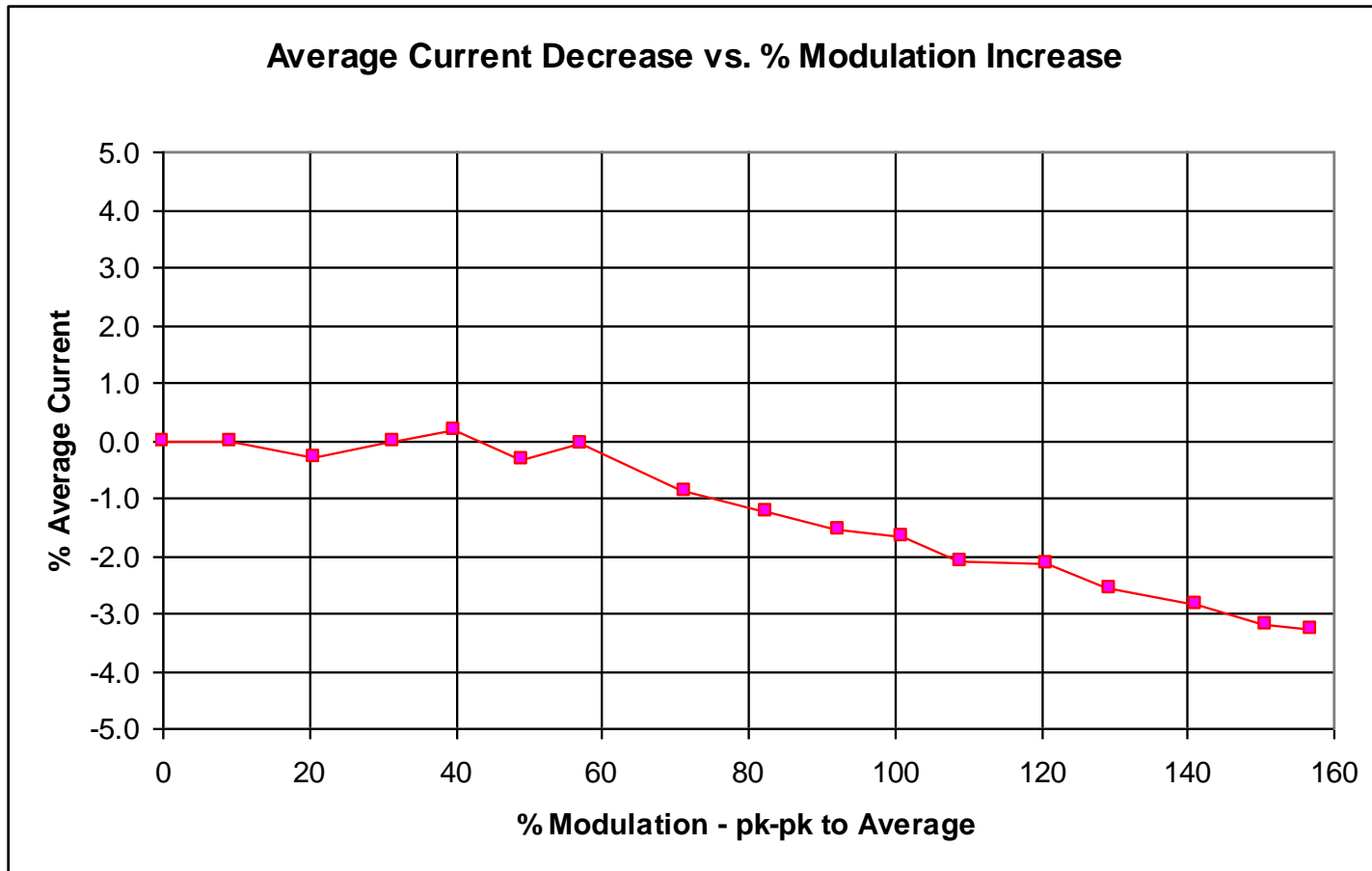
Sine Wave Results



Sine Wave Results



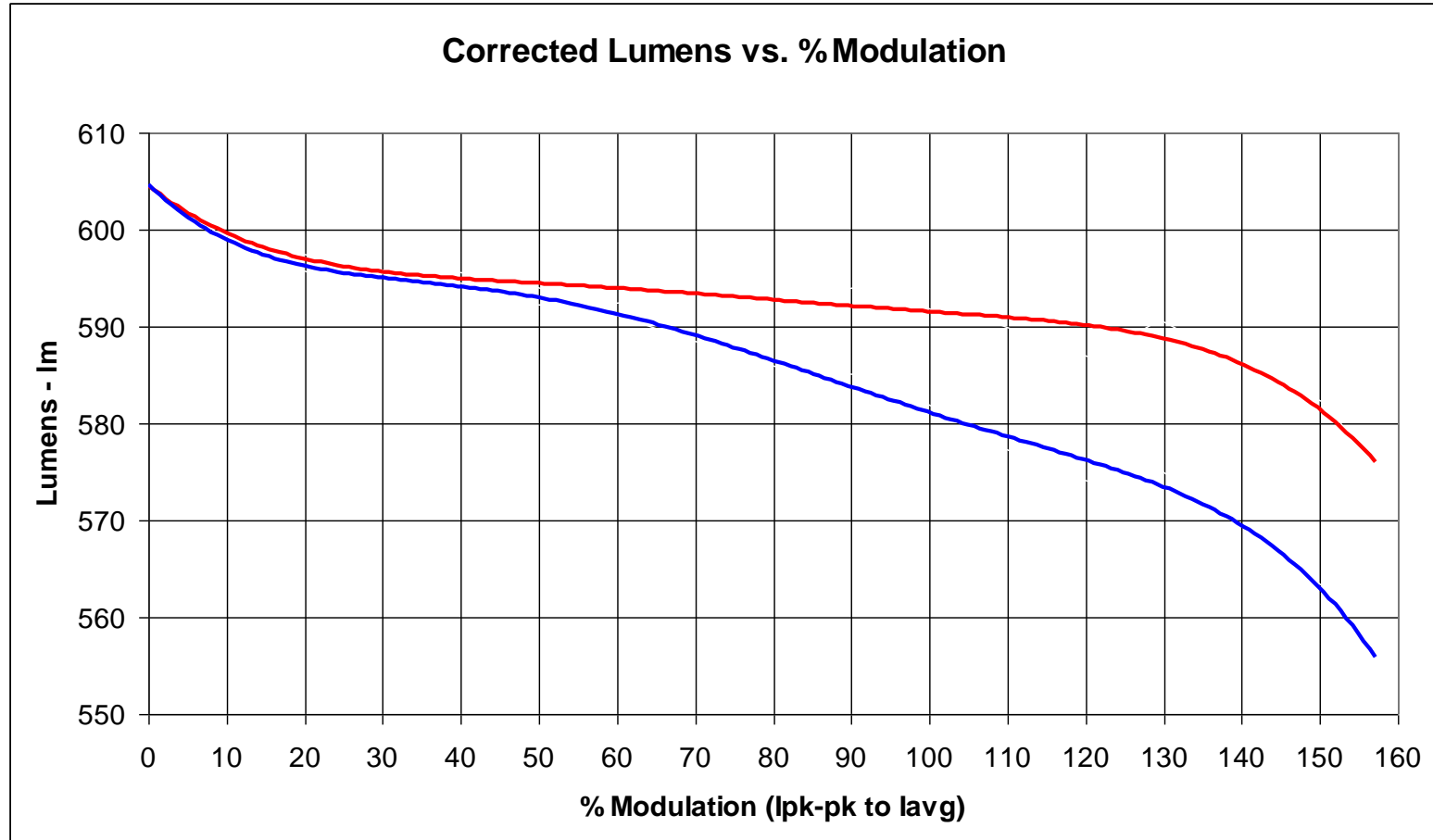
I_F Reduction vs. % Modulation



3.3% of 700mA = 23mA. A 3.3% change in forward current = 4.4% change in lumen output (26.4 lm).

So, at 157% modulation, I need to add 26.4 lumens to correct for the I_{AVG} reduction.

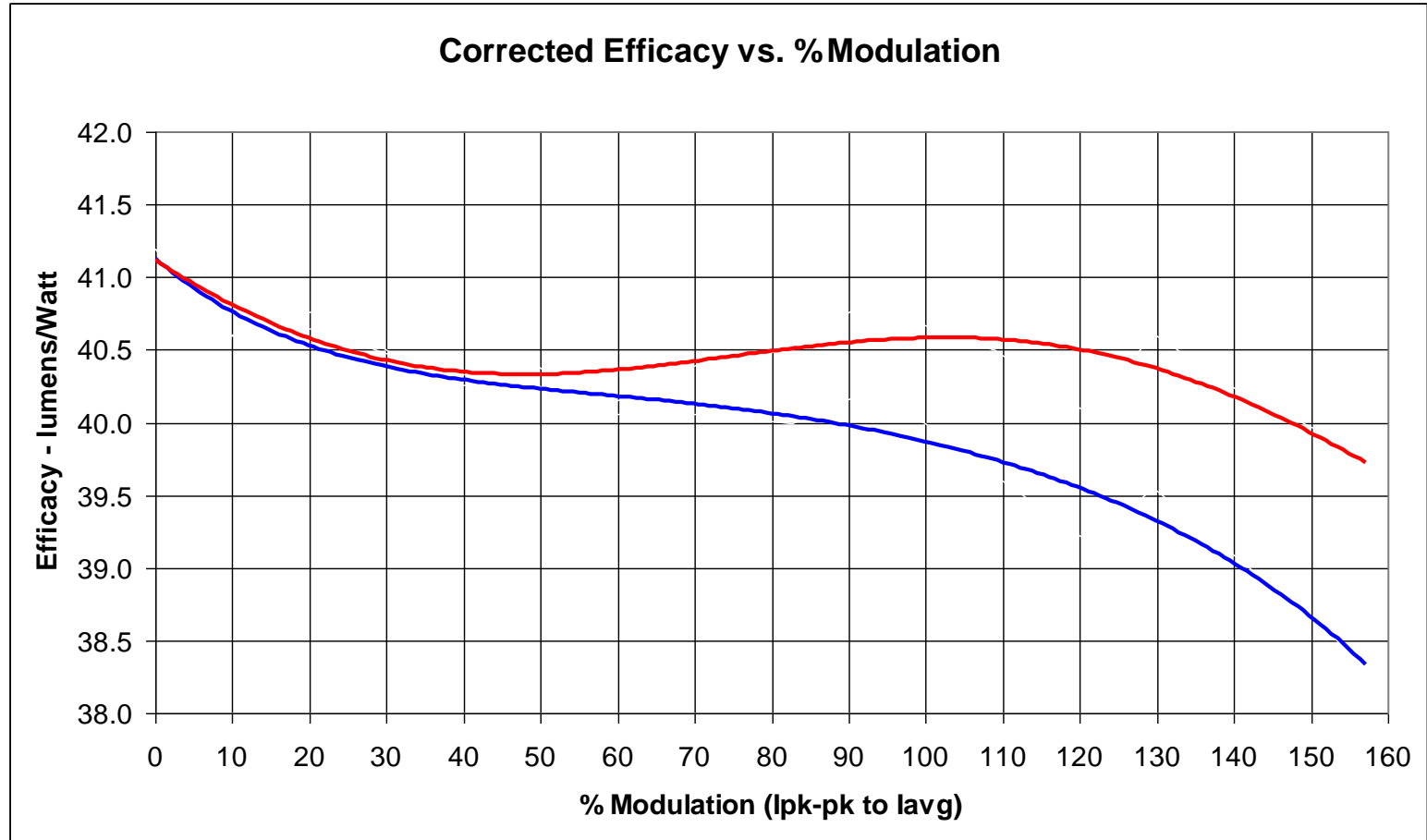
Lumens vs. % Mod. (corrected)



Uncorrected = Effects of Ripple & Lowered I_{AVG}

Corrected = Effects of Ripple Only

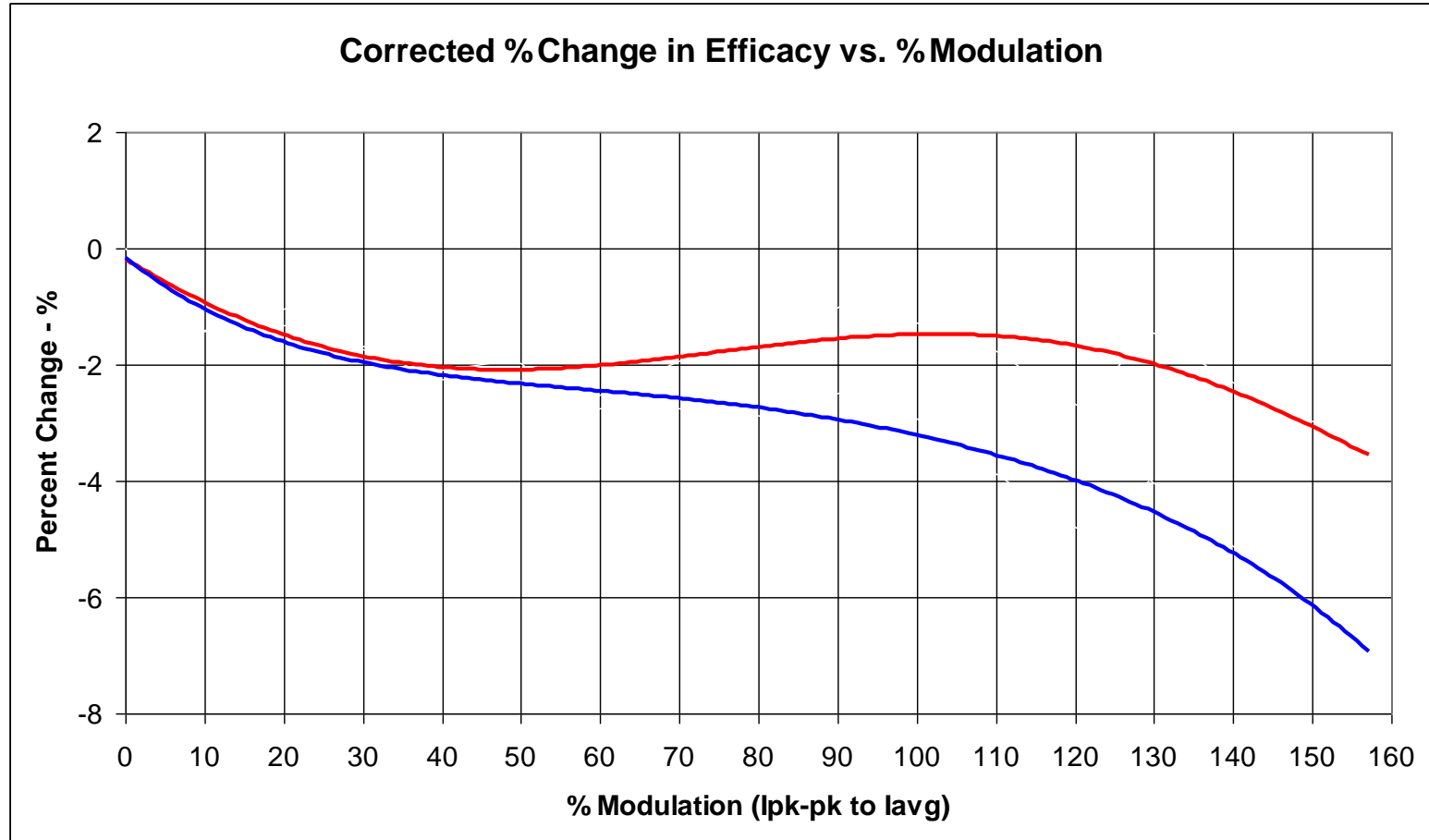
Efficacy vs. % Mod. (corrected)



Uncorrected = Effects of Ripple & Lowered I_{AVG}

Corrected = Effects of Ripple Only

% Efficacy vs. % Mod. (corrected)



Uncorrected = Effects of Ripple & Lowered I_{AVG}

Corrected = Effects of Ripple Only

CFL vs. LED: Photometric Ripple

- CFL Basics
 - CFL lamps operate from line voltage
 - Their drivers contain some amount of 120Hz electrical ripple
 - This electrical ripple translates into photometric ripple
 - Your eyes do not detect it, due to the amplitude & frequency
 - This amount of photometric ripple has been “good enough”
- So, the 60W replacement CFL became our “reference” lamp



CFL vs. LED: Photometric Ripple

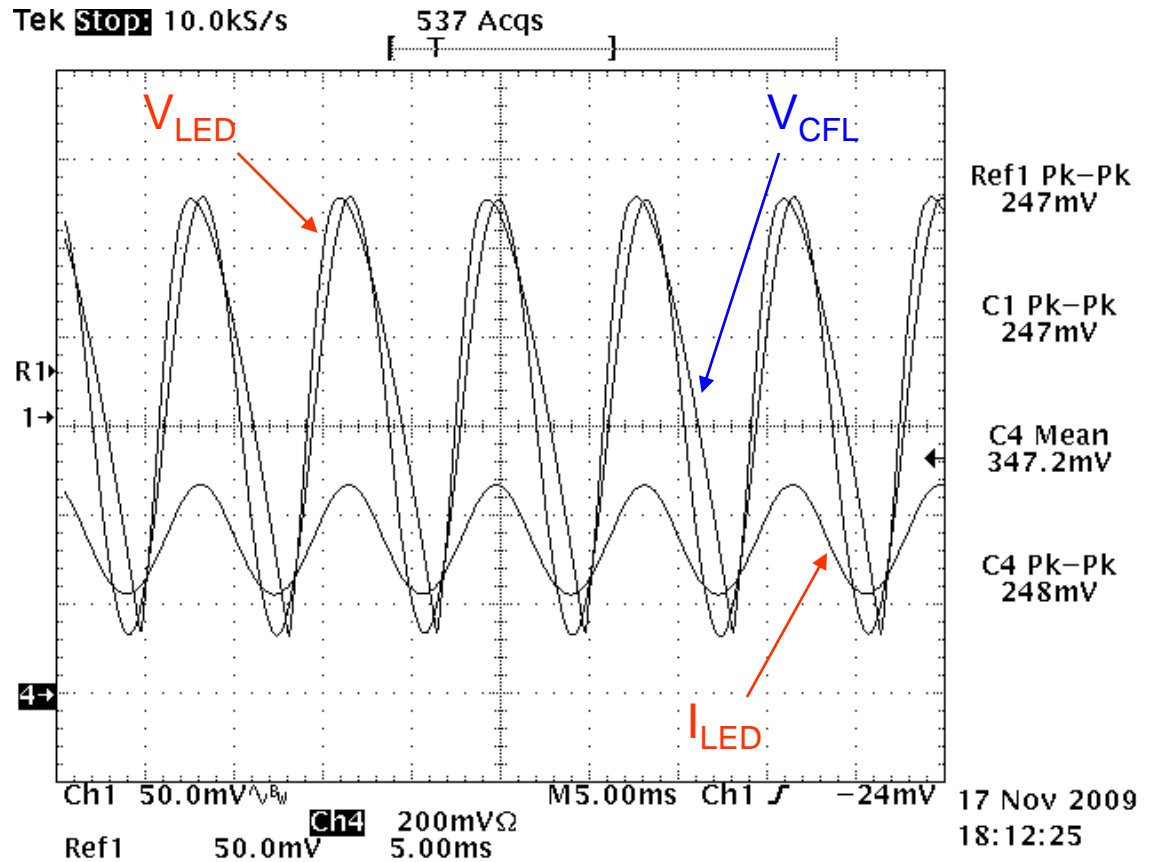
- How do you measure light ripple?
 - Cannot use a spectroradiometer – long measurement intervals
 - Wide-spectrum phototransistor – fast response time (6us)
- Test Method:
 - Power-up CFL and let it settle thermally/electrically
 - Measure its light ripple (relative value) ϕ_{CFL}
 - Drive the LED at rated DC current (350mA)
 - Superimpose a 120 Hz sine wave
 - Adjust the modulation amplitude until $\phi_{\text{LED}} = \phi_{\text{CFL}}$
 - Let the LED settle thermally/electrically
 - Measure the LED current ripple ($I_{\text{pk-pk}}$)

CFL vs. LED: Photometric Ripple

- ϕ CFL = 247mV

- LED = 347mA
plus sinusoidal
 ϕ LED occurred @
248mA_{pk-pk}

- % Mod. $I_{pk-pk} / I_{avg} =$
71%



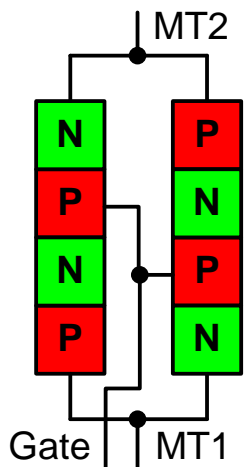
Summary

- Current ripple *does not* have a major effect on:
 - Color coordinates, or CCT
- Current ripple *does* effect:
 - Lumens, Efficacy – but *very minor effect*
 - If P_{DIS} is not regulated (as it was in this experiment), increasing the % ripple will increase the LED T_J
- Current CFL technology has high levels of optical ripple compared to typical LED levels.

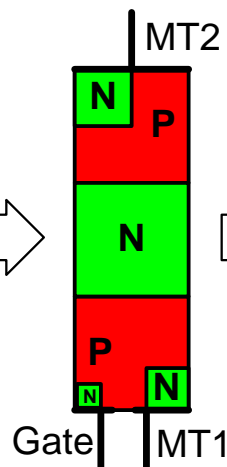
The TRIAC

- TRIAC: five layer semiconductor with gate
- Functions as two SCR's connected in inverse parallel
- Bipolar device driven to conduction by gate current or applied voltage
- Conducts provided the holding current requirements are met
- Can be triggered by fast dv/dt

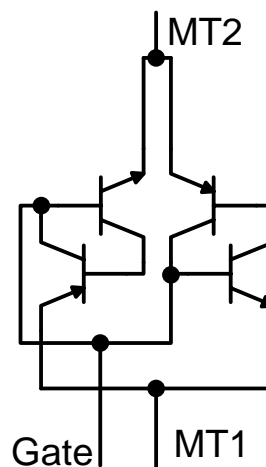
Inverse parallel SCR's



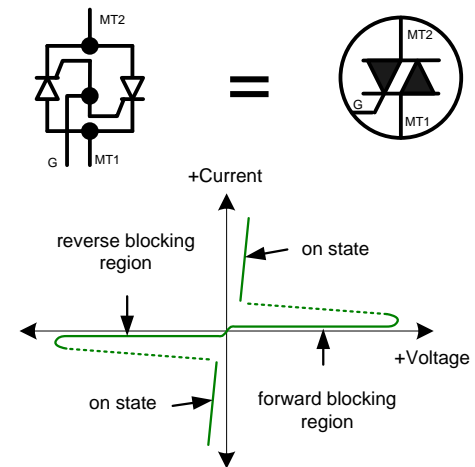
Triac



Equivalent Circuit

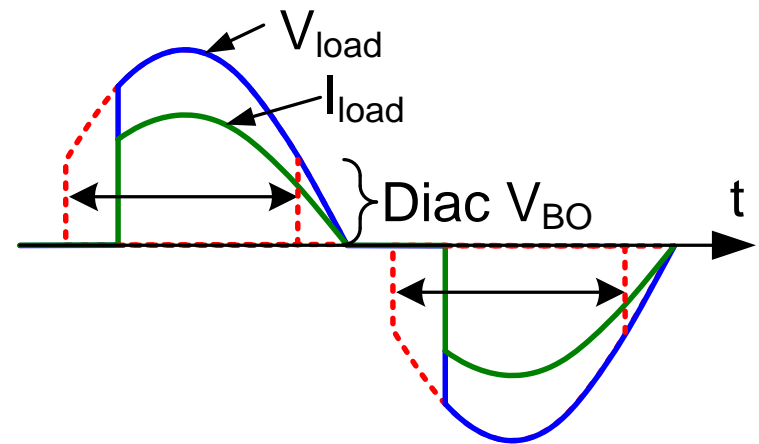
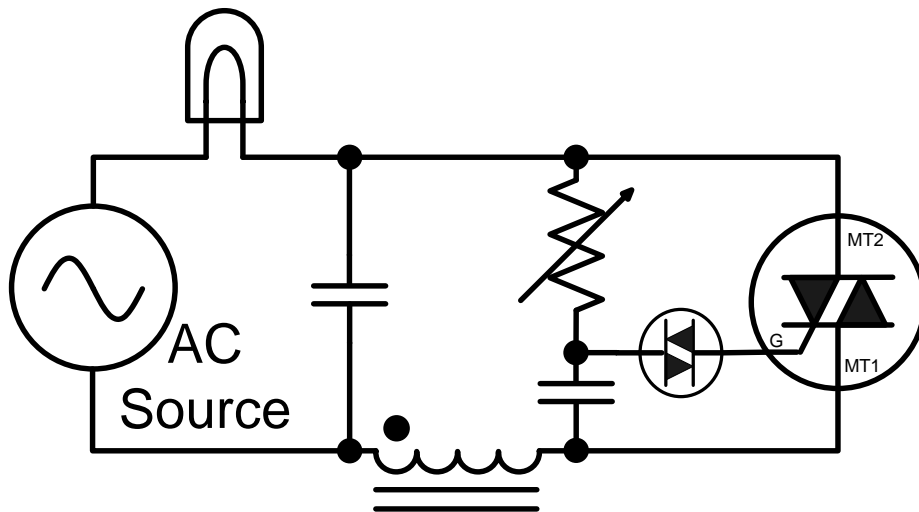


Triac Symbol



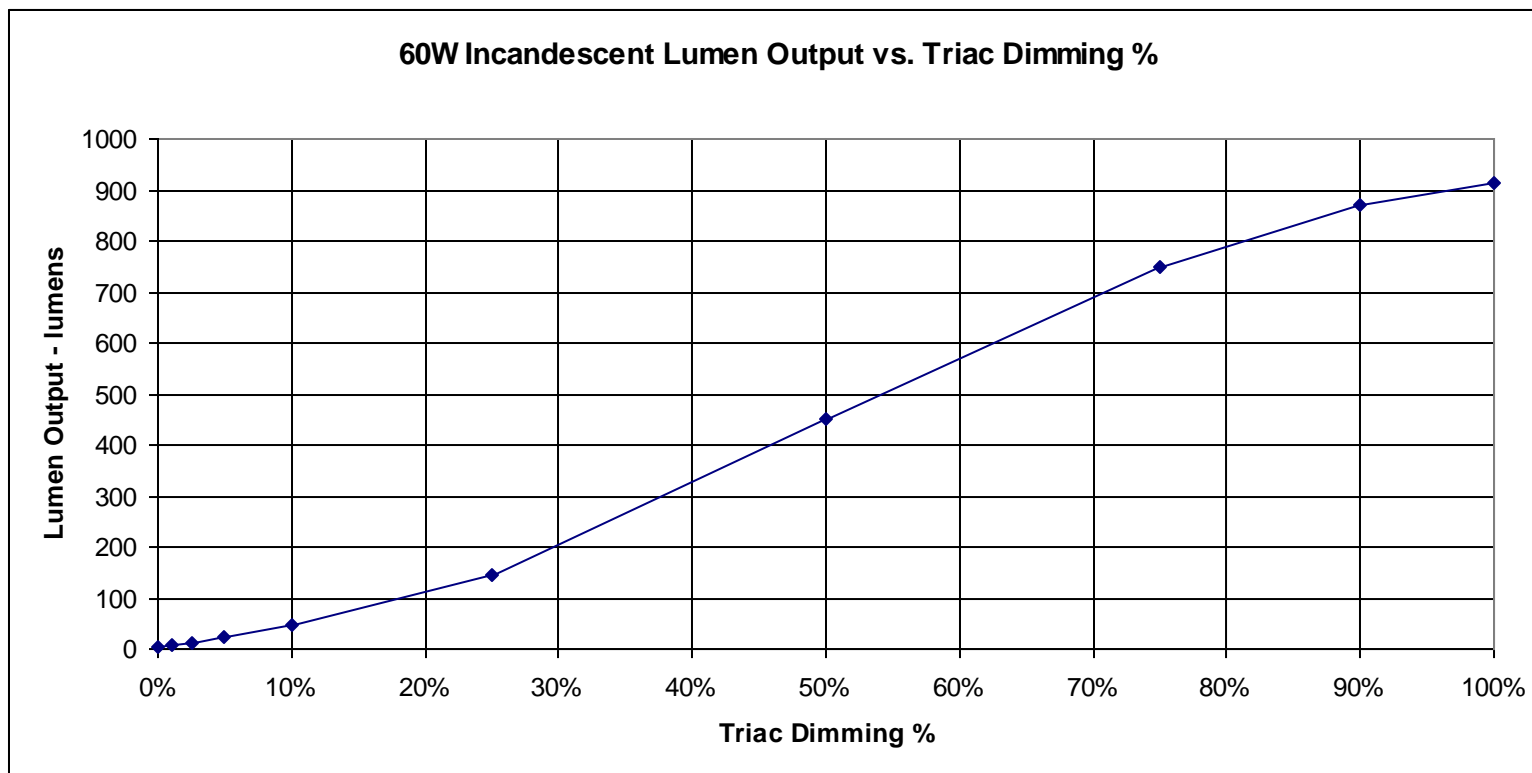
Practical TRIAC Dimmer

- Removes a portion of the leading edge of each line half-cycle
- Will trigger at any angle where line voltage exceeds Diac threshold
- More symmetrical triggering
- Resistance to Line Voltage Transients
- Compatible with resistive and inductive loads such as magnetic low-voltage halogen transformers (large inductive loads may damage dimmer)



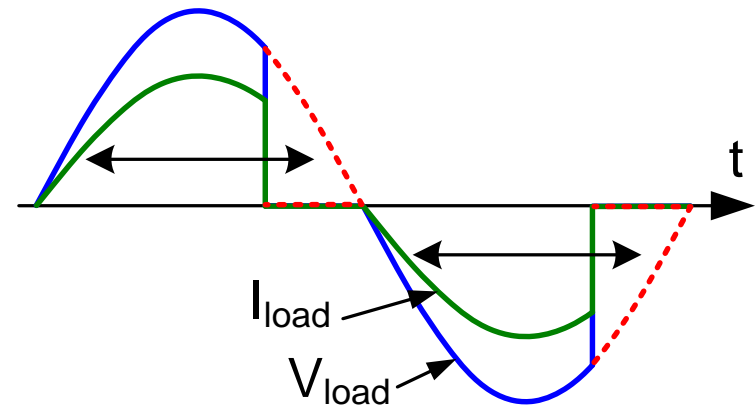
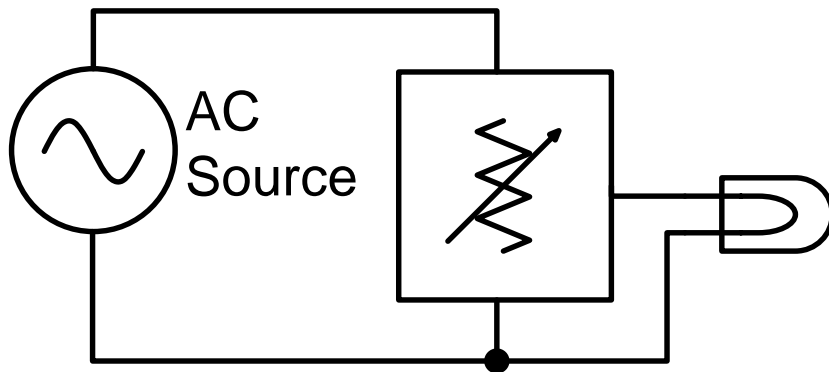
TRIAC Dimmer w/60W Incandescent Lamp

- Dimming profile of a 60W incandescent lamp connected to a triac dimmer.



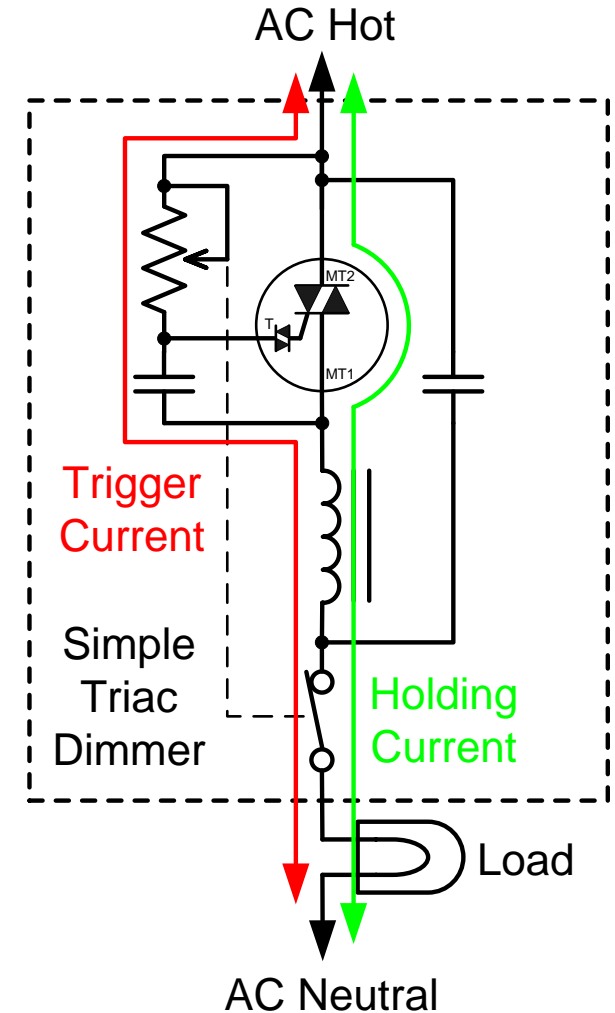
Trailing Edge Dimmer

- Requires a solid state switch that can be turned-off during the line half-cycle (MOSFET, IGBT, not a TRIAC).
- Compatible with resistive and capacitive loads such as electronic low-voltage halogen transformers



Practical Design Considerations for Triac Compatibility

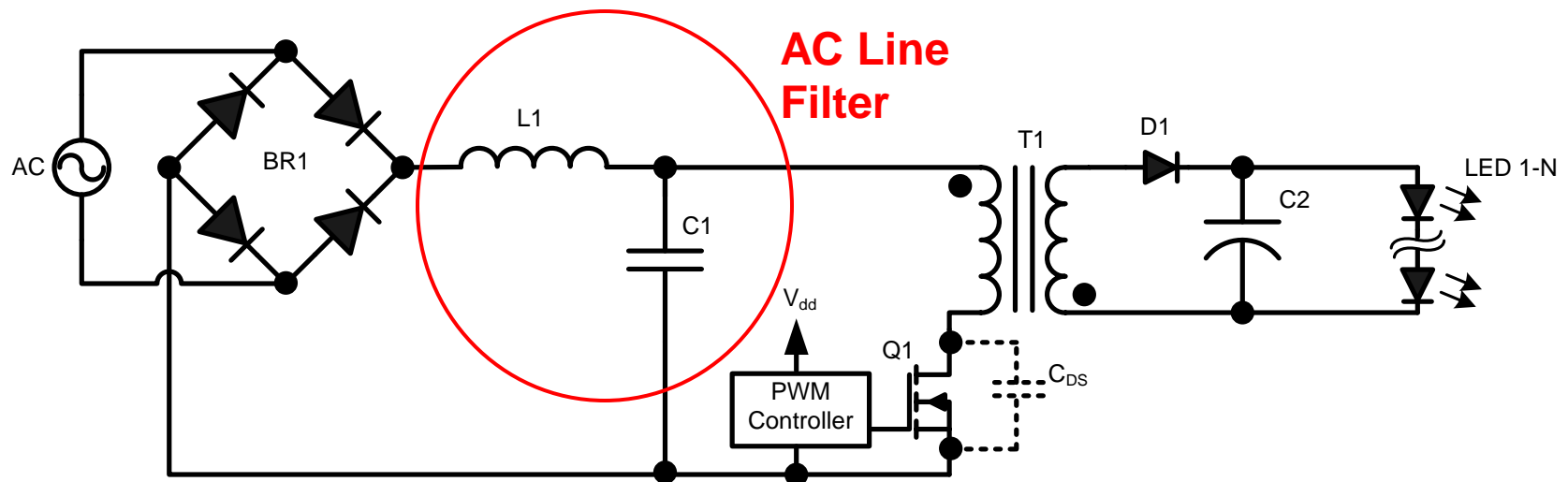
- Triac Trigger Requirements
 - The load is an integral and necessary part of the trigger circuit. Load impedance must remain sufficiently low at all times or maximum conduction angles will not be reached.
 - Trigger circuit must supply sufficient current to initially latch-on Triac
- Triac Holding Current Requirements
 - Typically 10-20mA, Triac will resume blocking if minimum holding current is not maintained continuously. Room temperature holding current requirements nearly double at -45C.



Practical Design Considerations for Triac Compatibility

- **AC Line Filter**

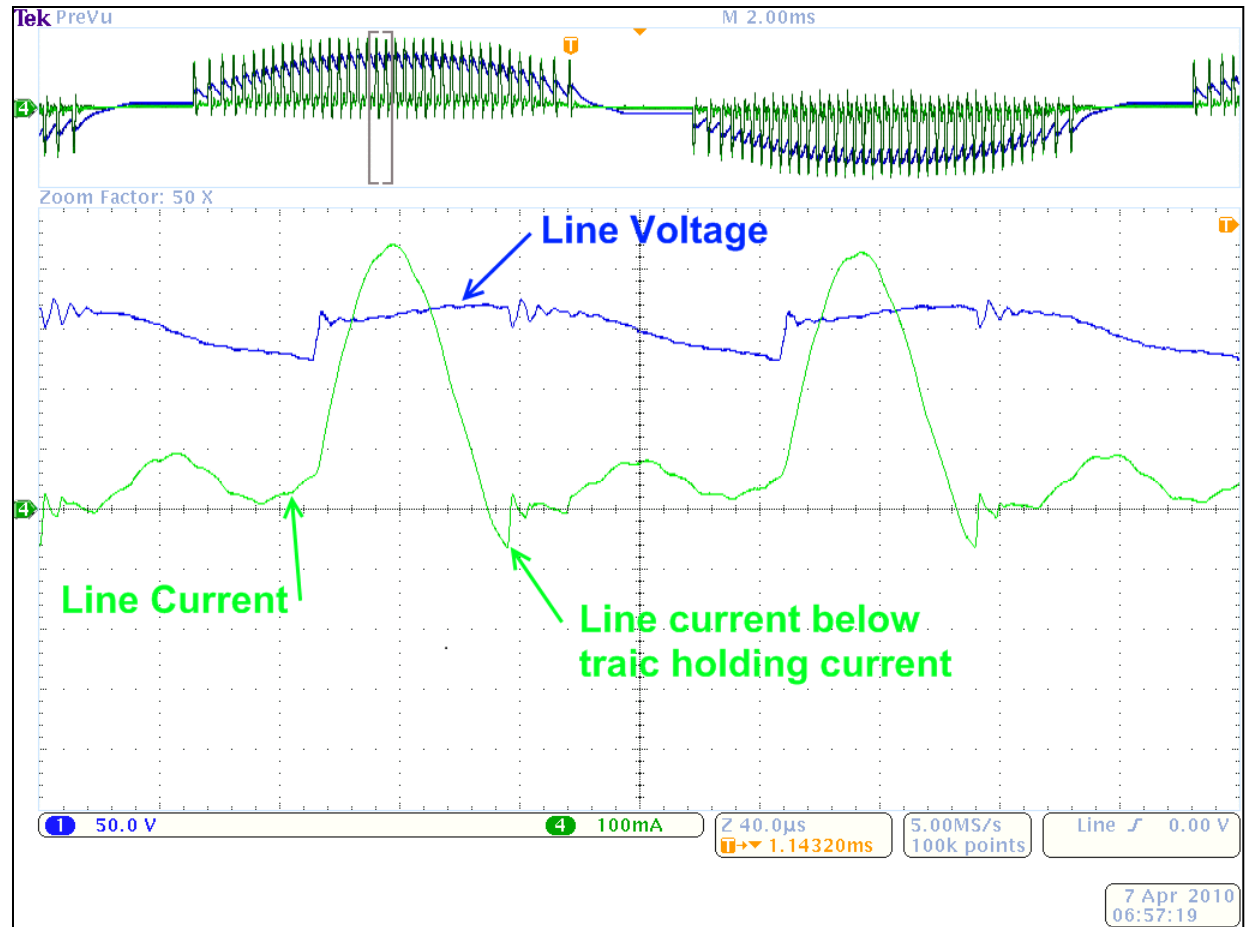
- A low pass filter is necessary to prevent high frequency switching currents from reaching the AC line as conducted emissions.
- The low pass filter must have low resistive losses and a high Q and so will ring when subjected to the fast rising edge of the Triac dimmer turn-on.
- Line filter ringing may result in line current reduction or reversal which in turn may cause the Triac to cease conduction.
- The simple solution is resistance in series or parallel with the AC line but will be accompanied by losses, particularly for 100VAC operation.



Practical Design Considerations for Triac Compatibility

•AC Line Filter

An example of an un-damped AC line filter causing a TRIAC dimmer to oscillate: After each TRIAC trigger the ringing line filter causes the line current to reverse which results in TRIAC turn-off. The cycle repeats for as long as the TRIAC trigger requirements are satisfied.



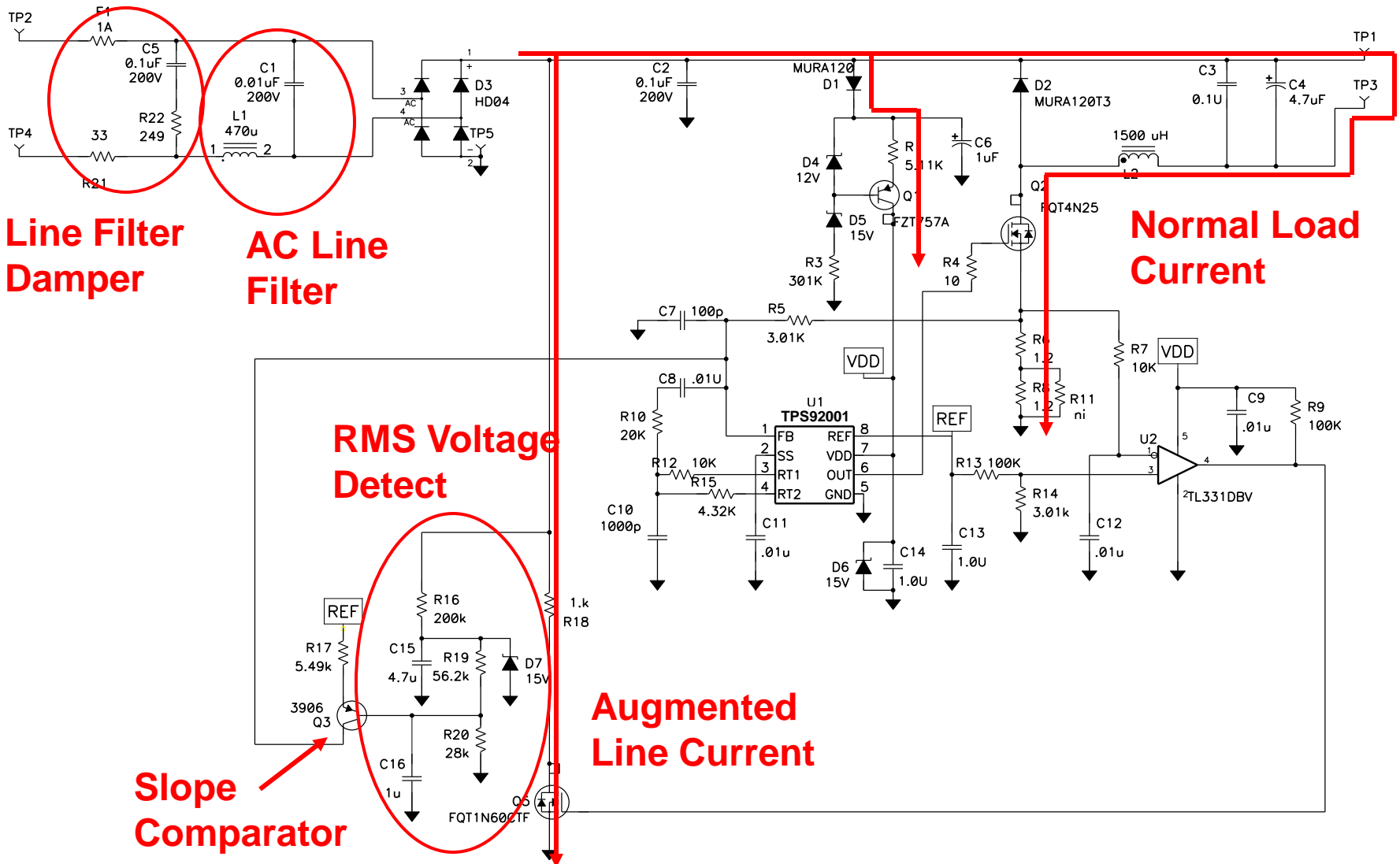
Practical Design Considerations for TRIAC Compatibility

- TRIAC Conduction angle detection
 - Dimming base on actual TRIAC conduction angle rather than RMS line voltage will provide rejection to line voltage variations
- Dimming profile
 - Like the human ear, the human eye has a log response to intensity. Consequently, a log dimming profile is more pleasing than a linear dimming profile.

TPS92001 Reference Design Strategy

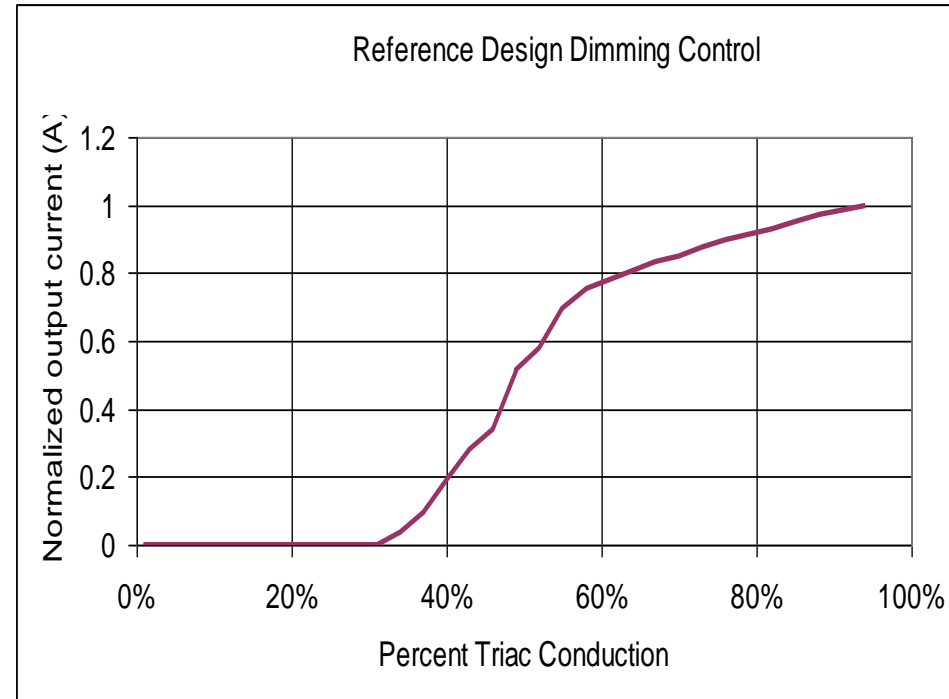
- AC Line Filter Damping:
 - Passive R-RC
- TRIAC Trigger Current:
 - Normal or augmented line current
- TRIAC Holding Current:
 - Active line current augmentation
- TRIAC Conduction Angle Detection:
 - Filtered RMS Line Voltage
- Dimming Profile:
 - Dual slope

TPS92001 PMP4981 Reference Design Schematic



TPS92001 PMP5163 LED Driver Dimming

- Operation with existing TRIAC dimmers requires a minimum current to maintain conduction
- Dual slope feature improves low angle dimming
- Audible noise can occur with PWM dimming, particularly with a high 120Hz ripple content. However, this reference design takes steps to minimize this noise.
- Color shift is negligible
- LED efficacy reduction is low

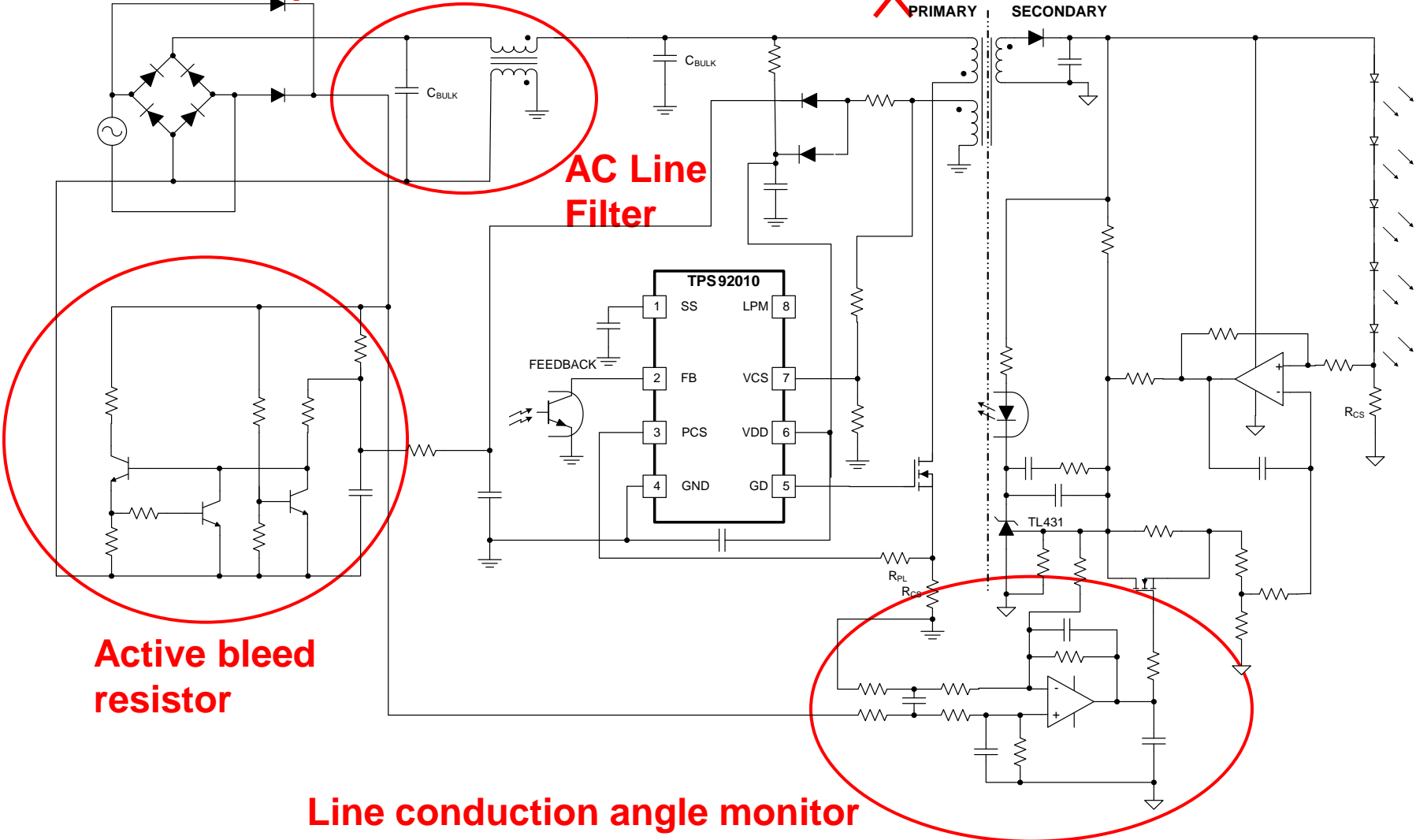


TPS92010 Design Strategy

- AC Line Filter Damping:
 - Not required
- Triac Trigger Current:
 - Active bleed resistor
- Triac Holding Current:
 - Not required
- Triac Conduction Angle Detection:
 - Direct AC Line Conduction Angle Monitor
- Dimming Profile:
 - Dual slope

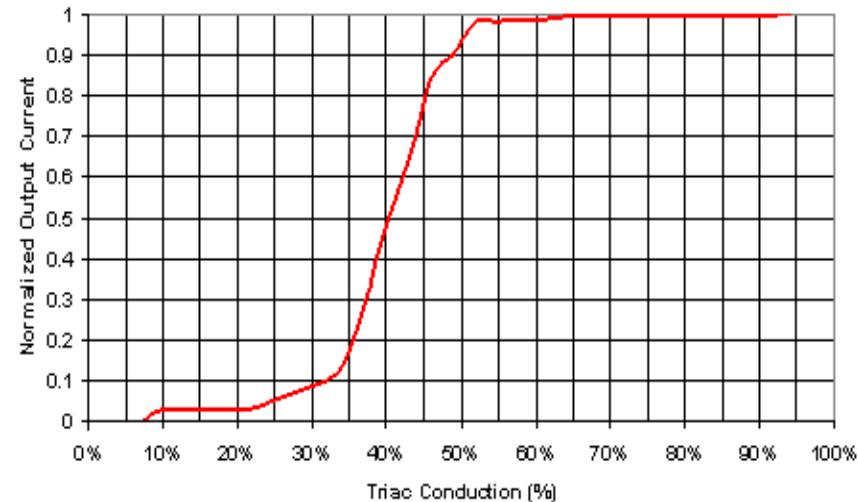
TPS92010EVM Schematic

No Damping
~~**Requires holding current!**~~ ❌



TPS92010EVM Dimming Performance

- Traditional problems TRIAC triggering and holding currents with LED lighting are solved.
- Dimmer triggering provides loading of the TRIAC at AC line crossover for proper dimmer operation.
- **DC current during dimming**
 - **No Stroboscopic effect**
 - **No audible noise**
 - **No ripple current efficacy loss**
- **Steady deep dimming**
 - **Two Step dimming pleasing to eye**



TPS92210 Reference Design Strategy

- AC Line Filter Damping:
 - Active RC Damper... low loss
- Triac Trigger Current:
 - Normal line current or source follower
- Triac Holding Current:
 - Active line current augmentation (secondary side)
- Triac Conduction Angle Detection:
 - Reconstructed Line Voltage (secondary side)
- Dimming Profile:
 - Log + Linear

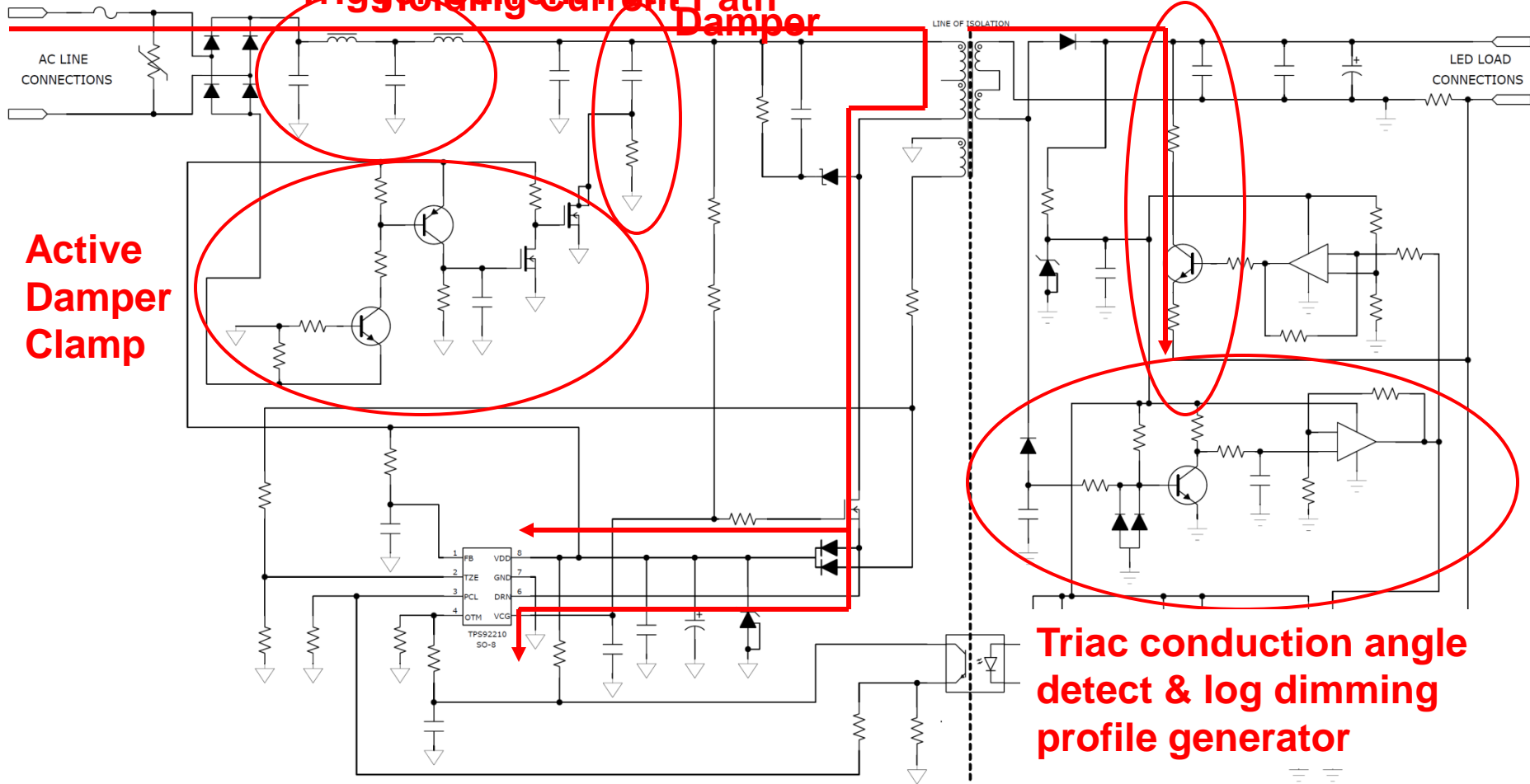
TPS92210 Reference Design

Schematic

AC Line Filter
Trigger Current Path
Line Filter
Dampers

Line current
augmentation

Active
Damper
Clamp



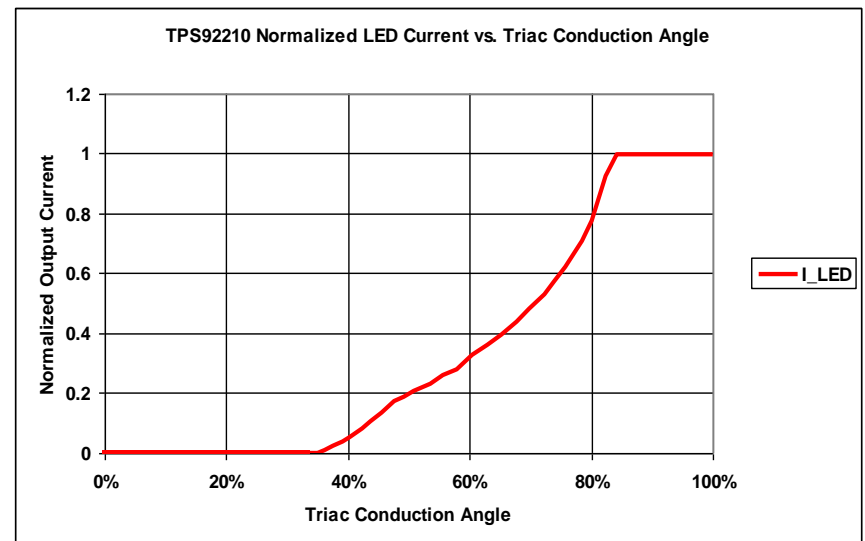
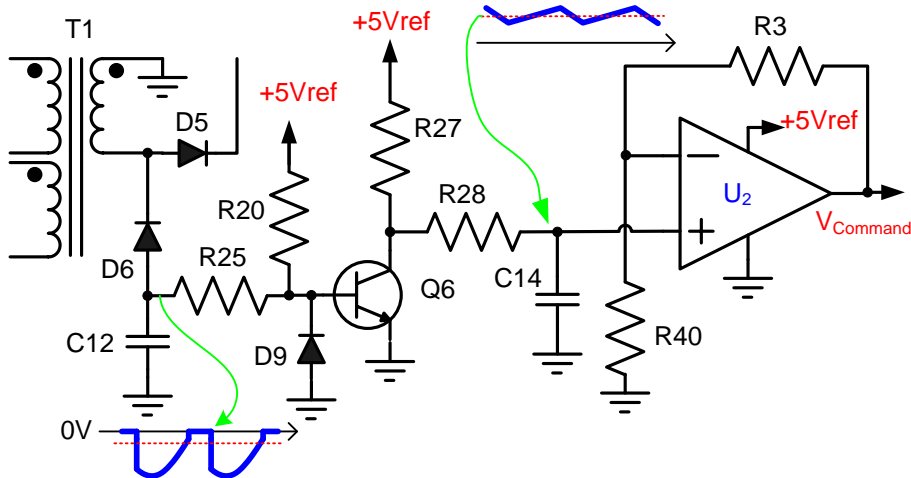
TPS92210 Dimming Performance

- **Dimmer Compatibility**

- Dimming Profile:

- The TPS92210 EVM dimming angle detection circuit has a logarithmic duty-cycle to voltage transfer function accurate over more than a decade and then responds linearly to near zero. An offset on the measured output current allows dimming the LED to total darkness. Logarithmic dimming closely matches the response of the human eye.

- Ripple in LED current causes negligible color shift and efficacy reduction



Conclusions

- LED drivers must provide a path for TRIAC dimmer trigger current
- LED drivers must meet the minimum holding current requirement of the TRIAC dimmer to insure full conduction for each line half-cycle
- AC line filters must be critically damped to avoid erratic TRIAC behavior.
- Non power factor corrected LED drivers can ignore the holding current requirements of the TRIAC dimmer

Thank You

- Special Thanks to Joel Brassfield and Gary Guenther with Texas Instruments for putting together the content of this presentation.

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