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DN05046/D

120 V_{AC}, Low-Cost, Dimmable, Linear, Parallel-to-Series LED Driving Circuit

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DESIGN NOTE

Table 1. DEVICE DETAILS

Device	Application	Topology	Input Voltage	Input Power	Power Factor	THD
NSIC2030B	LED Lighting	Linear	100 to 130 V_{AC}	6.7 W	0.97	24%

Overview

This design is a low-cost, off-line, dimmable, linear LED driver solution suitable for general illumination applications in the commercial, industrial, and consumer market sectors. The circuit uses the ON Semiconductor Constant Current Regulator to control the current through the LEDs and to protect against voltage surges. It is comprised of two sets of LEDs that are switched between parallel and series configurations when a threshold voltage is passed to provide improved efficiency (tunable from 72% to 94%), power factor, and total harmonic distortion attributes. The circuit is completely functional with standard phase-cut dimmers for incandescent lights. It is designed to function consistently over a wide range of temperatures and has been proven from −40 to +60°C.

Key Circuit Features

- Fully Functional with Standard Phase-cut Dimmers
- High Light Output
- Very Low-Cost
- No Inductors
- Power Factor = 0.97
- Input Current THD = 24%
- Efficiency = 72% (94% with Four LEDs per String)
- Tested and Proven from −40 to +60°C
- Wide Input Voltage Range
- Constant Current and Protection for LEDs
- Suitable for Small Form Factor Applications
- Adaptable to Drive more LEDs

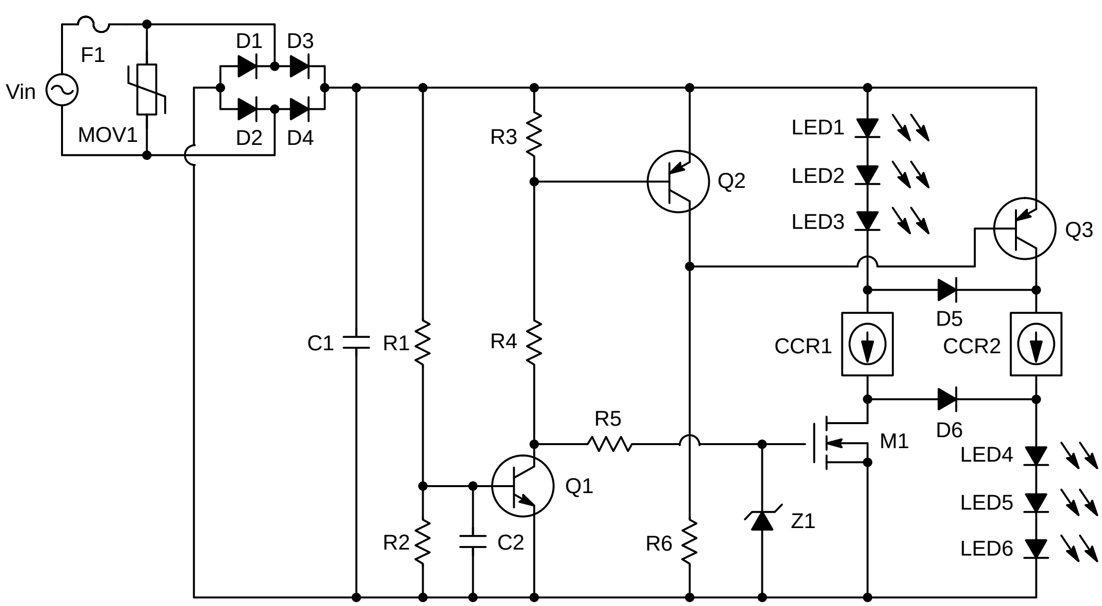

Figure 1. 2-stage Parallel-to-Series CCR Lighting Circuit

Circuit Description

The circuit consists of a full-wave bridge rectifier (D1−D4), a threshold detection and switching circuit (D5−D6, Q1−Q3, and M1), two LED strings (LED1−LED3 and LED4−LED6), and two ON Semiconductor Constant Current Regulators (CCR1 and CCR2).

Circuit Operation

The bridge rectifies the 60 Hz, 120 V_{rms} input providing a 120 Hz half-sin waveform with a peak voltage of 170 V. The bridge output is referenced from the cathodes of D3 and D4 to the anodes of D1 and D2. The bridge output voltage is applied across R1 and R2 creating a voltage divider. The voltage at the junction of R1 and R2 is used to turn on Q1, triggering the switching between the parallel and series configurations. The voltage at which the circuit switches is referenced as V_{SWITCH}.

It is recommended that V_{SWITCH} be set just above the forward voltage of the two LED strings in series configuration, which is about 110 V in the provided circuit. Referring to Figure 1, V_{SWITCH} depends on R1, R2, and the $V_{BE(sat)}$ of Q1. This relationship is expressed by the following equation:

$$V_{SWITCH} = V_{BE(sat)} \cdot \left(\frac{R1 + R2}{R2}\right)$$

Q1 is an ON Semiconductor MMBT3904L. A $V_{BE(sat)}$ value of Q1 at 25°C is 0.68 V. With R1 = 1 MΩ and R2 = 6.2 kΩ, VSWITCH is about 110 V.

When the bridge output voltage is less than 110 V, the two LED strings are in parallel. As shown in Table 2, Q1 & Q2 are off and M1 & Q3 are on. D5 and D6 do not conduct because they are reverse-biased. Z1 protects the gate of M1. When the bridge output voltage is greater than 110 V, the two LED strings are in series. Q1 & Q2 are on and M1 & Q3 are off. D5 and D6 conduct and join the two LED strings.

The circuit achieves an efficiency of 72%. Improved efficiency of 94% is achievable by inserting an additional LED in each string. However, with four LEDs per string, power factor falls from 0.97 to 0.90, THD rises from 24% to 47%, and dimming performance is degraded.

Table 2. STATES OF THE TRANSISTORS AND CONNECTING DIODES IN PARALLEL AND SERIAL OPERATION

	LED Configuration	
	Parallel	**Series**
D5	Reverse-Biased	Forward-Biased
D6	Reverse-Biased	Forward-Biased
M1	On	Off
Q1	Off	On
Q2	Off	On
Q3	On	Off

Circuit Data

Table 3. ELECTRICAL CHARACTERISTICS FOR THE CIRCUIT SHOWN IN FIGURE 1

Criteria	110 V_{AC} Result	120 V_{AC} Result	130 V_{AC} Result
Input Frequency (Hz)	60	60	60
Power (W)	6.11	6.72	7.28
Input Current (mA_{rms})	57.1	57.4	57.3
Power Factor	0.970	0.972	0.974
THD (%, Input I_{rms})	25.0	24.1	23.3
Efficiency (%)	75.6	72.4	69.0

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

Dimmers Tested

Table 4. THE CIRCUIT WAS FULLY FUNCTIONAL WITH EACH DIMMER TESTED

Dimmer
Cooper Aspire 9530
GE DI 61
Kuei Lin AC 110 V, 500 W
Leviton 6615−POW
Leviton 6633−PLW
Leviton 6674 Universal
Leviton Illumatech IPI06
Leviton OC58L1
Lightolier CT600WC
Lutron CT−603PGH
Lutron CTCL−153PD
Lutron MAW−600H
Lutron TG−10PR
Lutron TG−600P−AC
Lutron TG−600PH
Lutron S−600PR
Pass & Seymour D703PLAV
Pass & Seymour DCL453PTC
Pass & Seymour LS603PLAV
Pass & Seymour LSLV603PWV
Pass & Seymour WS703PW
SCT YM2508A
WattStopper DCD267 Universal

Representational Circuit Diagrams

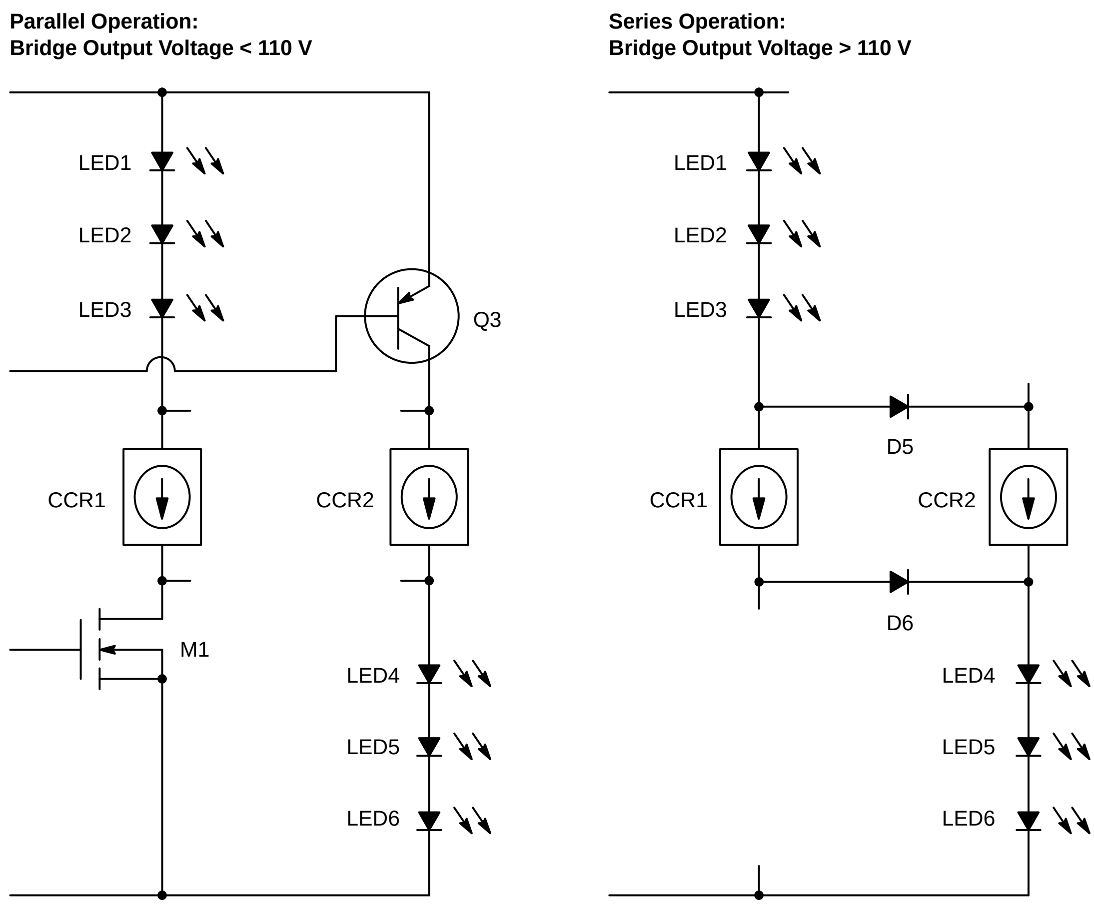

Figure 2. The Circuit Switches between Parallel and Series LED Configurations as the Bridge Output Voltage Passes 110 Volts. Total Input Current is the Same in both Configurations.

Waveforms

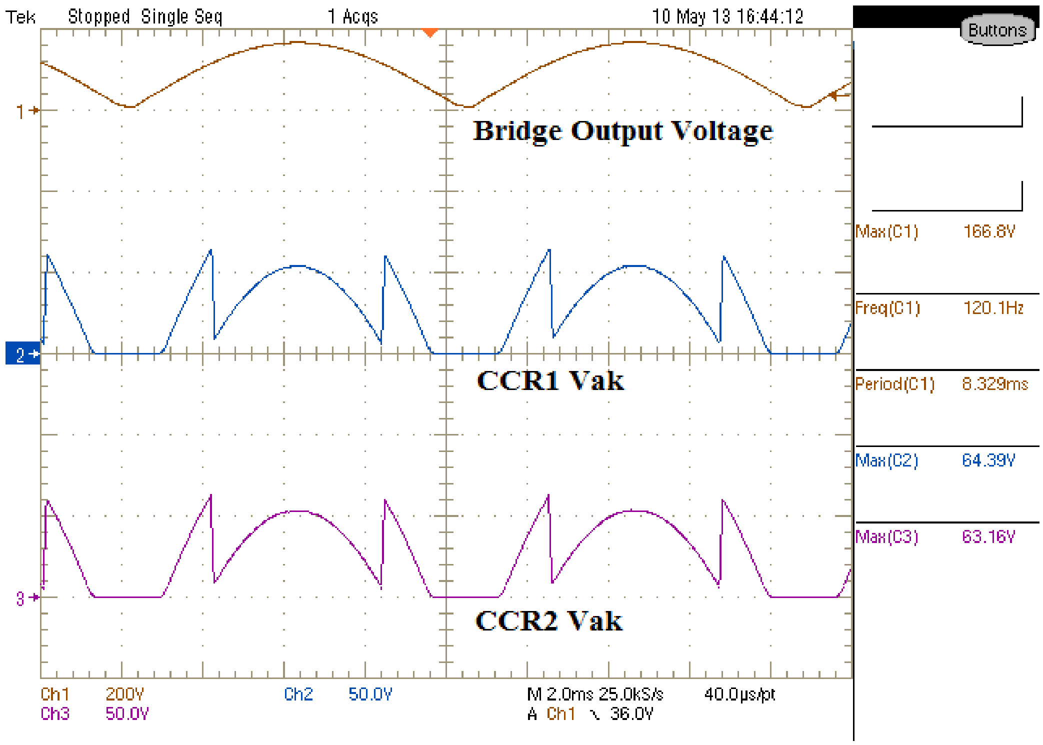

Figure 3. The Voltage across each CCR Changes as the Circuit Switches between Parallel and Series.

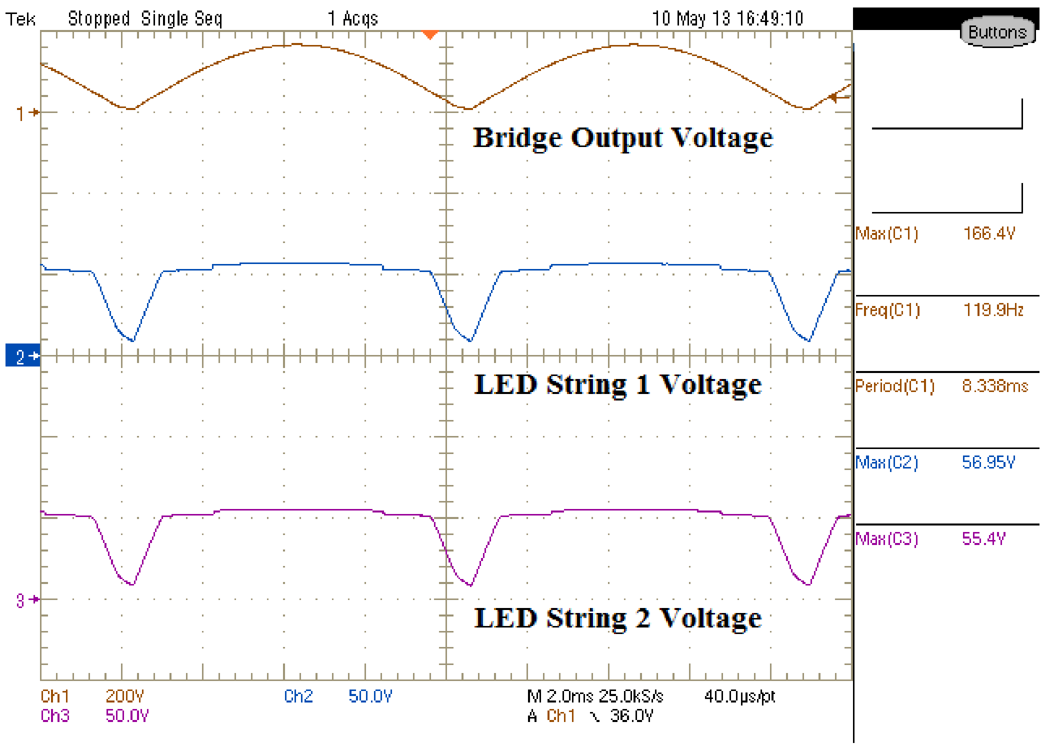

Figure 4. The LEDs are On for almost the Entire Cycle. Each LED String Consists of Fhree Cree MX-S LEDs.

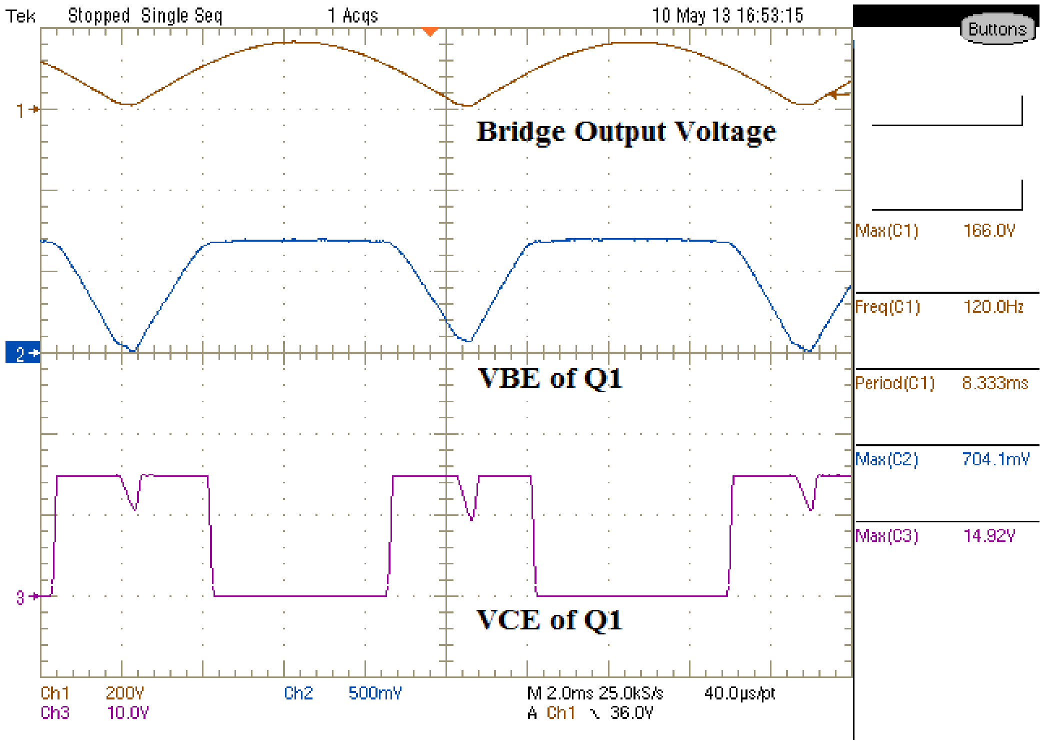

Figure 5. Q1 Switches as the Bridge Output Voltage Passes 110 V, Triggering the Switching of M1 and Q2.

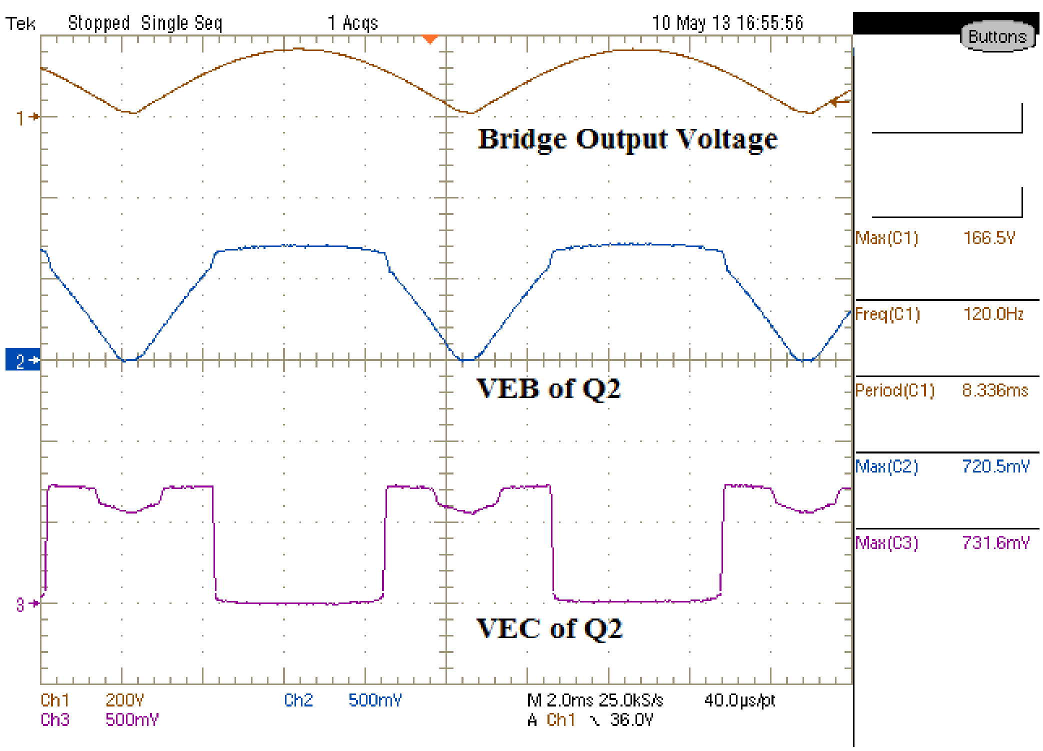

Figure 6. Q2 Switches as the Bridge Output Voltage Passes 110 V in Order to Cause Q3 to Switch.

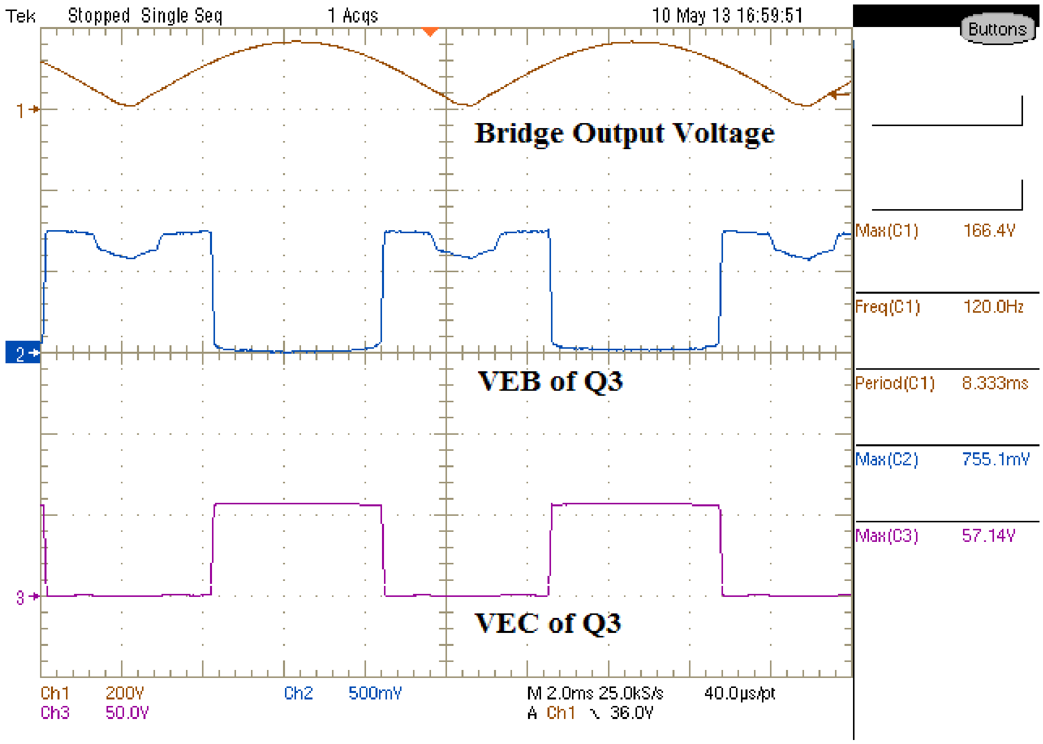

Figure 7. Q3 is Off when Q2 is On.

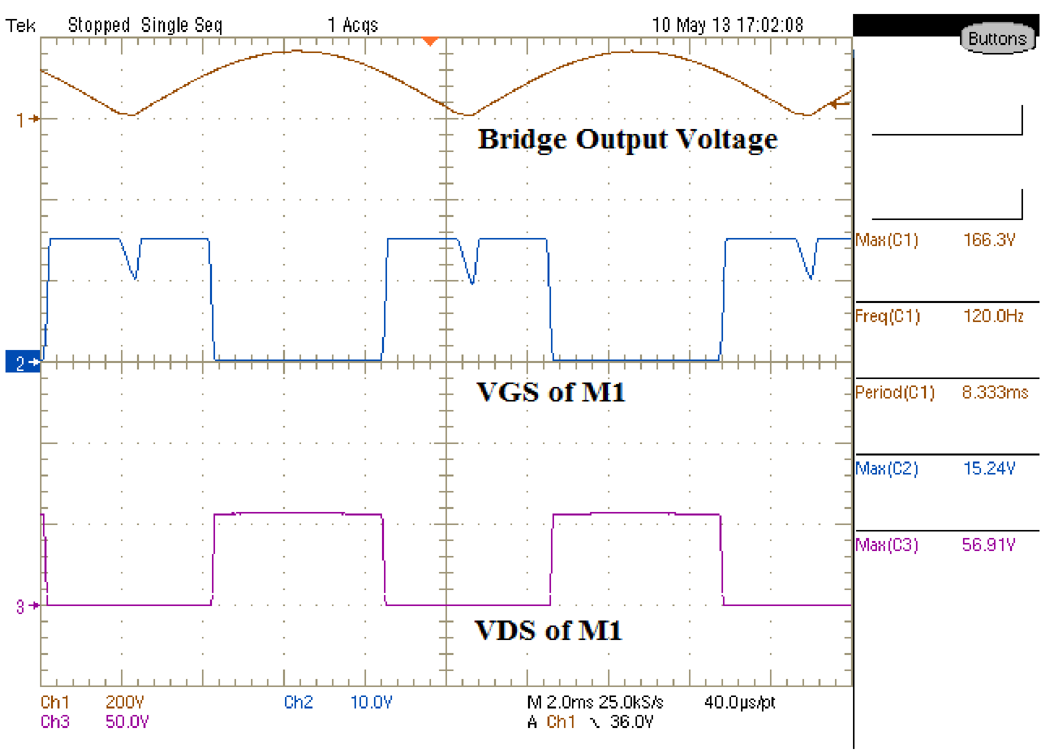

Figure 8. M1 is Pulled Low as Q1 Turns On.

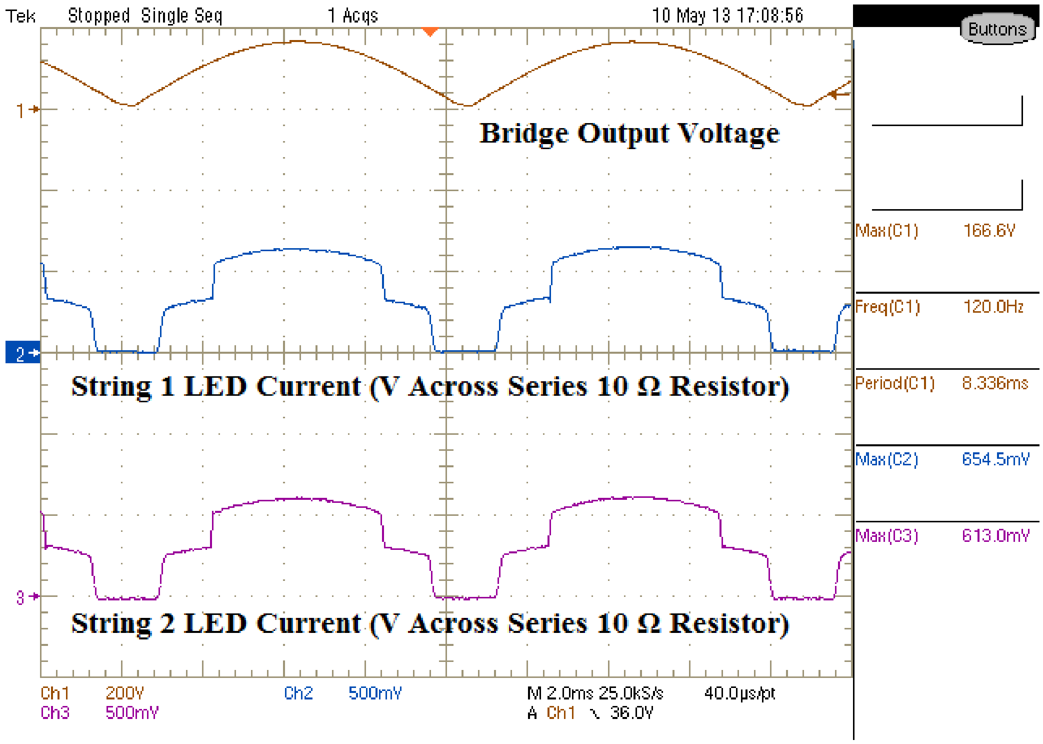

Figure 9. The LED Current in each String is 30 mA in Parallel Configuration and 60 mA in Series Configuration.

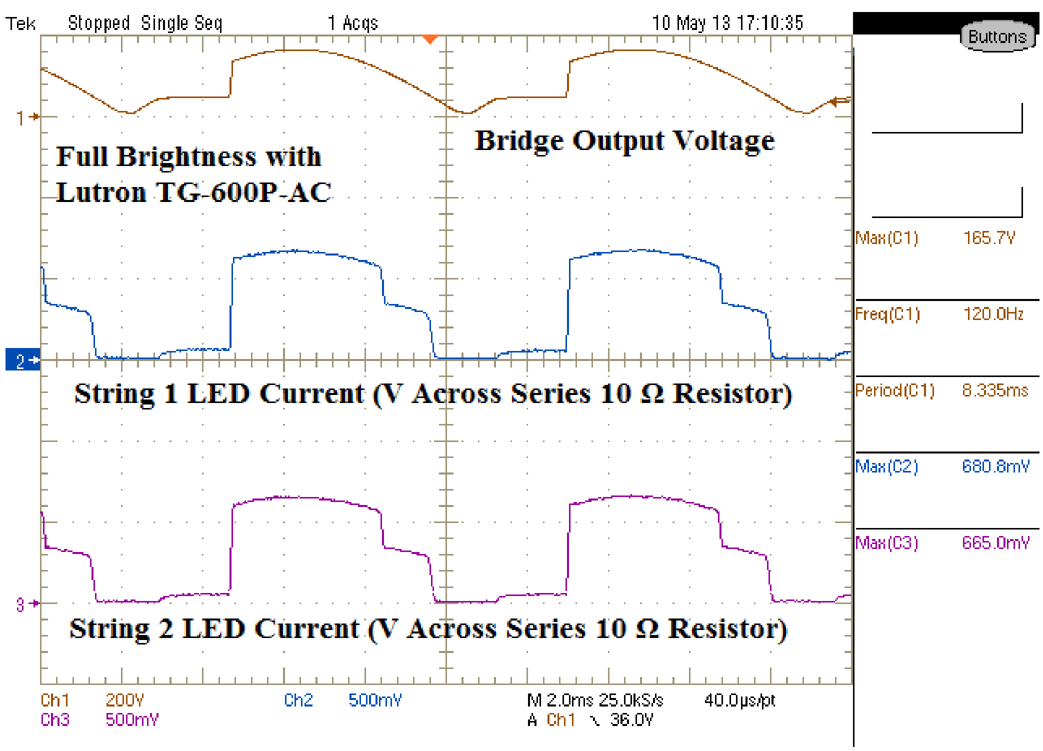

Figure 10. The Circuit is Fully Functional with Standard Phase-cut Incandescent Dimmers.

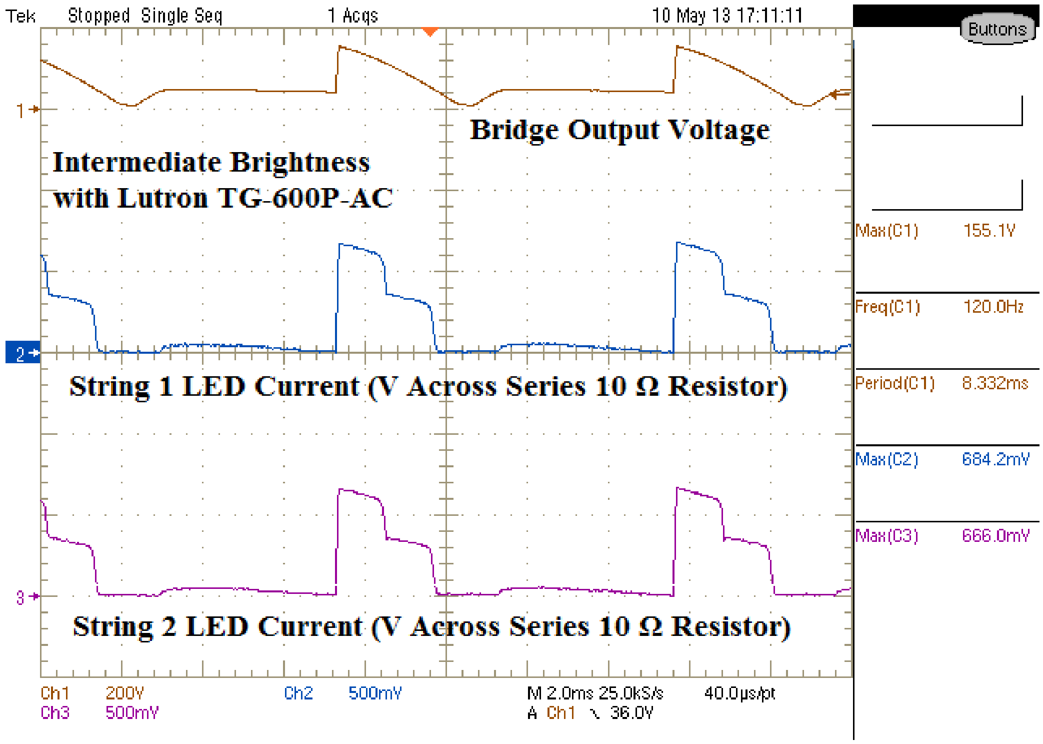

Figure 11. The Current Waveforms Closely Track the Bridge Output Voltage as the Circuit is Dimmed.

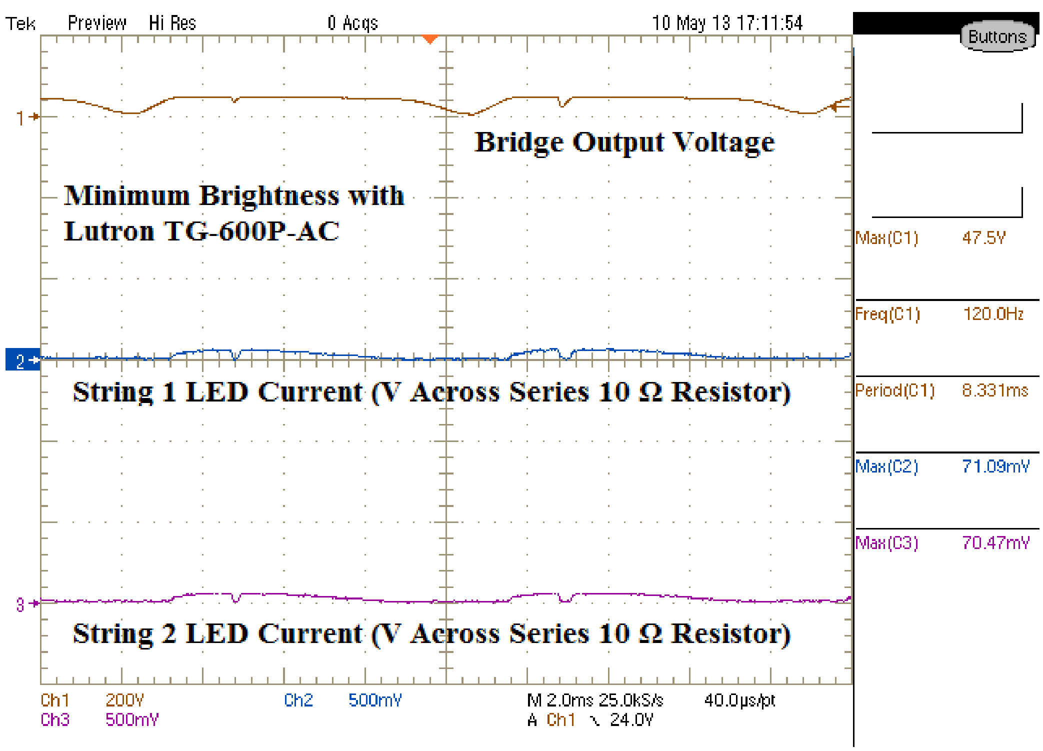

Figure 12. At the Least Bright Setting, the Lights are Barely On. Total Input Current was 7.1 mA_{rms}.

Bill of Materials

Table 5. BILL OF MATERIALS FOR CIRCUIT SHOWN IN FIGURE 1

Designator	Qty	Description	Value	Tolerance	Manufacturer	Part Number
C1	1	Capacitor	2.2 nF, 250 V	−	Any	−
C2	1	Capacitor	1 nF, 10 V	−	Any	−
CCR1−CCR2	2	Constant Current Regulator	120 V, 30 mA	±15%	ON Semiconductor	NSIC2030B
D1−D4	4	Diode	400 V, 1 A	−	ON Semiconductor	MRA4004
D5−D6	2	Diode	75 V, 200 mA	−	ON Semiconductor	BAS16H
F1	1	Fuse	250 Vac, 1 A	−	Any	−
LED1−LED6	6	LED	20 V, 175 mA	−	Cree	MX−6S
M1	1	N-MOSFET	100 V, 17 A	−	ON Semiconductor	NTD6416AN
MOV1	1	Varistor	150 V	−	Littelfuse	V150LA5P
Q1	1	NPN	40 V, 200 mA	−	ON Semiconductor	MMBT3904L
Q2	1	PNP	40 V, 200 mA	−	ON Semiconductor	MMBT3906L
Q3	1	PNP	150 V, 500 mA	−	ON Semiconductor	MMBT5401L
R1	1	Resistor	1 MΩ, 1/8 W	±1%	Any	−
R2	1	Resistor	6.2 kΩ, 1/8 W	±1%	Any	−
R3	1	Resistor	360 Ω, 1/8 W	±1%	Any	−
R4	1	Resistor	62 kΩ, 1/8 W	±1%	Any	−
R5	1	Resistor	10 Ω, 1/8 W	±10%	Any	−
R6	1	Resistor	150 kΩ, 1/8 W	±10%	Any	−
Z1	1	Zener Diode	15 Vz	±5%	ON Semiconductor	MMSZ15

ADDENDUM

Alternative Circuit

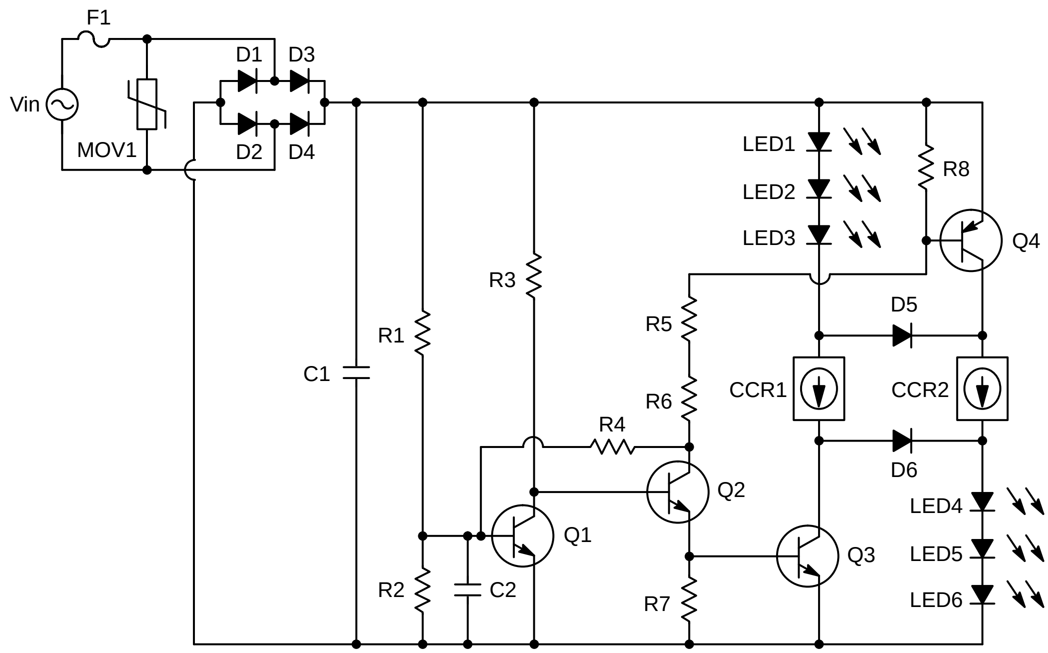

Figure 13. Alternative Circuit

Alternative Schematic Circuit Data

- With Hysteresis/EMI Suppression Resistor R4 (Table 6)
- Without Hysteresis/EMI Suppression Resistor R4 (Table 7)

Table 6. ELECTRICAL CHARACTERISTICS FOR ALTERNATIVE SCHEMATIC WITH R4

	110 V_{AC}	120 V_{AC}	130 V_{AC}
Input Frequency (Hz)	60	60	60
Power (W)	5.40	6.02	6.47
Input Current (mA_{rms})	50.66	50.62	51.80
Power Factor	0.957	0.964	0.968
THD (%, Input I_{rms})	29.38	26.69	24.94
Efficiency (%)	82.2	78.9	73.1

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

Table 7. ELECTRICAL CHARACTERISTICS FOR ALTERNATIVE SCHEMATIC WITHOUT R4

	110 V_{AC}	120 V_{AC}	130 V_{AC}
Input Frequency (Hz)	60	60	60
Power (W)	5.54	6.08	6.59
Input Current (mA_{rms})	51.88	51.83	51.74
Power Factor	0.963	0.967	0.970
THD (%, Input I_{rms})	27.33	25.66	24.48
Efficiency (%)	80.8	76.1	72.1

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

Bill of Materials

Table 8. BILL OF MATERIALS FOR ALTERNATIVE CIRCUIT

Designator	Qty	Description	Value	Tolerance	Manufacturer	Part Number
C1	1	Capacitor	2.2 nF, 250 V	−	Any	−
C2	1	Capacitor	1 nF, 10 V		Any	−
CCR1−CCR2	2	Constant Current Regulator	120 V, 30 mA	±15%	ON Semiconductor	NSIC2030B
D1−D4	4	Diode	400 V, 1 A	−	ON Semiconductor	MRA4004
D5−D6	2	Diode	100 V, 200 mA	−	ON Semiconductor	MMBD914L
F1	1	Fuse	250 Vac, 1 A	−	Any	−
LED1−LED6	6	LED	20 V, 175 mA	−	Cree	MX−6S
MOV1	1	Varistor	150 V	−	Littelfuse	V150LA5P
Q1	1	NPN	40 V, 200 mA	−	ON Semiconductor	MMBT3904L
Q2	1	NPN	350 V, 100 mA	−	ON Semiconductor	MMBT6517L
Q3	1	NPN	150 V, 600 mA	−	ON Semiconductor	MMBT5550L
Q4	1	PNP	150 V, 500 mA	−	ON Semiconductor	MMBT5401L
R1	1	Resistor	1 MΩ, 1/8 W	±1%	Any	−
R2	1	Resistor	6.2 kΩ, 1/8 W	±1%	Any	−
R3	1	Resistor	301 kΩ, 1/8 W	±1%	Any	−
R4	1	Resistor	10 MΩ, 1/8 W	±5%	Any	−
R5	1	Resistor	27 kΩ, 1/8 W	±1%	Any	−
R6	1	Resistor	27 kΩ, 1/8 W	±1%	Any	−
R7	1	Resistor	2.2 kΩ, 1/8 W	±1%	Any	−
R8	1	Resistor	2.2 kΩ, 1/8 W	±1%	Any	−

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