Application Report
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Speed-Control Techniques in AC-DC Operated BLDC Applications

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BLDC Motor Drivers

ABSTRACT

To achieve energy efficiency, ceiling fans and ventilation fans are moving from simple alternate-current (AC) induction motors to brushless direct-current (DC) motors (BLDC). An AC-operated BLDC motor requires two sections to run the BLDC motor: the AC-DC power conversion section and the DC to 3-phase AC conversion section. The Texas Instruments reference design, TIDA-00652, helps to meet these challenges of higher efficiency and power factor in a simpler way by using a single-stage power supply to convert the AC mains input into a low-voltage DC output. This reference design also combines a fully integrated and well protected single-chip, DRV10983, sensor-less sinusoidal brushless motor controller for low-noise operation.

For the DRV10983 device, the motor can be controlled directly through PWM, analog, or I^{2}C inputs. With the physical arrangement of ceiling fans, the speed control of an AC-operated BLDC motor can be possible with an infrared (IR) remote or any high-end wireless control. The speed can also be varied with a change in the supply voltage of the DRV10983 device, but with the variation of AC over universal range, the output of AC-DC is regulated to 24 VDC. Therefore the speed of the fan is controlled by providing a fixed DC or PWM signal at the SPEED pin of the DRV10983 device. The speed of the fan can also be controlled using the I^{2}C input of theDRV10983 device, as demonstrated in the TIDA-00652 reference design.

This application report presents two different ways to control the AC-operated BLDC ceiling fan with existing infrastructure. The first solution is to vary the speed by only toggling the AC mains switch. The second solution is to vary the speed using the TRIAC component similar to an existing AC-operated ceiling fan.

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Trademarks

1 Speed Control of BLDC motor by toggling the AC mains switch

1.1 Introduction

Figure 1 shows a basic block diagram for an AC-operated BLDC ceiling fan demonstrated using the TIDA-00652 reference design.

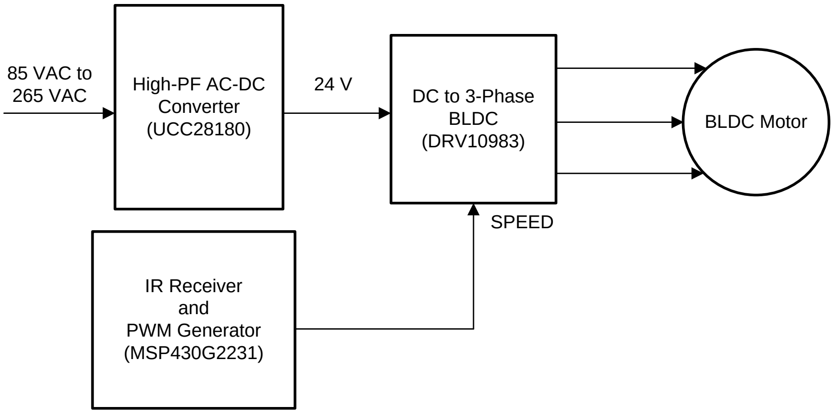


Figure 1. BLDC Ceiling Fan Demonstrated in TIDA-00652

With the addition of a proposed circuit to the existing solution, the speed can be controlled by only toggling the AC mains switch. The proposed solution can completely eliminate the option of a remote to reduce the cost of the microcontroller (MCU), remote, and IR receiver. These devices can be replaced by a low-cost solution based on a ring counter (TI's CD74HC4017 device) and inverter (TI's SN74HCT14 device) which varies the speed by only toggling the AC mains and avoids the cost of a TRIAC component which are used in conventional ceiling fans. This solution can also be used along with the IR remote solution and can be used as additional control in case of the remote is lost.

In addition, using the proposed solution, an arrangement of sequence LEDs can be implemented on the surface of the fan to indicate the speed of the fan. Figure 3 shows this modification of the proposed solution.

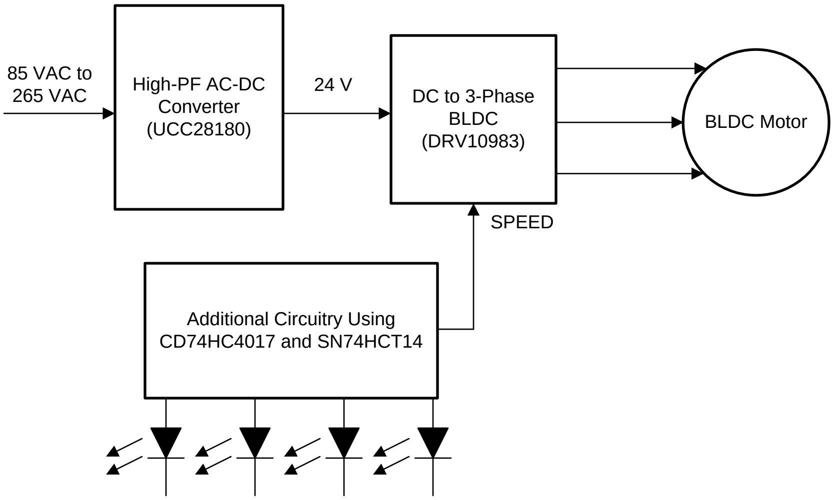


Figure 2. Modified Block Diagram

1.2 Additional Circuit Using CD74HC4017 and SN74HCT14

Figure 3 shows the working of an additional circuit. Whenever the AC is turned on, 24 V is formed at the output of the AC-DC section which is fed to the DRV10983 device. A 5-V supply is then formed to CD74HC4017 and 74HCT4017 using a Zener diode of 5V1. The 24 V is divided using a resistor divider and fed to the SN74HCT14 device to form 5 V at the input. If the AC is tuned off, 24 V goes to zero making the input of Inverter to zero and, because the 5-V supply is still present because of a high capacitor value, the output of inverter is high. And now, if the AC is turned on again, 24 V is formed at the AC-DC section and gives a high signal at the input of the inverter. The high signal at the input of the inverter provides a high-to-low signal at the output which is fed to the clock of the counter resulting in a change of the output state. Therefore, with each toggle of the AC mains Q0, Q1, Q2, and Q3 turn on consecutively. With each signal output, the resistor divider network forms different voltages between 0 and 3.3 V in four different levels that can be fed to the SPEED pin of the DRV10983 device for different speeds of the fan. Q4 is connected to the master reset (MR) to revert back to initial step. The number of steps of speed can be increased by increasing the use of the number of outputs and adjusting the resistor divider network accordingly.

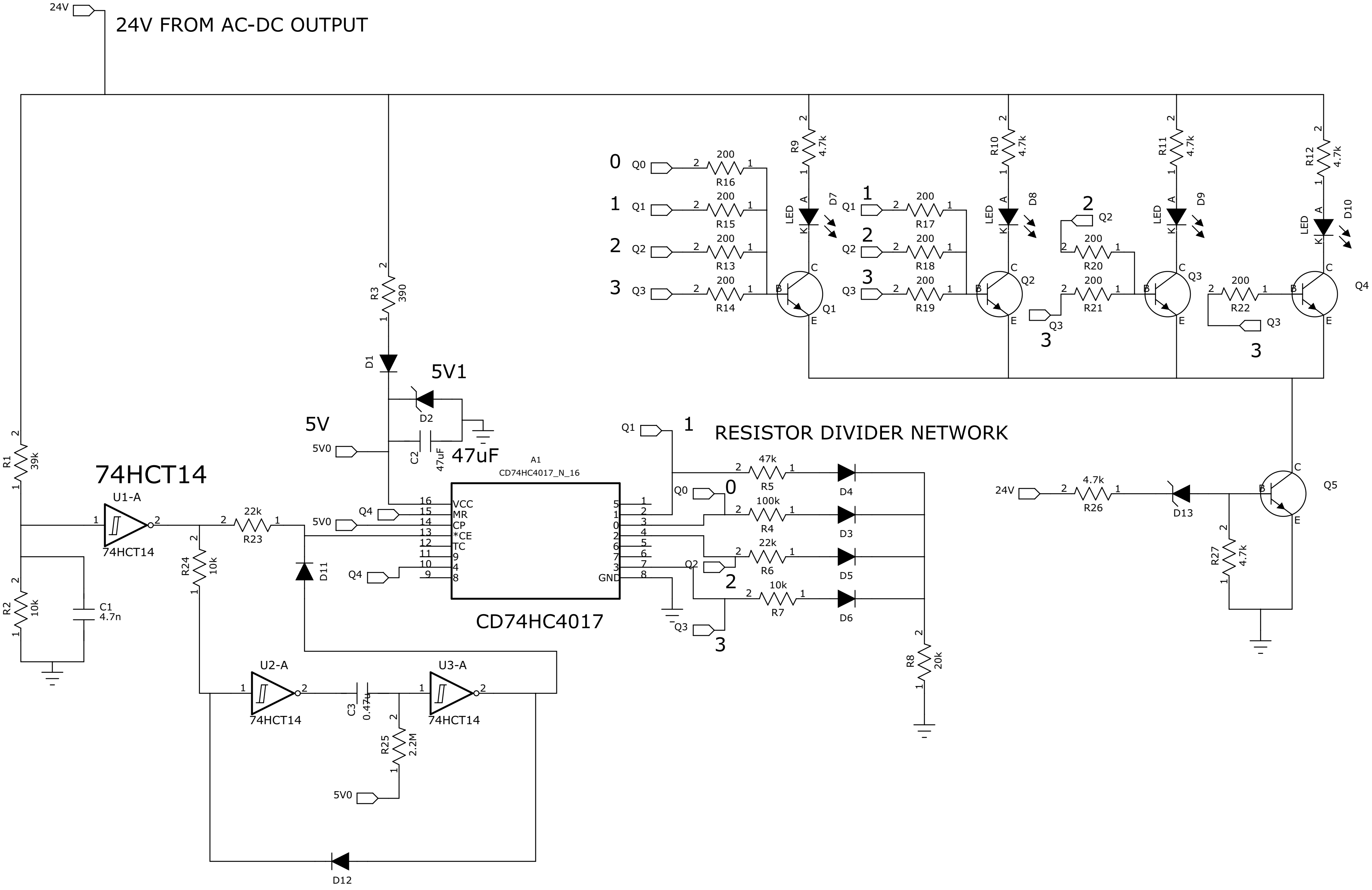


Figure 3. Proposed Solution to Control the Speed of the Fan by Toggling AC

To achieve four different steps of speed, 0.8 V, 1.6 V, 2.4 V, and 3.3 V must be generated at the output of the network. If 20 kΩ is used at the output, the R4, R5, R6, and R7 resistors must be used at the outputs of the ring counter.

$$\text{When Q0 is ON, } R4 = ((20\ \text{k}\Omega / 0.8) \times 5\ \text{V}) - 20\text{k} = 105\ \text{k}\Omega \tag{1}$$

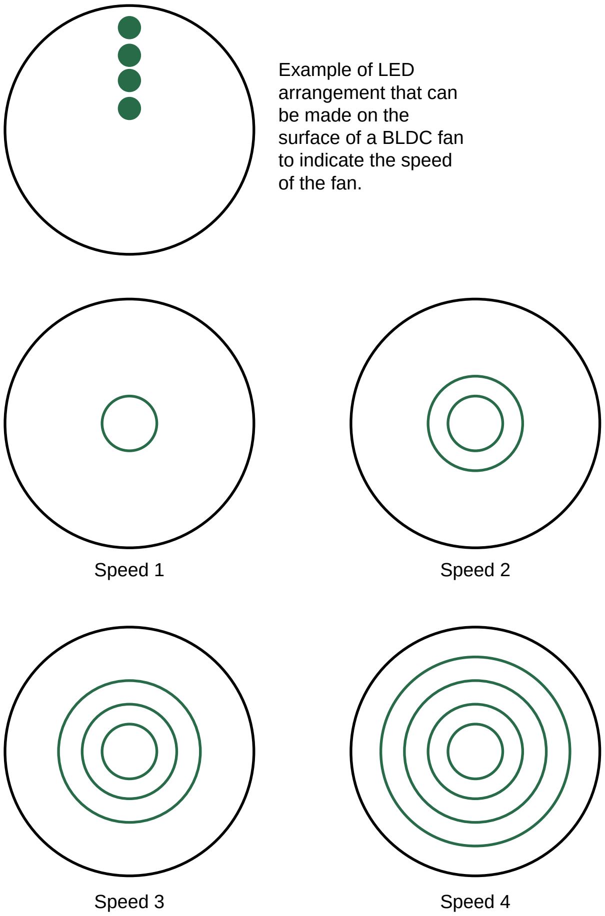
$$\text{When Q1 is ON, } R5 = ((20\ \text{k}\Omega / 1.6) \times 5\ \text{V}) - 20\text{k} = 42.5\ \text{k}\Omega \tag{2}$$

$$\text{When Q2 is ON, } R6 = ((20\ \text{k}\Omega / 2.4) \times 5\ \text{V}) - 20\text{k} = 21.67\ \text{k}\Omega \tag{3}$$

$$\text{When Q3 is ON, } R7 = ((20\ \text{k}\Omega / 3.3) \times 5\ \text{V}) - 20\text{k} = 10\ \text{k}\Omega \tag{4}$$

In the schematic, the closest available resistor values were used

In addition, the output of Q0, Q1, Q2 and Q3 can be used to create an LED indication as shown in Figure 4. Whenever Q0 turns on, one LED turns on, and when Q1 turns on, two LEDs turn on, and so on. These LEDs can be kept on the surface of the ceiling fan which appears as a circle and variation of speed can be indicated with variation in size of circle accordingly.



Example of LED arrangement that can be made on the surface of a BLDC fan to indicate the speed of the fan.

Figure 4. Probable LED Arrangement to Indicate the Speed of Fan

2 TRIAC Control of BLDC Motor

2.1 *Optocoupler Circuit to Detect the Firing Angle*

In a BLDC motor, the variation of RMS AC source does not change the output DC. The TIDA-00652 reference design (BLDC ceiling fan TI Design) is used to implement TRIAC-based fan control. A small optocoupler-based circuit is connected to the TIDA-00652 BLDC board as shown in Figure 5. The rectified AC is sensed using the optocoupler. As the phase angle of TRIAC is varied, a PWM signal is generated accordingly. The average of PWM is fed to the SPEED pin of the DRV10983 device.

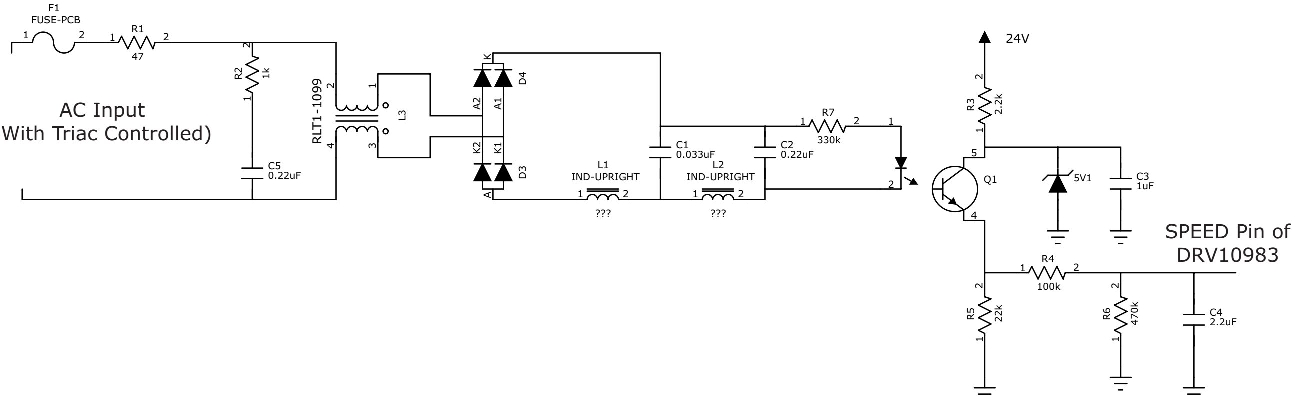


Figure 5. TRIAC-Based Control of AC Operated BLDC Fan

The AC waveform chopped with a TRIAC at a certain firing angle generates a PWM signal corresponding to the firing angle as shown in Figure 6. This PWM signal is averaged using the RC low-pass filer. The variation in the PWM signal from 10% to 90% results in analog voltage from 0.8 V to 3.3 V correspondingly. The DRV10983 device can be used in Analog control mode and this output analog voltage can be connected to the SPEED pin of the DRV10983 device.

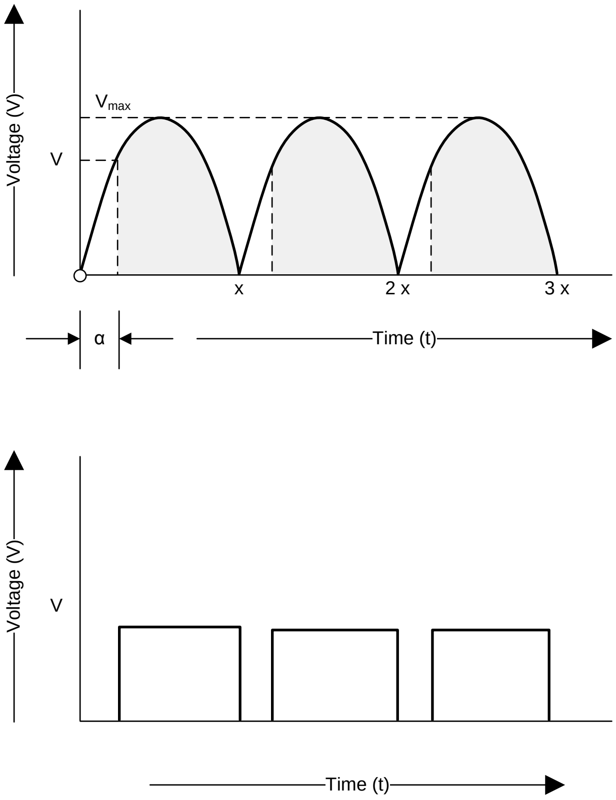


Figure 6. PWM Signal at Emitter of Optocoupler

2.2 Additions to Input Filter for TRIAC Operation

The resonance of the undamped EMI filter causes the input current, iin(t) to oscillate in response to the step change in the input voltage caused by the TRIAC firing action. Each time the input current falls below the holding current, ITH, the TRIAC commutates off. The internal RC timer initiates a new firing sequence leading to repeated firing and misfiring of the TRIAC. Therefore the transient response of the EMI filter must be controlled by incorporating suitable damping circuits. The standard method is to use RC snubber as shown in Figure 9.

A small value selected for R2 will cause the pole to move away from the zero while a large value for R2 will lead to insufficient damping of complex filter poles. As a result, a small optimal range of resistance between 100 Ω and 2 kΩ exists, which leads to a non-zero input current. This value can either be iteratively derived using simulation software or empirically estimated based on experimental data.

The TRIAC-chopped AC looks similar to the waveform shown in Figure 7. With addition of an R and C snubber, false triggering is eliminated and should result in the waveform shown in Figure 8.

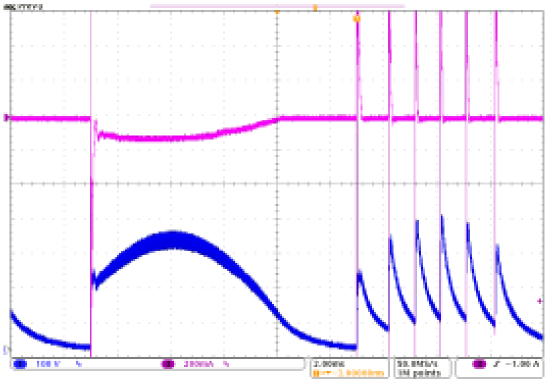


Figure 7. TRIAC Current and Input Rectified Voltage Without RC-Damped Circuit

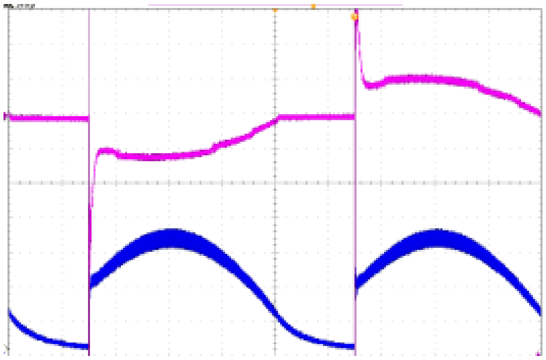


Figure 8. TRIAC Current and Input Rectified Voltage With RC-Damped Circuit

Rapid charging of the EMI filter capacitance during the firing sequence causes a large inrush current to flow through the TRIAC. A single series resistor, R1, shown in Figure 9, is required to limit the inrush current. The resistor also damps any high frequency oscillations caused by the internal TRIAC inductance or parasitic inductance and the EMI filter capacitance. The value of R1 is generally in the range of 10 Ω to 100 Ω and is limited by the acceptable power loss and efficiency. Improvement in efficiency is achieved by incorporating an active MOSFET-based bypass circuitry at the cost of additional components.

Figure 9 shows the addition of the Ri and RC snubber in the input filter section with the previously mentioned considerations.

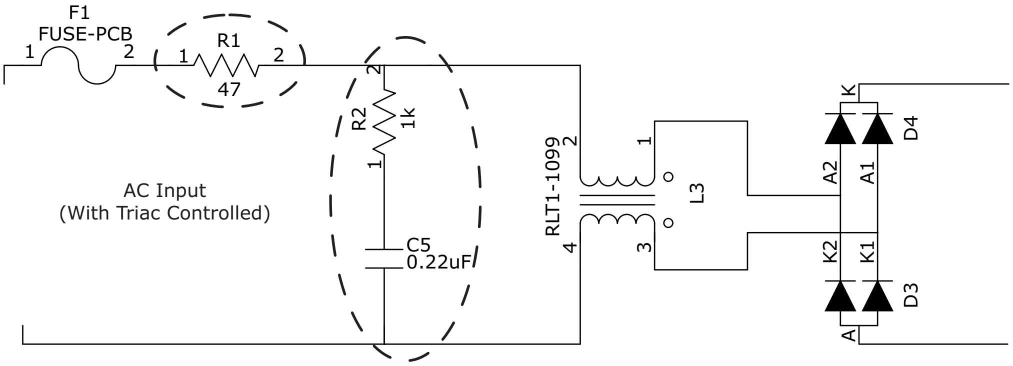


Figure 9. Input Resistor and RC-Damping Circuit Added to Input Filter

3 References

- *90- to 265-V AC, 91% Efficiency, >0.94 PF Buck-PFC Plus 24-V, 30-W Brushless DC Motor Drive Reference Design* (TIDUAS3)
- CD74HC4017 *High Speed CMOS Logic Decade Counter/Divider with 10 Decoded Outputs* (SCHS200)
- *DRV10983 12- to 24-V, Three-Phase, Sensorless BLDC Motor Driver* (SLVSCP6)
- M.D. Singh, K.B. Khanchandani, Power Electronics, Second Edition, Tata McGraw-Hill Education, 2007.
- Montu Doshi, James Patterson ; Lighting Power Products, Texas Instruments, Inc., Longmont, Colorado; “Input filter design for TRIAC dimmable LED lamps,” IEEE Energy Conversion Congress and Exposition, Sept. 2013, pp. 4631 – 4638.
- SN74HCT14 *Hex schmitt-trigger inverters* (SCLS225)

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