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FL5150/60

IGBT and MOSFET AC Phase Cut Dimmer Controller

Features

- Selectable Earth Ground or Line-Hot Zero Cross Detection: Complies with UL1472 2015 2nd Edition for Addition of Ground Leakage Current for Flicker Reduction (North America)
- User Programmable Leading or Trailing Edge Dimming Control
- Dynamic Over-Current and Temperature Protection
- Powered from the AC Line
- Symmetric AC Current Control
- IGBT or MOSFET Gate Driver
- Gate Pulse Width Programmable from 0 to 100% t_{ON}
- 8 Bit ADC Input for Dimming Control with an Adjustable Resistor or 0 to 10 V DC Voltage
- 226 Dimming Pulse Widths with 25 μ s Resolution and Built-in Ramp Up/Down Control for Smooth Dimming
- Automatically Maximum Gate Pulse Width Control (Auto Max.)
- Minimum External Components
- 600 μ A Quiescent Current
- Precision Temperature Compensated 2% Internal Timer
- Low Power Electronic Off State Mode
- Space Savings SOIC 10-pin Package
- 50 Hz and 60 Hz Options

Applications

- Dimmer Switches
- AC Controls

Description

The FL5150 and FL5160 are controllers for varying the pulse width for AC loads. The FL5150 is for 50 Hz and the FL5160 is for 60 Hz applications. The FL5150/60 is powered from the AC line and generates a programmable gate drive for controlling the pulse width for external IGBT or MOSFET transistors. The pulse width can be user programmable with either an external resistor or 0 to 10 V DC signal or controlled by a μ P with a logic signal. The pulse width can be controlled from 0 to 100% duty cycle to provide a wide AC symmetric dimming control function when biased with a 3-wire application. For 2-wire Line-Hot and Load-Hot applications, the pulse width can typically be varied from 0 to a maximum gate pulse so that the load voltage is >95% of the AC line voltage. The FL5150/60 will automatically override the pulse width control setting to allow maximum gate pulse width without flicker.

The FL5150/60 takes advantage of the UL1472 2015 2nd edition code revision that allows for up to 0.5 mA of ground leakage current when a neutral wire is not available in the switch box. This improves the flicker performance for non-resistive loads. If the application does not allow ground leakage current then the Line Hot signal can be used as the ZC signal.

The FL5150/60 has user programmable over-current and temperature protection. With external sense resistors, the maximum voltage drop across Q1 and Q2 can be set to limit the maximum current and transistor power dissipation.

The FL5150/60 can be programmed for trailing edge dimming when the DIM Mode pin is low at startup (pulse width starts at the zero-crossing) or leading edge dimming when the DIM Mode pin is connected to the VDD pin at startup (pulse width ends at the zero crossing). When an OFF state is selected (DIM Control pin is 0 V) the FL5150/60 will go into a low power electronic OFF state that reduces the power consumption to less than 100 mW if an external NPN transistor is used.

The FL5150/60 has an internal 8 bit ADC that allows for typically 226 selectable dimming pulse widths with a resolution of 25 μ s per step. The FL5150/60 controls the dim pulse width rate of change so that the minimum to maximum dim ramp time is approximately 1 second. This feature allows for a smooth dim transition.

Internally, the FL5150/60 contains a 17 V shunt regulator, 5 V linear regulator, 8Bit ADC, detection comparators, control logic and an IGBT or MOSFET gate driver.

The 10-pin SOIC package provides for a low-cost, compact design and layout.

Ordering Information

| Part Number | Operating Temperature Range | Package | Packing Method |
|-------------|-----------------------------|--|----------------|
| FL5150MX | -40°C to +85°C | 10 Lead SOIC, JEDEC MS-012, 150" Narrow Body | Tape and Reel |
| FL5160MX | | | |

Typical Applications

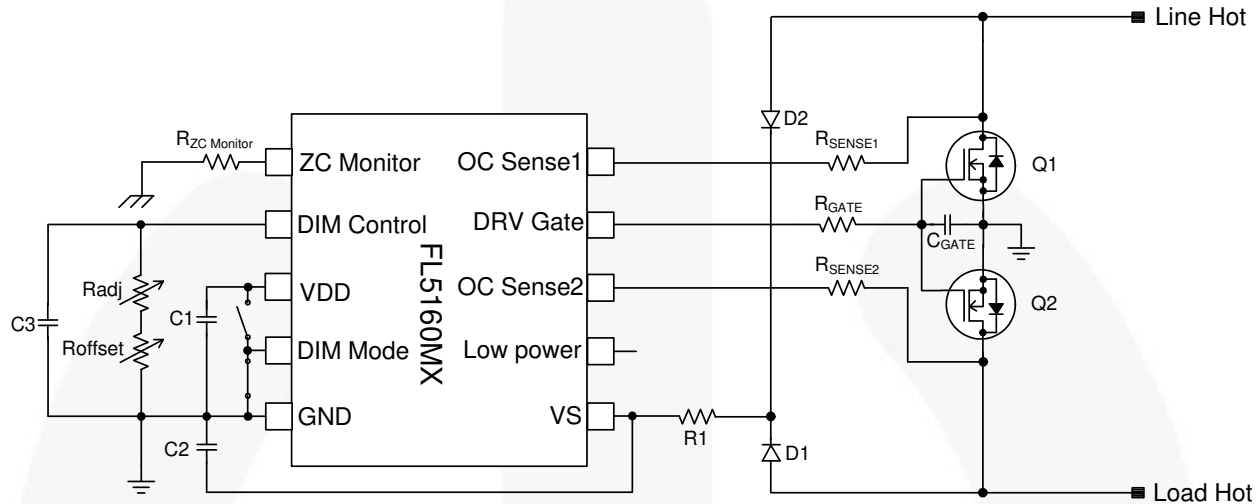


Figure 1. Typical 120 V_{AC} 60 Hz Application with Air Gap Switch (TE Mode Selected)

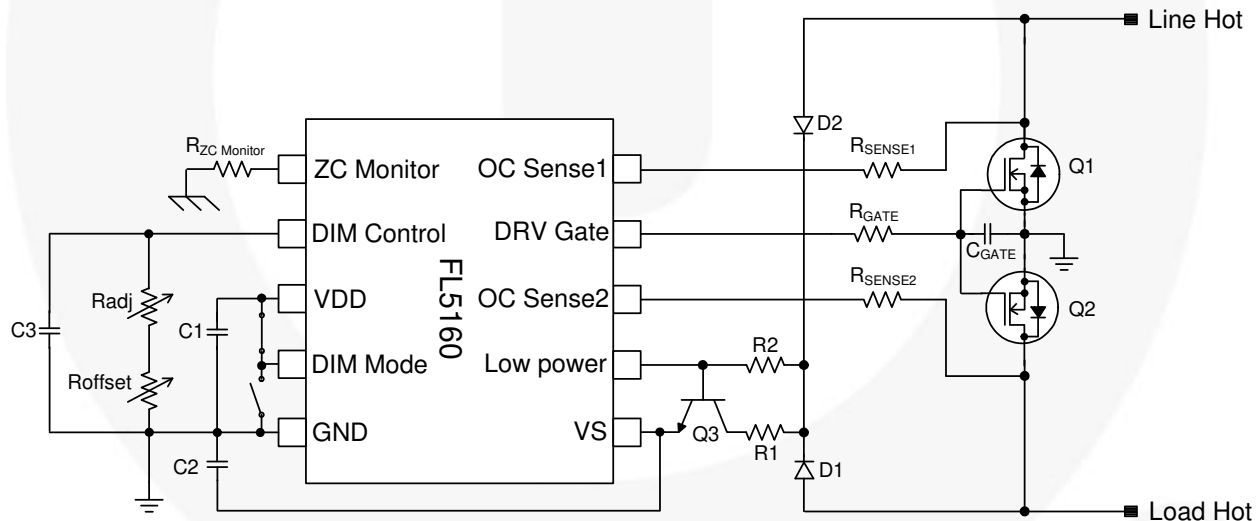


Figure 2. Typical 120 V_{AC} 60 Hz Low Power Application (LE Mode Selected)

Table 1. Typical Values

| | | | | | |
|----------------------------|----------------------------|--------------------------------|----------------------------------|--------------------------------|--------------------------|
| R1: 10 kΩ | R2: 150 kΩ | R _{ADJ} : 0 to 250 kΩ | R _{OFFSET} : 0 to 50 kΩ | R _{ZC Monitor} : 1 MΩ | R _{GATE} : 1 kΩ |
| R _{SENSE1} : 1 MΩ | R _{SENSE2} : 1 MΩ | C1: 100 nF | C2: 2.5 μF | C3: 100 nF | |
| C _{GATE} : 22 nF | Q1: FDPF33N25 | Q2: FDPF33N25 | Q3: KSP44 | | |

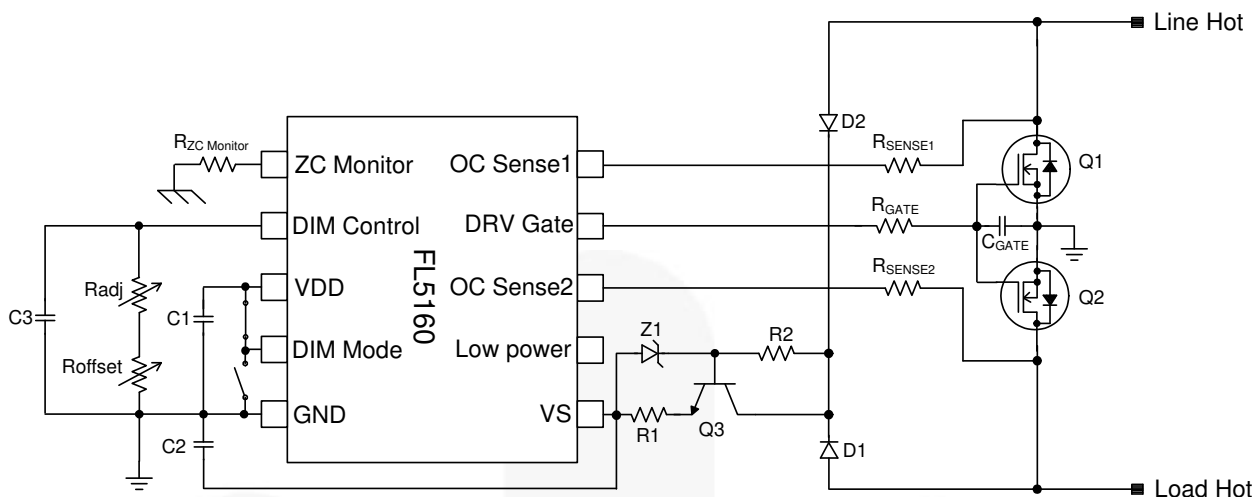


Figure 3. 120 V_{AC} 60 Hz Application with Current Mirror for R1 Lower Power Dissipation (LE Mode Selected)

Table 2. Typical Values

| | | | | | |
|----------------------------|----------------------------|--------------------------------|----------------------------------|--------------------------------|---------------------------|
| R1: 2 kΩ | R2: 150 kΩ | R _{ADJ} : 0 to 250 kΩ | R _{OFFSET} : 0 to 50 kΩ | R _{ZC Monitor} : 1 MΩ | R _{GATE} : 1 kΩ |
| R _{SENSE1} : 1 MΩ | R _{SENSE2} : 1 MΩ | C1: 100 nF | C2: 2.5 μF | C3: 100 nF | C _{GATE} : 22 nF |
| Z1: 7.5 V | Q1: FDPF33N25 | Q2: FDPF33N25 | Q3: KSP44 | | |

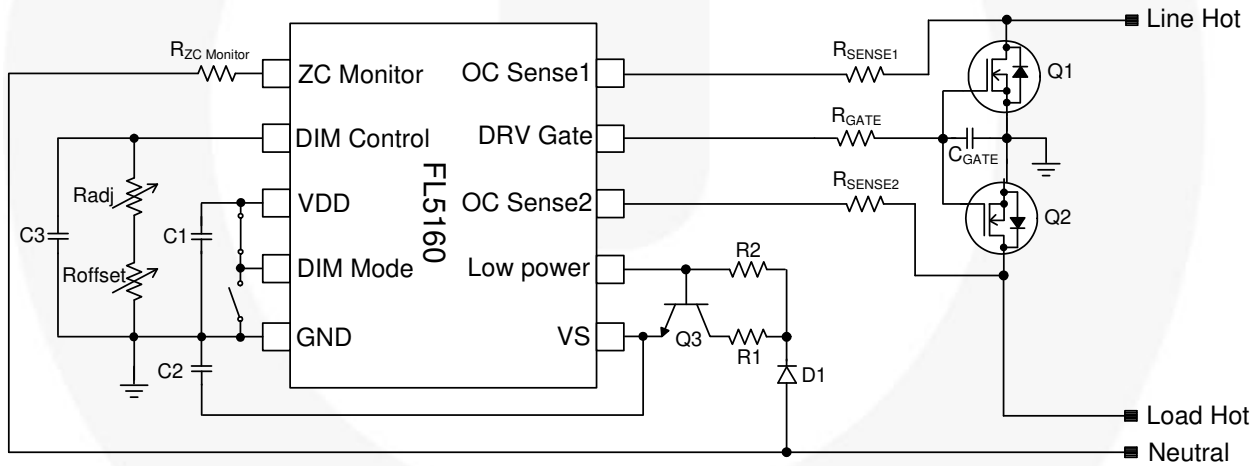


Figure 4. Typical 120 V_{AC} 60 Hz Low Power 3-Wire Application

Table 3. Typical Values

| | | | | | |
|----------------------------|--------------------------------|------------|--------------------------------|--------------------------|----------------------------|
| R1: 30 kΩ | R _{ADJ} : 0 to 250 kΩ | R2: 150 kΩ | R _{ZC Monitor} : 1 MΩ | R _{GATE} : 1 kΩ | R _{SENSE1} : 1 MΩ |
| R _{SENSE2} : 1 MΩ | C1: 100 nF | C2: 4.7 μF | C _{GATE} : 22 nF | C3: 100 nF | |
| Q1: FDPF33N25 | Q2: FDPF33N25 | Q3: KSP44 | | | |

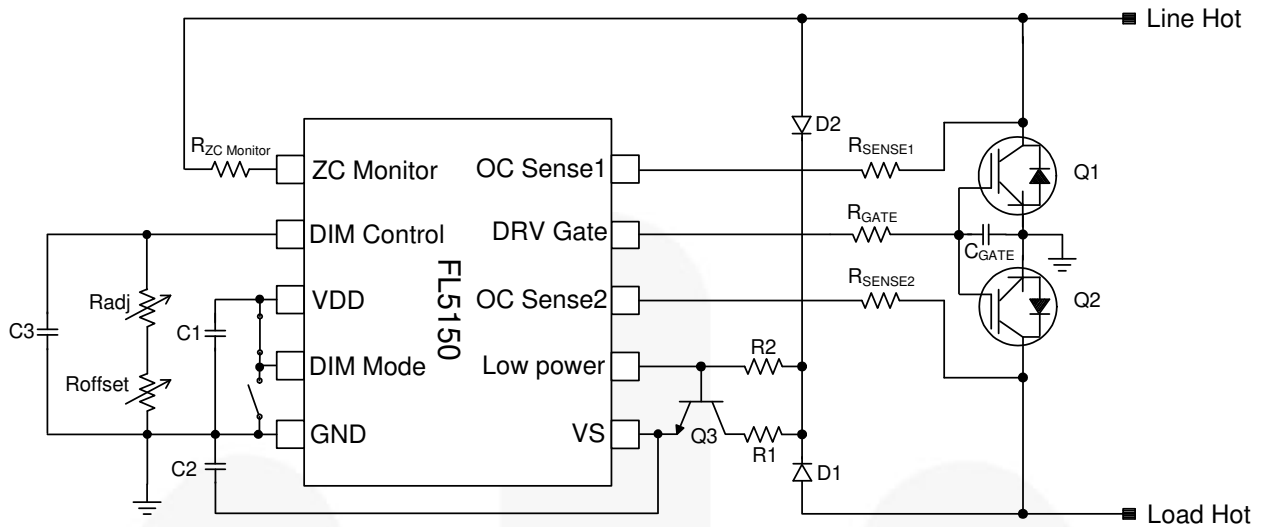


Figure 5. Typical 230 V_{AC} 50 Hz 2-Wire Application (LE Mode Shown)

Table 4. Typical Values

| | | | | | |
|-----------------------------|--------------------------------|-------------------------|--------------------------------|--------------------------|----------------------------|
| R ₁ : 35 kΩ | R _{ADJ} : 0 to 250 kΩ | R ₂ : 350 kΩ | R _{ZC Monitor} : 2 MΩ | R _{GATE} : 1 kΩ | R _{SENSE1} : 2 MΩ |
| R _{SENSE2} : 2 MΩ | C ₁ : 100 nF | C ₂ : 3 μF | C _{GATE} : 22nF | C ₃ : 100 nF | |
| Q ₁ :NGTB10N60FG | Q ₂ : NGTB10N60FG | Q ₃ : KSP44 | | | |

Block Diagram

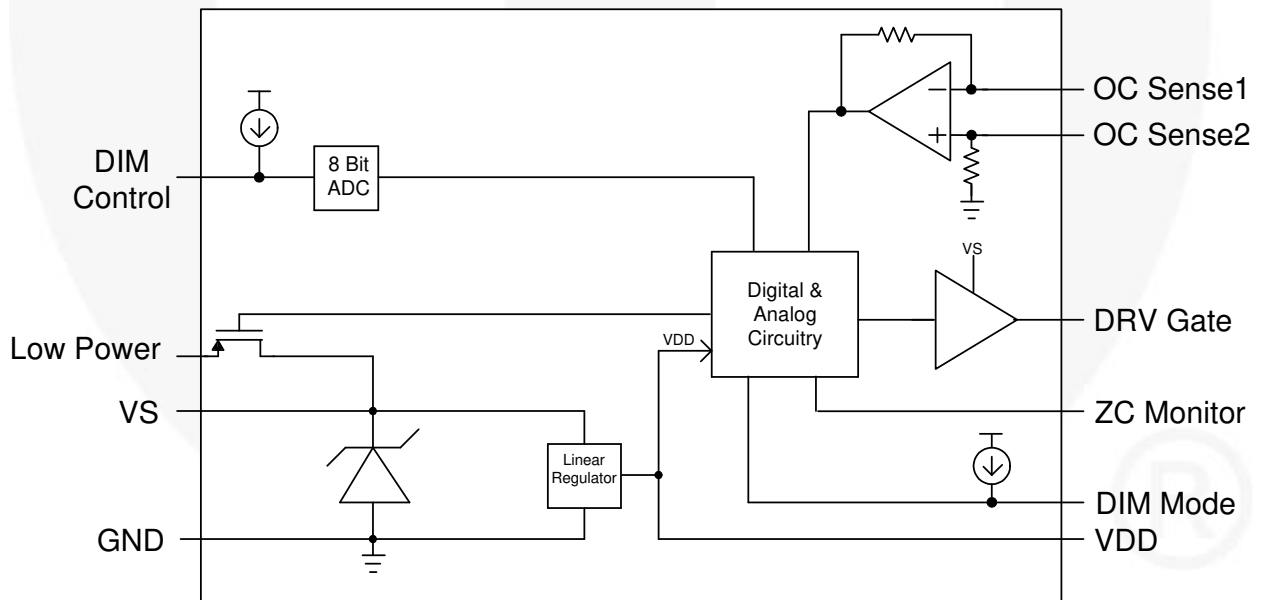


Figure 6. Block Diagram

Pin Configuration

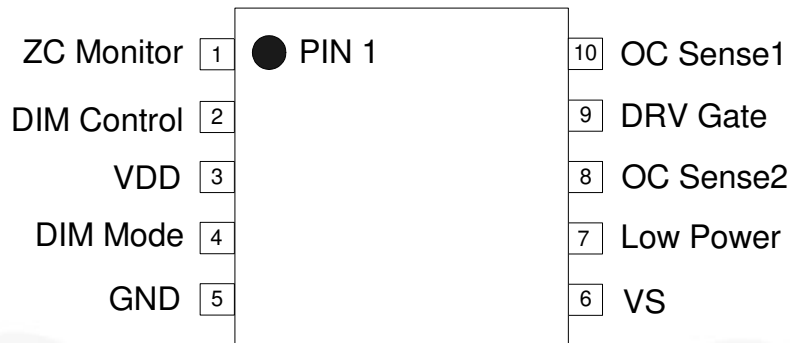


Figure 7. Pin Assignments

Pin Definitions

| Pin# | Name | Description |
|------|-------------|--|
| 1 | ZC Monitor | ZC Monitor This signal is used for the zero crossing threshold. |
| 2 | DIM Control | DIM Control The voltage at this pin is the input for an 8 Bit ADC with a 2.5 V reference. Table 5 shows the pulse width selection per DIM Control pin voltage. This pin sources 10 μ A of current so that with an external adjustable resistor, the dim pulse width can be selected. With a 4 to 1 resistor divided, a 0 to 10 V DC (Ground reference to pin 5) signal can be used to control the dim pulse width. |
| 3 | VDD | VDD The internal 5 V supply for the digital logic |
| 4 | DIM Mode | DIM Mode This pin selects either trailing edge or leading edge pulse width dimming. When a Power-On-Reset (POR) occurs, this pin will be monitored for its logic level. If it is connected to GND then trailing edge dimming will be selected. If it is connected to VDD then leading edge dimming will be selected. The DIM Mode state is latched at startup (60 ms) and will remain in its selected DIM Mode until a POR signal occurs. |
| 5 | GND | GND Supply input for the FL5150/60 circuitry |
| 6 | VS | VS Supply input for the FL5150/60 circuitry. An internal shunt regulator will clamp this pin at 17 V. |
| 7 | Low Power | Low Power When an off state is selected (DIM Control pin at 0 V) an internal PMOS transistor will be enabled which shorts this pin to VS. If an external NPN transistor is used per Figure 2, the FL5150/60 power consumption will be reduced to typically 100 mW. |
| 8 | OC Sense2 | OC Sense2 An external resistor connected to the collector/drain of Q2 sets the maximum voltage difference across Q1 and Q2 for both positive and negative half cycles. |
| 9 | DRV Gate | DRV Gate Gate drive signal for external IGBT or MOSFET transistors. |
| 10 | OC Sense1 | OC Sense1 An external resistor connected to the collector/drain of Q1 sets the maximum voltage difference across Q1 and Q2 for both positive and negative half cycles. |

Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only.

| Symbol | Parameter | Condition | Min. | Max. | Unit |
|------------------|------------------------------------|-----------------------------------|------|------|------|
| IS | Supply Current | Continuous Current, VS to GND | | 25 | mA |
| VS | Supply Voltage | Continuous Voltage, VS to GND | -0.8 | 20.0 | V |
| DRVG LP | DRV Gate and Low Power | Continuous Voltage to GND | -0.8 | 20.0 | V |
| OCSen1 OCSen2 | Sense1, Sense2 | Continuous Voltage to GND | -0.8 | 5.0 | V |
| | All other pins | Continuous Voltage to GND | -0.8 | 6.0 | |
| T _{STG} | Storage Temperature Range | | -65 | +150 | °C |
| ESD | Electrostatic Discharge Capability | Human Body Model, JESD22-A114 | | 2 | kV |
| | | Charged device Model, JESD22-C101 | | 2 | |

Recommended Operating Conditions

The Recommended Operating Conditions table defines the conditions for actual device operation. Recommended operating conditions are specified to ensure optimal performance to the data sheet specifications. Fairchild does not recommend exceeding them or designing to Absolute Maximum Ratings. Unless otherwise specified, refer to Figure 1 to Figure 5. $T_A=25^\circ\text{C}$, $I_{SHUNT}=5\text{ mA}$, and phase=60 Hz.

| Symbol | Parameter | Conditions | Min. | Typ. | Max. | Unit | |
|--|--|--|------------------|-------|-------|---------------|-----|
| FL5150/60 Electrical Parameters ($T_A=25^\circ\text{C}$, $I_{shunt}=5\text{ mA}$, unless otherwise specified) | | | | | | | |
| VS | Power Supply Shunt Regulator Voltage | VS to GND | 16 | 17 | 18 | V | |
| UVLO | Under-Voltage Lockout (Power-on-Reset) | VS to GND, Rising Enable FL5160/50 | 9.2 | 9.5 | 9.8 | V | |
| | | VS to GND, Falling Hysteresis Terminate DRV Gate Pulse | | 0.5 | | | |
| | | VS to GND, Falling Hysteresis Disable FL5150/60 | | 2.2 | | | |
| I_Q | Quiescent Current | VS to GND = 12 V | | 600 | 800 | μA | |
| VDD | VDD Supply Voltage | VPW Control = 0 | 4.5 | 5.0 | 5.5 | V | |
| OCSen1 _{VH} OCSen2 _{VH} | Sense1&2 Clamp High | IH = 350 μA | | | 4.0 | V | |
| OCSen1 _{VL} OCSen2 _{VL} | Sense1&2 Clamp Low | IL = -350 μA | -0.7 | | | V | |
| ZCMon _{VH} | ZC Monitor Clamp High | IH = 350 μA | | | 4.0 | V | |
| ZCMon _{VL} | ZC Monitor Clamp Low | IH = -350 μA | -0.7 | | | V | |
| OSC | Internal Timer | FL5160 | VDIM Control = 0 | 194 | 200 | 206 | kHz |
| | | FL5150 | | 161.7 | 166.7 | 171.7 | |
| DIMCN _{ISOURCE} | DIM Control Source Current | VDIM Control = 0 | 9.4 | 10.0 | 10.6 | μA | |
| DIMCN _{VFORCE} | DIM Control 100% Duty Cycle | VDIM Control | VDD - 0.5 | | | V | |
| VREF _{ADC} | ADC Reference Voltage | VADC (8-Bit) | | 2.56 | | V | |
| DRVG _{VH} | DRV Gate High | RADJ Open (VS=17 V) | 16.0 | 17.0 | | V | |
| DRVG _{VL} | DRV Gate Low | RADJ Connected to GND | | | 100 | mV | |
| DRVG _{TLH} | DRV Gate L to H | C _{Load} = 3 nF, 10 to 90% | | 150 | 250 | ns | |
| DRVG _{THL} | DRV Gate H to L | C _{Load} = 3 nF, 10 to 90% | | 50 | 100 | ns | |
| DM _{VL} | DIM Mode Logic Low (Select Trailing Edge) | VL | | | 1.0 | V | |
| DM _{VH} | DIM Mode Logic High (Select Leading Edge) | VH | VDD - 1.0 | | | V | |
| DM _{ISOURCE} | DIM Mode Source Current | IDIM Mode | 7 | 10 | 13 | μA | |
| DM _{TSEL} | DIM Mode Selection Time after Under-Voltage lock Out Enable Threshold | FL5160 | | 60 | | ms | |
| | | FL5150 | | 72 | | | |
| LPM _{TEN} | LP Mode Enable Time | FL5160, VDIM Control = 0 | | 100 | | ms | |
| | | FL5150, VDIM Control = 0 | | 120 | | | |
| OC _{VTH} | Over-Current Threshold, Trailing Edge $R_{SENSE1,2} = 1\text{ M}\Omega$ $I_{Q1DRAIN} - Q2DRAIN\ I$ | Half Cycle Phase Angle | 0 to 43° | | 3.5 | V | |
| | | | 43° to 65° | | 2.9 | | |
| | | | 65° to 86° | | 2.4 | | |
| | | | 86° to 180° | | 2.0 | | |

Table 5. DIM Control Voltage Pulse Width Selection⁽¹⁾

| DIM_Control Voltage (mV) | VOUT _{RMS} (V) ⁽²⁾ | DIM Mode=0 | DIM Mode=0 | DIM Mode=1 | DIM Mode=1 |
|--------------------------|--|-----------------------------|------------------------------|------------------------------|-------------------------------|
| | | Trailing Edge | Trailing Edge | Leading Edge | Leading Edge |
| | | t _{ON} (Rising) μs | t _{ON} (Falling) μs | t _{OFF} (Rising) μs | t _{OFF} (Falling) μs |
| 0 | 0 | 0 | 0 | >8333 | >8333 |
| 0 | 0 | 0 | 0 | >8333 | >8333 |
| 0 | 0 | 0 | 0 | >8333 | >8333 |
| 0 | 0 | 0 | 0 | >8333 | >8333 |
| 40 | 0 | 0 | 0 | >8333 | >8333 |
| 50 | 0 | 0 | 500 | >8333 | 7800 |
| 60 | 0 | 0 | 500 | >8333 | 7800 |
| 70 | 0 | 0 | 500 | >8333 | 7800 |
| 80 | 0 | 0 | 500 | >8333 | 7800 |
| 90 | 0 | 0 | 500 | >8333 | 7800 |
| 100 | 4.5 | 500 | 500 | 7800 | 7800 |
| 110 | 5.3 | 550 | 550 | 7750 | 7750 |
| 120 | 6.1 | 600 | 600 | 7700 | 7700 |
| 130 | 6.9 | 650 | 650 | 7650 | 7650 |
| 140 | 7.7 | 700 | 700 | 7600 | 7600 |
| 150 | 8.5 | 750 | 750 | 7550 | 7550 |
| 160 | 9.4 | 800 | 800 | 7500 | 7500 |
| 170 | 10.3 | 850 | 850 | 7450 | 7450 |
| 180 | 11.2 | 900 | 900 | 7400 | 7400 |
| 190 | 12.1 | 950 | 950 | 7350 | 7350 |
| 200 | 13 | 1000 | 1000 | 7300 | 7300 |
| 210 | 14 | 1050 | 1050 | 7250 | 7250 |
| 220 | 15 | 1100 | 1100 | 7200 | 7200 |
| 230 | 16 | 1150 | 1150 | 7150 | 7150 |
| 240 | 17 | 1200 | 1200 | 7100 | 7100 |
| 250 | 18 | 1250 | 1250 | 7050 | 7050 |
| 260 | 18.5 | 1275 | 1275 | 7025 | 7025 |
| 270 | 19 | 1300 | 1300 | 7000 | 7000 |
| 280 | 19.5 | 1325 | 1325 | 6975 | 6975 |
| 290 | 20 | 1350 | 1350 | 6950 | 6950 |
| 300 | 20.5 | 1375 | 1375 | 6925 | 6925 |
| 310 | 21 | 1400 | 1400 | 6900 | 6900 |
| 320 | 21.5 | 1425 | 1425 | 6875 | 6875 |
| 330 | 22 | 1450 | 1450 | 6850 | 6850 |
| 340 | 22.5 | 1475 | 1475 | 6825 | 6825 |
| 350 | 23 | 1500 | 1500 | 6800 | 6800 |

Continued on the following page...

Table 5. DIM Control Voltage Pulse Width Selection⁽¹⁾ (Continued)

| | | DIM Mode=0 | DIM Mode=0 | DIM Mode=1 | DIM Mode=1 |
|--------------------------|--|-----------------------------|------------------------------|------------------------------|-------------------------------|
| | | Trailing Edge | Trailing Edge | Leading Edge | Leading Edge |
| DIM_Control Voltage (mV) | VOUT _{RMS} (V) ⁽²⁾ | t _{ON} (Rising) μs | t _{ON} (Falling) μs | t _{OFF} (Rising) μs | t _{OFF} (Falling) μs |
| 360 | 23.6 | 1525 | 1525 | 6775 | 6775 |
| 370 | 24.2 | 1550 | 1550 | 6750 | 6750 |
| 380 | 24.8 | 1575 | 1575 | 6725 | 6725 |
| 390 | 25.4 | 1600 | 1600 | 6700 | 6700 |
| 400 | 26 | 1625 | 1625 | 6675 | 6675 |
| 410 | 26.6 | 1650 | 1650 | 6650 | 6650 |
| 420 | 27.2 | 1675 | 1675 | 6625 | 6625 |
| 430 | 27.8 | 1700 | 1700 | 6600 | 6600 |
| 440 | 28.4 | 1725 | 1725 | 6575 | 6575 |
| 450 | 29 | 1750 | 1750 | 6550 | 6550 |
| 460 | 29.6 | 1775 | 1775 | 6525 | 6525 |
| 470 | 30.2 | 1800 | 1800 | 6500 | 6500 |
| 480 | 30.8 | 1825 | 1825 | 6475 | 6475 |
| 490 | 31.4 | 1850 | 1850 | 6450 | 6450 |
| 500 | 32 | 1875 | 1875 | 6425 | 6425 |
| 510 | 32.6 | 1900 | 1900 | 6400 | 6400 |
| 520 | 33.2 | 1925 | 1925 | 6375 | 6375 |
| 530 | 33.8 | 1950 | 1950 | 6350 | 6350 |
| 540 | 34.4 | 1975 | 1975 | 6325 | 6325 |
| 550 | 35 | 2000 | 2000 | 6300 | 6300 |
| 560 | 35.6 | 2025 | 2025 | 6275 | 6275 |
| 570 | 36.2 | 2050 | 2050 | 6250 | 6250 |
| 580 | 36.8 | 2075 | 2075 | 6225 | 6225 |
| 590 | 37.4 | 2100 | 2100 | 6200 | 6200 |
| 600 | 38 | 2125 | 2125 | 6175 | 6175 |
| 610 | 38.6 | 2150 | 2150 | 6150 | 6150 |
| 620 | 39.2 | 2175 | 2175 | 6125 | 6125 |
| 630 | 39.8 | 2200 | 2200 | 6100 | 6100 |
| 640 | 40.4 | 2225 | 2225 | 6075 | 6075 |
| 650 | 41 | 2250 | 2250 | 6050 | 6050 |
| 660 | 41.6 | 2275 | 2275 | 6025 | 6025 |
| 670 | 42.2 | 2300 | 2300 | 6000 | 6000 |
| 680 | 42.8 | 2325 | 2325 | 5975 | 5975 |
| 690 | 43.4 | 2350 | 2350 | 5950 | 5950 |
| 700 | 44 | 2375 | 2375 | 5925 | 5925 |
| 710 | 44.6 | 2400 | 2400 | 5900 | 5900 |

Continued on the following page...

Table 5. DIM Control Voltage Pulse Width Selection⁽¹⁾ (Continued)

| | | DIM Mode=0 | DIM Mode=0 | DIM Mode=1 | DIM Mode=1 |
|--------------------------|--|-----------------------------|------------------------------|------------------------------|-------------------------------|
| | | Trailing Edge | Trailing Edge | Leading Edge | Leading Edge |
| DIM_Control Voltage (mV) | VOUT _{RMS} (V) ⁽²⁾ | t _{ON} (Rising) μs | t _{ON} (Falling) μs | t _{OFF} (Rising) μs | t _{OFF} (Falling) μs |
| 720 | 45.2 | 2425 | 2425 | 5875 | 5875 |
| 730 | 45.8 | 2450 | 2450 | 5850 | 5850 |
| 740 | 46.4 | 2475 | 2475 | 5825 | 5825 |
| 750 | 47 | 2500 | 2500 | 5800 | 5800 |
| 760 | 47.6 | 2525 | 2525 | 5775 | 5775 |
| 770 | 48.2 | 2550 | 2550 | 5750 | 5750 |
| 780 | 48.8 | 2575 | 2575 | 5725 | 5725 |
| 790 | 49.4 | 2600 | 2600 | 5700 | 5700 |
| 800 | 50 | 2625 | 2625 | 5675 | 5675 |
| 810 | 50.6 | 2650 | 2650 | 5650 | 5650 |
| 820 | 51.2 | 2675 | 2675 | 5625 | 5625 |
| 830 | 51.8 | 2700 | 2700 | 5600 | 5600 |
| 840 | 52.4 | 2725 | 2725 | 5575 | 5575 |
| 850 | 53 | 2750 | 2750 | 5550 | 5550 |
| 860 | 53.6 | 2775 | 2775 | 5525 | 5525 |
| 870 | 54.2 | 2800 | 2800 | 5500 | 5500 |
| 880 | 54.8 | 2825 | 2825 | 5475 | 5475 |
| 890 | 55.4 | 2850 | 2850 | 5450 | 5450 |
| 900 | 56 | 2875 | 2875 | 5425 | 5425 |
| 910 | 56.6 | 2900 | 2900 | 5400 | 5400 |
| 920 | 57.2 | 2925 | 2925 | 5375 | 5375 |
| 930 | 57.8 | 2950 | 2950 | 5350 | 5350 |
| 940 | 58.4 | 2975 | 2975 | 5325 | 5325 |
| 950 | 59 | 3000 | 3000 | 5300 | 5300 |
| 960 | 59.6 | 3025 | 3025 | 5275 | 5275 |
| 970 | 60.2 | 3050 | 3050 | 5250 | 5250 |
| 980 | 60.8 | 3075 | 3075 | 5225 | 5225 |
| 990 | 61.4 | 3100 | 3100 | 5200 | 5200 |
| 1000 | 62 | 3125 | 3125 | 5175 | 5175 |
| 1010 | 62.6 | 3150 | 3150 | 5150 | 5150 |
| 1020 | 63.2 | 3175 | 3175 | 5125 | 5125 |
| 1030 | 63.8 | 3200 | 3200 | 5100 | 5100 |
| 1040 | 64.4 | 3225 | 3225 | 5075 | 5075 |
| 1050 | 65 | 3250 | 3250 | 5050 | 5050 |
| 1060 | 65.6 | 3275 | 3275 | 5025 | 5025 |
| 1070 | 66.2 | 3300 | 3300 | 5000 | 5000 |

Continued on the following page...

Table 5. DIM Control Voltage Pulse Width Selection⁽¹⁾ (Continued)

| | | DIM Mode=0 | DIM Mode=0 | DIM Mode=1 | DIM Mode=1 |
|--------------------------|--|-----------------------------|------------------------------|------------------------------|-------------------------------|
| | | Trailing Edge | Trailing Edge | Leading Edge | Leading Edge |
| DIM_Control Voltage (mV) | VOUT _{RMS} (V) ⁽²⁾ | t _{ON} (Rising) μs | t _{ON} (Falling) μs | t _{OFF} (Rising) μs | t _{OFF} (Falling) μs |
| 1080 | 66.8 | 3325 | 3325 | 4975 | 4975 |
| 1090 | 67.4 | 3350 | 3350 | 4950 | 4950 |
| 1100 | 68 | 3375 | 3375 | 4925 | 4925 |
| 1110 | 68.6 | 3400 | 3400 | 4900 | 4900 |
| 1120 | 69.2 | 3425 | 3425 | 4875 | 4875 |
| 1130 | 69.8 | 3450 | 3450 | 4850 | 4850 |
| 1140 | 70.4 | 3475 | 3475 | 4825 | 4825 |
| 1150 | 71 | 3500 | 3500 | 4800 | 4800 |
| 1160 | 71.6 | 3525 | 3525 | 4775 | 4775 |
| 1170 | 72.2 | 3550 | 3550 | 4750 | 4750 |
| 1180 | 72.8 | 3575 | 3575 | 4725 | 4725 |
| 1190 | 73.4 | 3600 | 3600 | 4700 | 4700 |
| 1200 | 74 | 3625 | 3625 | 4675 | 4675 |
| 1210 | 74.6 | 3650 | 3650 | 4650 | 4650 |
| 1220 | 75.2 | 3675 | 3675 | 4625 | 4625 |
| 1230 | 75.8 | 3700 | 3700 | 4600 | 4600 |
| 1240 | 76.4 | 3725 | 3725 | 4575 | 4575 |
| 1250 | 77 | 3750 | 3750 | 4550 | 4550 |
| 1260 | 77.5 | 3775 | 3775 | 4525 | 4525 |
| 1270 | 78 | 3800 | 3800 | 4500 | 4500 |
| 1280 | 78.5 | 3825 | 3825 | 4475 | 4475 |
| 1290 | 79 | 3850 | 3850 | 4450 | 4450 |
| 1300 | 79.5 | 3875 | 3875 | 4425 | 4425 |
| 1310 | 80 | 3900 | 3900 | 4400 | 4400 |
| 1320 | 80.5 | 3925 | 3925 | 4375 | 4375 |
| 1330 | 81 | 3950 | 3950 | 4350 | 4350 |
| 1340 | 81.5 | 3975 | 3975 | 4325 | 4325 |
| 1350 | 82 | 4000 | 4000 | 4300 | 4300 |
| 1360 | 82.5 | 4025 | 4025 | 4275 | 4275 |
| 1370 | 83 | 4050 | 4050 | 4250 | 4250 |
| 1380 | 83.5 | 4075 | 4075 | 4225 | 4225 |
| 1390 | 84 | 4100 | 4100 | 4200 | 4200 |
| 1400 | 84.5 | 4125 | 4125 | 4175 | 4175 |
| 1410 | 85 | 4150 | 4150 | 4150 | 4150 |
| 1420 | 85.5 | 4175 | 4175 | 4125 | 4125 |
| 1430 | 86 | 4200 | 4200 | 4100 | 4100 |

Continued on the following page...

Table 5. DIM Control Voltage Pulse Width Selection⁽¹⁾ (Continued)

| | | DIM Mode=0 | DIM Mode=0 | DIM Mode=1 | DIM Mode=1 |
|--------------------------|--|-----------------------------|------------------------------|------------------------------|-------------------------------|
| | | Trailing Edge | Trailing Edge | Leading Edge | Leading Edge |
| DIM_Control Voltage (mV) | VOUT _{RMS} (V) ⁽²⁾ | t _{ON} (Rising) μs | t _{ON} (Falling) μs | t _{OFF} (Rising) μs | t _{OFF} (Falling) μs |
| 1440 | 86.5 | 4225 | 4225 | 4075 | 4075 |
| 1450 | 87 | 4250 | 4250 | 4050 | 4050 |
| 1460 | 87.5 | 4275 | 4275 | 4025 | 4025 |
| 1470 | 88 | 4300 | 4300 | 4000 | 4000 |
| 1480 | 88.5 | 4325 | 4325 | 3975 | 3975 |
| 1490 | 89 | 4350 | 4350 | 3950 | 3950 |
| 1500 | 89.5 | 4375 | 4375 | 3925 | 3925 |
| 1510 | 90 | 4400 | 4400 | 3900 | 3900 |
| 1520 | 90.5 | 4425 | 4425 | 3875 | 3875 |
| 1530 | 91 | 4450 | 4450 | 3850 | 3850 |
| 1540 | 91.5 | 4475 | 4475 | 3825 | 3825 |
| 1550 | 92 | 4500 | 4500 | 3800 | 3800 |
| 1560 | 92.4 | 4525 | 4525 | 3775 | 3775 |
| 1570 | 92.8 | 4550 | 4550 | 3750 | 3750 |
| 1580 | 93.2 | 4575 | 4575 | 3725 | 3725 |
| 1590 | 93.6 | 4600 | 4600 | 3700 | 3700 |
| 1600 | 94 | 4625 | 4625 | 3675 | 3675 |
| 1610 | 94.4 | 4650 | 4650 | 3650 | 3650 |
| 1620 | 94.8 | 4675 | 4675 | 3625 | 3625 |
| 1630 | 95.2 | 4700 | 4700 | 3600 | 3600 |
| 1640 | 95.6 | 4725 | 4725 | 3575 | 3575 |
| 1650 | 96 | 4750 | 4750 | 3550 | 3550 |
| 1660 | 96.4 | 4775 | 4775 | 3525 | 3525 |
| 1670 | 96.8 | 4800 | 4800 | 3500 | 3500 |
| 1680 | 97.2 | 4825 | 4825 | 3475 | 3475 |
| 1690 | 97.6 | 4850 | 4850 | 3450 | 3450 |
| 1700 | 98 | 4875 | 4875 | 3425 | 3425 |
| 1710 | 98.4 | 4900 | 4900 | 3400 | 3400 |
| 1720 | 98.8 | 4925 | 4925 | 3375 | 3375 |
| 1730 | 99.2 | 4950 | 4950 | 3350 | 3350 |
| 1740 | 99.6 | 4975 | 4975 | 3325 | 3325 |
| 1750 | 100 | 5000 | 5000 | 3300 | 3300 |
| 1760 | 100.4 | 5025 | 5025 | 3275 | 3275 |
| 1770 | 100.8 | 5050 | 5050 | 3250 | 3250 |
| 1780 | 101.2 | 5075 | 5075 | 3225 | 3225 |
| 1790 | 101.6 | 5100 | 5100 | 3200 | 3200 |

Continued on the following page...

Table 5. DIM Control Voltage Pulse Width Selection⁽¹⁾ (Continued)

| | | DIM Mode=0 | DIM Mode=0 | DIM Mode=1 | DIM Mode=1 |
|--------------------------|--|-----------------------------|------------------------------|------------------------------|-------------------------------|
| | | Trailing Edge | Trailing Edge | Leading Edge | Leading Edge |
| DIM_Control Voltage (mV) | VOUT _{RMS} (V) ⁽²⁾ | t _{ON} (Rising) μs | t _{ON} (Falling) μs | t _{OFF} (Rising) μs | t _{OFF} (Falling) μs |
| 1800 | 102 | 5125 | 5125 | 3175 | 3175 |
| 1810 | 102.4 | 5150 | 5150 | 3150 | 3150 |
| 1820 | 102.8 | 5175 | 5175 | 3125 | 3125 |
| 1830 | 103.2 | 5200 | 5200 | 3100 | 3100 |
| 1840 | 103.6 | 5225 | 5225 | 3075 | 3075 |
| 1850 | 104 | 5250 | 5250 | 3050 | 3050 |
| 1860 | 104.4 | 5275 | 5275 | 3025 | 3025 |
| 1870 | 104.8 | 5300 | 5300 | 3000 | 3000 |
| 1880 | 105.2 | 5325 | 5325 | 2975 | 2975 |
| 1890 | 105.6 | 5350 | 5350 | 2950 | 2950 |
| 1900 | 106 | 5375 | 5375 | 2925 | 2925 |
| 1910 | 106.4 | 5400 | 5400 | 2900 | 2900 |
| 1920 | 106.8 | 5425 | 5425 | 2875 | 2875 |
| 1930 | 107.2 | 5450 | 5450 | 2850 | 2850 |
| 1940 | 107.6 | 5475 | 5475 | 2825 | 2825 |
| 1950 | 108 | 5500 | 5500 | 2800 | 2800 |
| 1960 | 108.3 | 5525 | 5525 | 2775 | 2775 |
| 1970 | 108.6 | 5550 | 5550 | 2750 | 2750 |
| 1980 | 108.9 | 5575 | 5575 | 2725 | 2725 |
| 1990 | 109.2 | 5600 | 5600 | 2700 | 2700 |
| 2000 | 109.5 | 5625 | 5625 | 2675 | 2675 |
| 2010 | 109.8 | 5650 | 5650 | 2650 | 2650 |
| 2020 | 110.1 | 5675 | 5675 | 2625 | 2625 |
| 2030 | 110.4 | 5700 | 5700 | 2600 | 2600 |
| 2040 | 110.7 | 5725 | 5725 | 2575 | 2575 |
| 2050 | 111 | 5750 | 5750 | 2550 | 2550 |
| 2060 | 111.3 | 5775 | 5775 | 2525 | 2525 |
| 2070 | 111.6 | 5800 | 5800 | 2500 | 2500 |
| 2080 | 111.9 | 5825 | 5825 | 2475 | 2475 |
| 2090 | 112.2 | 5850 | 5850 | 2450 | 2450 |
| 2100 | 112.5 | 5875 | 5875 | 2425 | 2425 |
| 2110 | 112.8 | 5900 | 5900 | 2400 | 2400 |
| 2120 | 113.1 | 5925 | 5925 | 2375 | 2375 |
| 2130 | 113.4 | 5950 | 5950 | 2350 | 2350 |
| 2140 | 113.7 | 5975 | 5975 | 2325 | 2325 |
| 2150 | 113 | 6000 | 6000 | 2300 | 2300 |

Continued on the following page...

Table 5. DIM Control Voltage Pulse Width Selection⁽¹⁾ (Continued)

| | | DIM Mode=0 | DIM Mode=0 | DIM Mode=1 | DIM Mode=1 |
|--------------------------|--|-----------------------------|------------------------------|------------------------------|-------------------------------|
| | | Trailing Edge | Trailing Edge | Leading Edge | Leading Edge |
| DIM_Control Voltage (mV) | VOUT _{RMS} (V) ⁽²⁾ | t _{ON} (Rising) μs | t _{ON} (Falling) μs | t _{OFF} (Rising) μs | t _{OFF} (Falling) μs |
| 2160 | 113.2 | 6025 | 6025 | 2275 | 2275 |
| 2170 | 113.4 | 6050 | 6050 | 2250 | 2250 |
| 2180 | 113.6 | 6075 | 6075 | 2225 | 2225 |
| 2190 | 113.8 | 6100 | 6100 | 2200 | 2200 |
| 2200 | 114 | 6125 | 6125 | 2175 | 2175 |
| 2210 | 114.2 | 6150 | 6150 | 2150 | 2150 |
| 2220 | 114.4 | 6175 | 6175 | 2125 | 2125 |
| 2230 | 114.6 | 6200 | 6200 | 2100 | 2100 |
| 2240 | 114.8 | 6225 | 6225 | 2075 | 2075 |
| 2250 | 115 | 6250 | 6250 | 2050 | 2050 |
| 2260 | 115.2 | 6275 | 6275 | 2025 | 2025 |
| 2270 | 115.4 | 6300 | 6300 | 2000 | 2000 |
| 2280 | 115.6 | 6325 | 6325 | 1975 | 1975 |
| 2290 | 115.8 | 6350 | 6350 | 1950 | 1950 |
| 2300 | 116 | 6375 | 6375 | 1925 | 1925 |
| 2310 | 116.2 | 6400 | 6400 | 1900 | 1900 |
| 2320 | 116.4 | 6425 | 6425 | 1875 | 1875 |
| 2330 | 116.6 | 6450 | 6450 | 1850 | 1850 |
| 2340 | 116.8 | 6475 | 6475 | 1825 | 1825 |
| 2350 | 117 | 6500 | 6500 | 1800 | 1800 |
| 2360 | 117.2 | 6525 | 6525 | 1775 | 1775 |
| >4000 ⁽³⁾ | 119 | 8.333 | 8.333 | 0 | 0 |

Notes:

1. The pulse width times shown in Table 5 are reference to the ZC threshold. For trailing edge DIM mode, the pulse width time is the gate t_{ON} time. For leading edge DIM mode, the pulse width time is the gate t_{OFF} time. The shown pulse width time is typical for the FL5160. For the FL5150, the values will be scaled by +20%.
2. VOUT_{RMS} typical value with a 60 W incandescent Load and 120 V_{RMS} input.
3. If the DIM Control voltage is >4 V a 100% duty cycle is selected and the DRV Gate will be on 100%. However, a 100% duty cycle can only occur for a 3-wire application. If a 2-wire application is used and the DIM Control pin voltage is >4 V a POR will occur

Description

(Refer to Figure 1 to Figure 5)

Present AC controls or dimmer switches typically use TRIAC circuits to generate the AC symmetric chopped or phase cut current function. The TRIAC is basically two back to back SCR transistors that allow for symmetric AC operation in both the positive and negative half cycles. The TRIAC dimmer circuit controls the AC voltage pulse width to the load by turning off the TRIAC when its holding current is below the minimum threshold level. This occurs near the AC zero-crossing. The TRIAC is turned on at a selected phase angle during the half cycle. The TRIAC minimum holding current can become an issue for newer low wattage lighting products. In addition, newer lighting products typically have capacitive load impedance so the current and voltage phases are shifted. This can cause problems for the detection of the AC zero-cross signal and lead to unwanted flickering.

The FL5150/60 controller addresses these issues by controlling back to back MOSFET or IGBT transistors which can be turned on or off at any time during the AC half cycle. In addition, the FL5160 can use the earth ground leakage current to better determine the zero-cross threshold for non-resistive loads. Up to 500 μ A of ground leakage current is now allowed per the UL1472 2nd edition specification for 2-wire applications.

The FL5160 product is for North America 120 V_{AC} , 60 Hz applications and the FL5150 product is for 230 V_{AC} , 50 Hz applications. The internal timing oscillator is selected for 50 Hz for the FL5150 and 60 Hz for the FL5160. For the below description, the timing information is in reference to the FL5160 60 Hz option. For the FL5150 option, the t_{ON} pulse width is scaled by +20%.

The FL5160 has a selectable DIM Mode pin that allows for either Trailing Edge or Leading Edge dimming modulation. At startup when an under-voltage lockout enable signal is detected (POR) the DIM Mode pin is monitored for its logic state and after 60ms this state will be latched and program the FL5160 for either trailing edge dimming if this pin is low or leading edge dimming if this pin is high. The DIM Mode pin enables a 10 μ A pull up current source after Power-on-Reset (POR). Once the dimming mode is latched, this pin will be disabled until a POR enable signal occurs. For trailing edge dimming, the gate pulse is enabled at the ZC signal and disabled after the t_{ON} pulse width per Table 5. For leading edge dimming, the gate pulse is disabled at the ZC signal and enabled after the t_{OFF} pulse width per Table 5.

The gate pulse width is determined by the value of the voltage at the DIM Control pin. The DIM Control pin sources a 10 μ A current. The voltage at this pin is connected to an 8 Bit ADC with an internal full scale reference of 2.56 V so the ADC step size is ~10 mV. Table 5 shows the gate pulse width versus the DIM Control pin voltage for a 60 Hz FL5160 application. If the DIM Control pin is connected to VDD a force 100% duty cycle will be selected. However, if the VS voltage drops to the POR voltage threshold a logic reset will

occur. A 100% duty cycle can only be selected for a 3-wire application (Neutral wire present).

When the voltage on the DIM Control pin is changed, the FL5160 will increase or decrease the dim steps by one step every 4.17 ms (or two steps per half cycle). This provides for a smooth dim pulse width transition. From minimum to maximum pulse width, the FL5160 will control the dim ramp rate to about 1 second.

The FL5160 has an internal difference amplifier which measures the voltage difference across Q1 and Q2. With the external OC Sense 1&2 resistors, this diff amp will measure the voltage difference across the collectors or drains of Q1 and Q2 when the DRV Gate signal is high. If the maximum voltage threshold is exceeded for longer than 50 μ s the gate pulse will be disabled until the next AC zero-crossing. This feature will limit the maximum load current and also limit the power dissipation for Q1 and Q2. If 16 consecutive over current pulses occur (see Figure 12) the FL5160 will disable the DRV gate and require a POR to reset the disable state. The OC (over-current) trip threshold is dynamic: it is a function of the V_{AC} phase angle. The OC threshold is higher at startup to allow for higher transient currents during startup typical of incandescent bulbs.

The desired steady state (phase angle > 90°) over-current threshold can be programmed with the following equation:

$$|Q1_{VD} - Q2_{VD}| = 2 \times R_{SENSE} \quad (1)$$

$$I_{OC} \times R_{DSON} + V_F = 2 \times R_{SENSE}$$

Where:

R_{DSON} = MOSFET drain to source resistance
 V_F = MOSFET body diode

So,

$$I_{OC} = (2 \times R_{SENSE} - V_F) / R_{DSON} \quad (2)$$

note: R_{SENSE} in $M\Omega$

For the FDPF33N25 transistor,

$$R_{DSON} = 94 \text{ m}\Omega \text{ and } V_F = 0.7 \text{ V @ } 25^\circ\text{C} \quad (3)$$

$$R_{DSON} = 170 \text{ m}\Omega \text{ and } V_F = 0.6 \text{ V @ } 100^\circ\text{C}$$

So,

$$I_{OC} = 13.8 \text{ A @ } 25^\circ\text{C} \text{ with } R_{SENSE} = 1 \text{ M}\Omega \quad (4)$$

$$I_{OC} = 8.2 \text{ A @ } 100^\circ\text{C} \text{ with } R_{SENSE} = 1 \text{ M}\Omega$$

The FL5160 has a low power electronic off state feature. If an external NPN transistor is connected per Figure 2, the power consumption for the OFF state can be significantly reduced. When an OFF state is selected (DIM Control pin at 0 V) an internal 100 ms timer starts. After the timer expires, the FL5160 will enable an internal PMOS transistor which shorts the Low power and VS pins. This will turn off Q3 which de-biases R1. The FL5160 is now biased by R2. This reduces the electronic off state power consumption from 1 W to 100 mW for a 120 V_{AC} input.

Figure 4 shows a typical 3 wire application. For a three wire application, the neutral wire is available in addition to the Line Hot and Load Hot connections. External components D1, R1 and C2 provide for the DC bias of the FL5160. During the AC half cycle when Line Neutral is positive, the C2 capacitor will charge positive and be clamped to 17 V by the FL5160's shunt regulator connected to VS. The gate driver circuit is supplied from the VS pin. During the AC half cycle when Line Neutral is negative, the FL5160 is biased by the capacitor C2. Figure 8 shows the VS, DRV Gate and load current waveforms for a LED load. The pulse width can be controlled from 0 to 100% duty cycle with a 3-wire application. The R_{ZC} Monitor resistor detects the AC zero crossing. The typical value for this resistor is 1 M Ω for 120 V_{AC} applications.

Figure 1 shows a typical 120 V_{AC} 2-wire application. This 2-wire application does not have the neutral wire available, which is typical for most switch box applications in North America: only the Line Hot, Load Hot and earth ground wires are available. The FL5160 is powered from the AC line by D1, D2, R1 and C2.

Capacitor C2 charges when the Q1 & Q2 transistors are off. When Q1 and Q2 are on, C2 provides the bias for the FL5160. Since C2 can only charge when both Q1 and Q2 are off, a 100% duty cycle is not possible. The maximum duty cycle is determined by the load; however, because the FL5160 has a low quiescent

current, an output voltage typically >95% of the AC Line voltage is possible. Figure 9 shows the VS, DRV Gate and load current waveforms for a LED load. For the R1 and C2 values shown, a maximum gate pulse of 6.5 ms is possible. However, some LED loads will not allow a 6.5 ms maximum gate pulse. The FL5160 has a DIM Control override feature for LED loads that do not support a maximum gate pulse of 6.5 ms (Auto Max.). The FL5160 detects when the maximum gate pulse width occurs and overrides the DIM Control voltage to provide the maximum Load voltage without flicker. This feature automatically adjusts per the Load impedance.

The power dissipation for R1 (Figure 1) is highest when an off state is selected. To reduce the power dissipation for R1, an emitter follower current mirror circuit can be used as shown per Figure 3. Zener Z1 (7.5 V) will bias R1 so ~3.5 mA flows through R1, independent of the V_{AC} voltage. The power dissipation for R1 will be ~25 mW. The power dissipation for Q3 will be ~425 mW.

The above description refers predominantly to the FL5160 functionality. The FL5150 controller is the same as the FL5160 except the internal timer is trimmed for a 50 Hz AC frequency.

Whereas the above applications refer to V_{AC} input voltages of 120 and 230, other AC voltages can be used as long as the discrete components are correctly scaled.

Typical Performance Characteristics

Unless otherwise specified, $T_A=25^\circ\text{C}$ and according to Figure 1 to Figure 5.

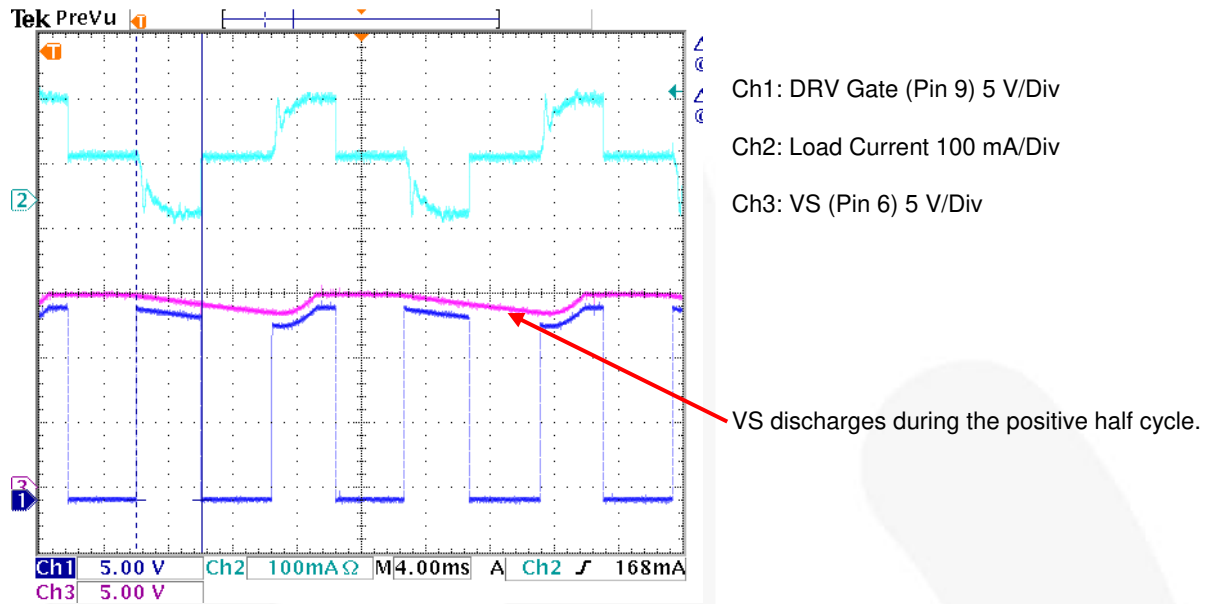


Figure 8. Typical 120 V_{AC} 60 Hz 3-Wire Waveforms with an 8 W LED Load (TE Mode)

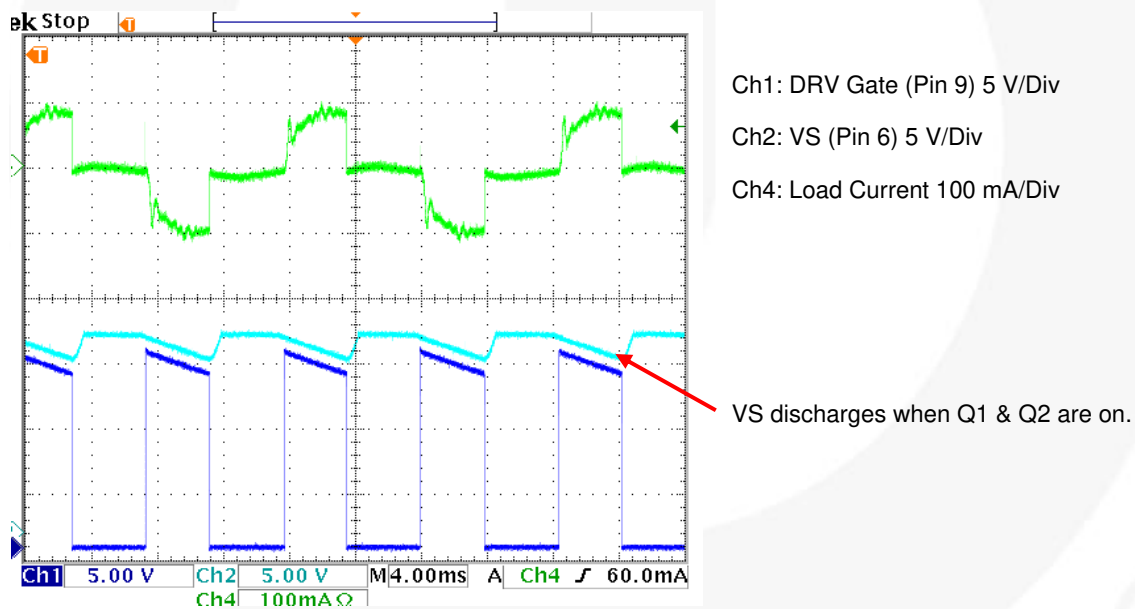
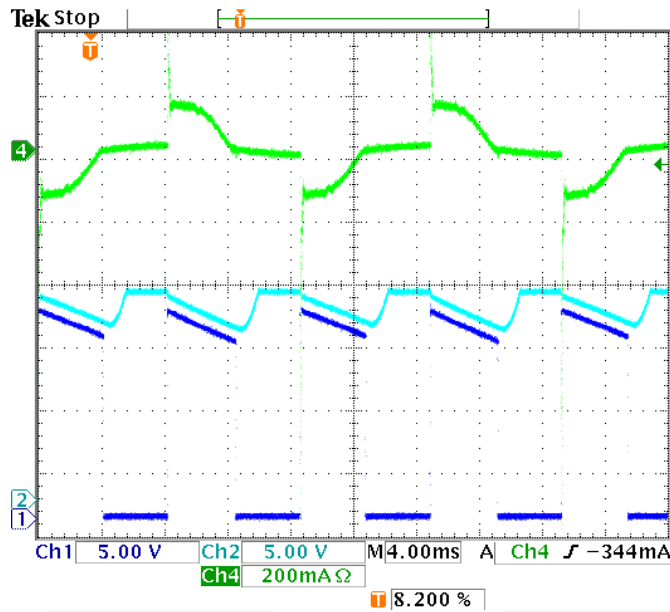


Figure 9. Typical 120 V_{AC} 60 Hz 2-Wire Waveforms with an 8 W LED Load (TE Mode)

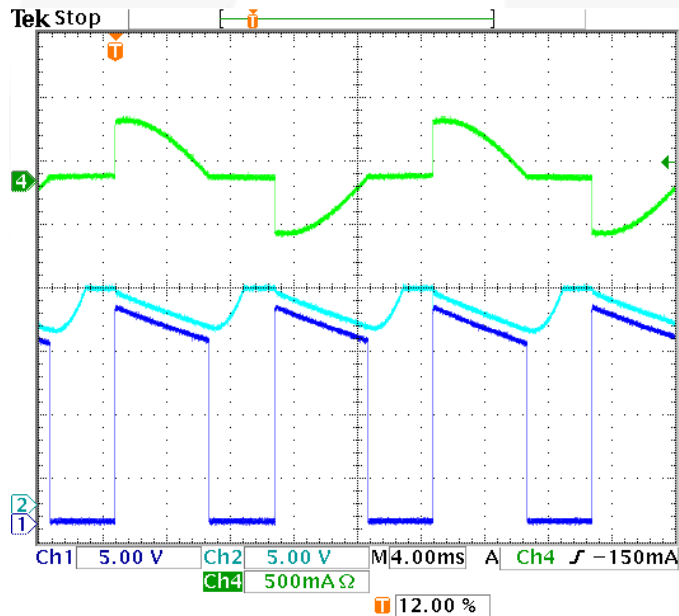
Typical Performance Characteristics (Continued)

Unless otherwise specified, $T_A=25^\circ\text{C}$ and according to Figure 1 to Figure 5.



Ch1: DRV Gate (Pin 9) 5 V/Div
Ch4: Load Current 200 mA/Div
Ch2: VS (Pin6) 5 V/Div

Figure 10. Typical 120 V_{AC} 60 Hz 2-Wire Waveforms with an 11 W LED Load (LE Mode)



Ch1: DRV Gate (Pin 9) 5 V/Div
Ch4: Load Current 500 mA/Div
Ch2: VS (Pin 6) 5 V/Div

Figure 11. Typical 230 V_{AC} 50 Hz 2-Wire Waveforms with a 60 W Incandescent Load (LE Mode)

Typical Performance Characteristics (Continued)

Unless otherwise specified, $T_A=25^\circ\text{C}$ and according to Figure 1 to Figure 5.

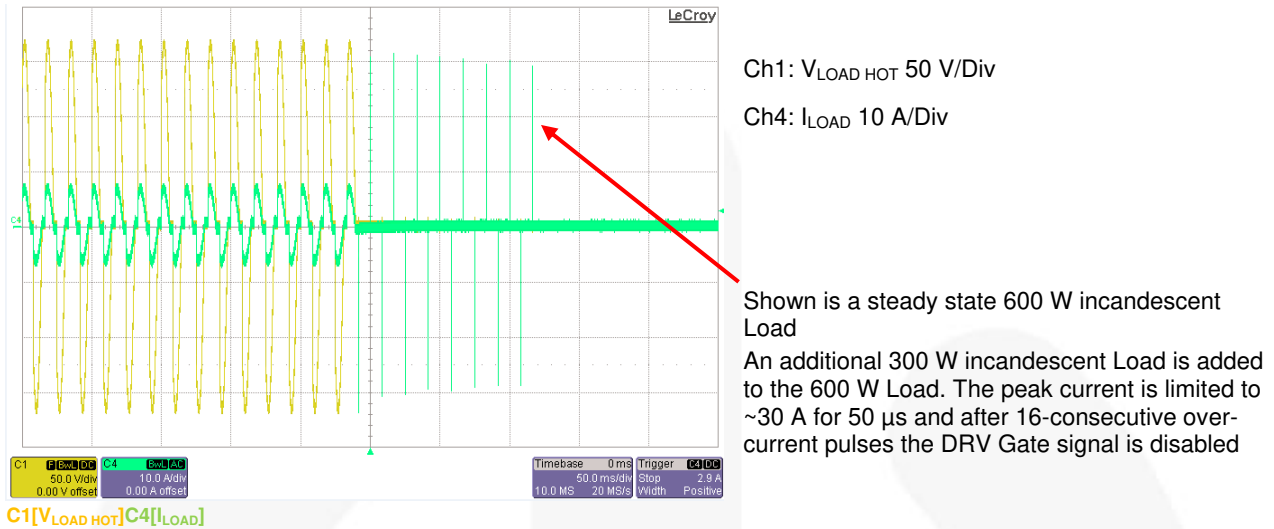


Figure 12. Over-Current Protection

Typical Temperature Characteristics

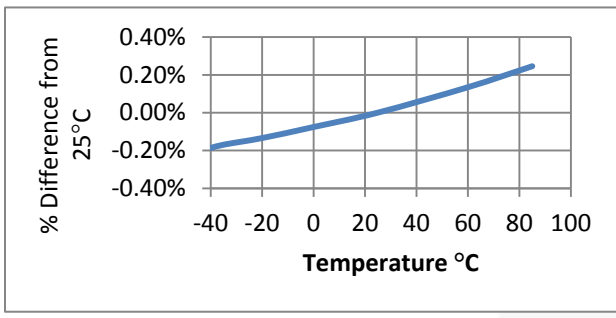


Figure 13. Shunt Regulator Voltage vs. Temperature

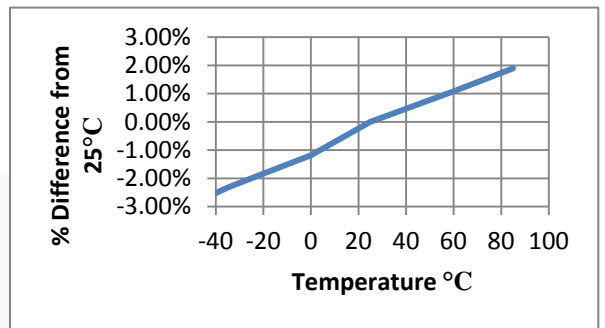


Figure 14. Quiescent Current vs. Temperature

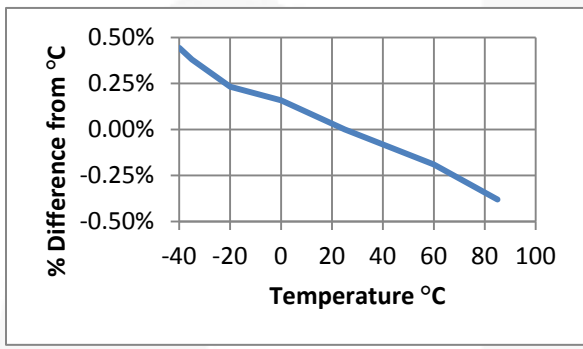


Figure 15. Under-Voltage Lockout Rising vs. Temperature

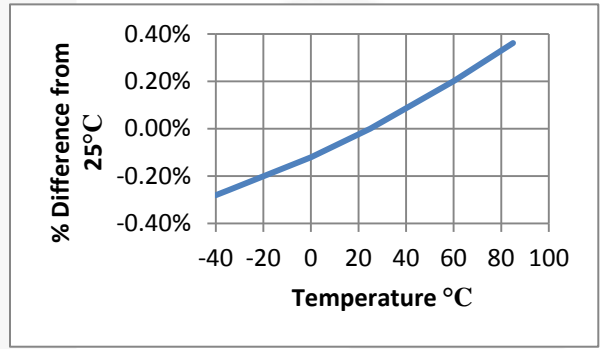


Figure 16. VDD vs. Temperature

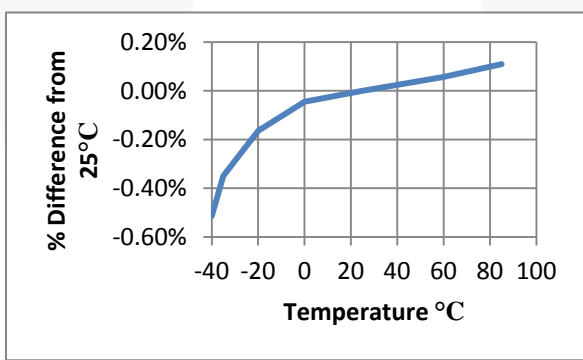


Figure 17. Oscillator Frequency vs. Temperature

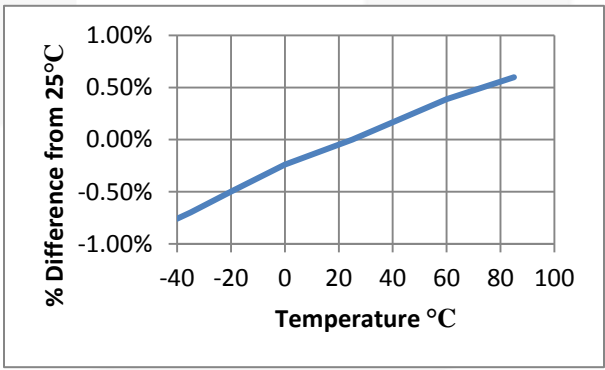
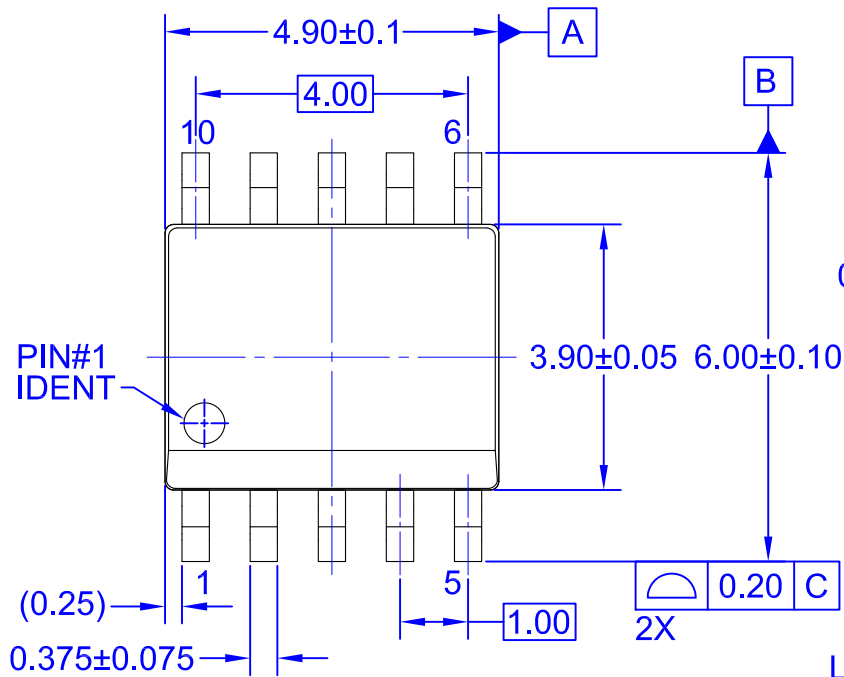
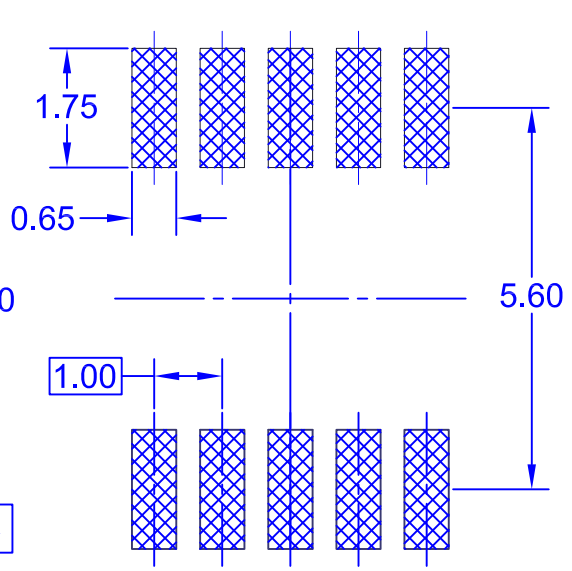


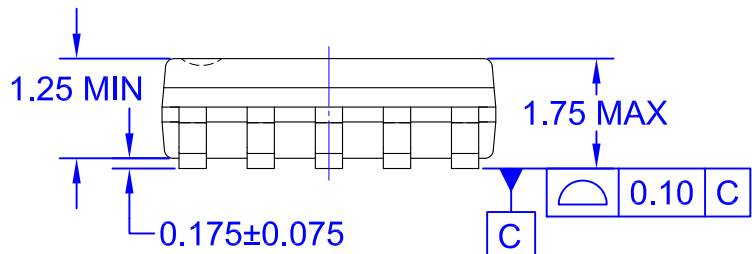
Figure 18. DIM Control Source Current vs. Temperature



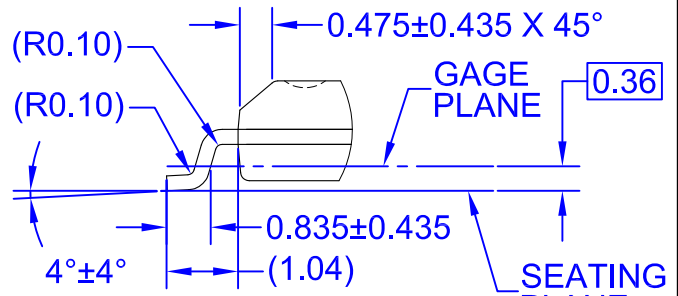
TOP VIEW



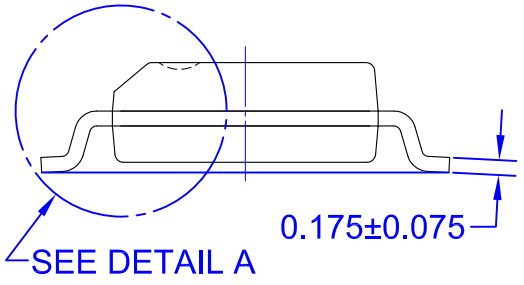
LAND PATTERN RECOMMENDATION



SIDE VIEW



DETAIL A




FRONT VIEW

- NOTES:
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 - B. ALL DIMENSIONS ARE IN MILLIMETERS.
 - C. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR BURRS.
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