MIC3205

High-Brightness LED Driver Controller with Fixed-Frequency Hysteretic Control

General Description

The MIC3205 is a hysteretic, step-down, high-brightness LED (HB LED) driver with a patent pending frequency regulation scheme that maintains a constant operating frequency over input voltage range. It provides an ideal solution for interior/exterior lighting, architectural and ambient lighting, LED bulbs, and other general illumination applications.

The MIC3205 is well suited for lighting applications requiring a wide input voltage range. The hysteretic control provides good supply rejection and fast response during load transients and PWM dimming. The high-side current sensing and on-chip current-sense amplifier deliver LED current with ±5% accuracy. An external high-side current-sense resistor is used to set the output current.

The MIC3205 offers a dedicated PWM input (DIM) which enables a wide range of pulsed dimming. A high-frequency switching operation up to 1.5MHz allows the use of smaller external components minimizing space and cost.

The MIC3205 operates over a junction temperature from –40°C to +125°C and is available in a 10-pin 3mm x 3mm MLF® package.

Data sheets and support documentation are available on Micrel's web site at: www.micrel.com.

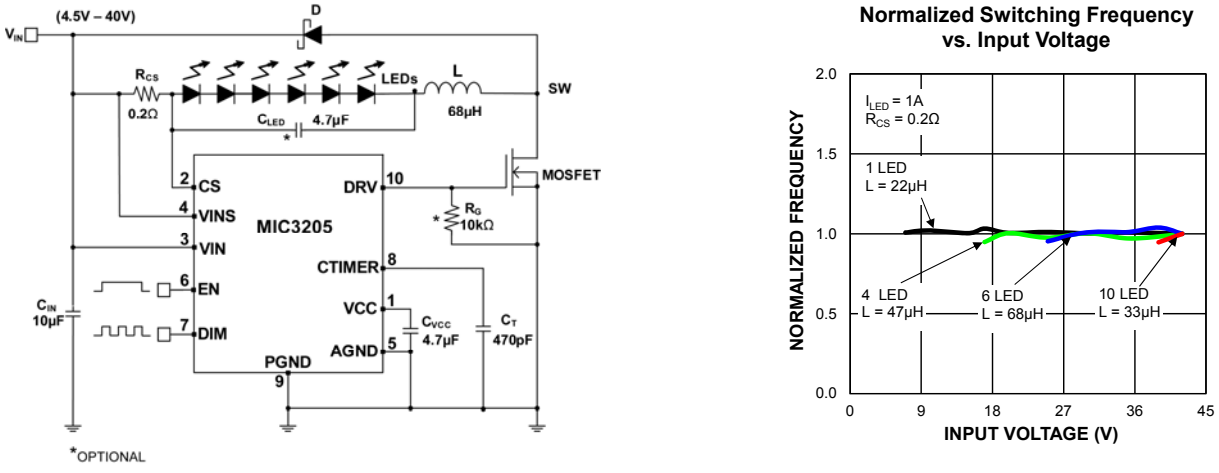
Features

- 4.5V to 40V input voltage range
- Fixed operating frequency over input voltage range
- High efficiency (>90%)
- ±5% LED current accuracy
- High-side current sense
- Dedicated dimming control input
- Hysteretic control (no compensation!)
- Up to 1.5MHz switching frequency
- Adjustable constant LED current
- Over-temperature protection
- –40°C to +125°C junction temperature range

Applications

- Architectural, industrial, and ambient lighting
- LED bulbs
- Indicators and emergency lighting
- Street lighting
- Channel letters
- 12V lighting systems (MR-16 bulbs, under-cabinet lighting, garden/pathway lighting)

Typical Application



MIC3205 Buck LED Driver

MLF and *Micro*LeadFrame are registered trademarks of Amkor Technology, Inc.

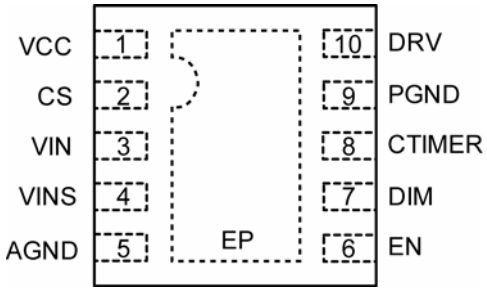
Ordering Information

Part Number	Junction Temperature Range	Package[1]
MIC3205YML	–40°C to +125°C	10-Pin 3mm x 3mm MLF

Note:

1. MLF is a GREEN RoHS-compliant package. Lead finish is NiPdAu. Mold compound is Halogen Free.

Pin Configuration



10-Pin 3mm x 3mm MLF (ML)
Top View

Pin Description

Pin Number	Pin Name	Pin Function
1	VCC	Voltage Regulator Output. The VCC pin is the output of a linear regulator powered from VIN, which supplies power to the internal circuitry. A 4.7µF ceramic capacitor is recommended for bypassing. Place it as close as possible to the VCC and AGND pins. Do not connect to an external load.
2	CS	Current Sense Input. Negative input to the current sense comparator. Connect an external sense resistor to set the LED current. Connect the current sense resistor as close as possible to the chip.
3	VIN	Input Power Supply. VIN is the input supply pin to the internal circuitry. Due to high frequency switching noise, a 10µF ceramic capacitor is recommended for bypassing and should be placed as close as possible to the VIN and PGND pins. See "PCB Layout Guidelines."
4	VINS	VIN Sense. Positive input to the current sense comparator. Connect as close as possible to the current sense resistor.
5	AGND	Analog Ground. Ground for all internal low-power circuitry.
6	EN	Enable Input. Logic high (greater than 2V) powers up the regulator. A logic low (less than 0.4V) powers down the regulator and reduces the supply current of the device to less than 2µA. A logic low pulls down the DRV pin turning off the external MOSFET. Do not drive the EN pin above VIN. Do not leave floating.
7	DIM	PWM Dimming Input. A PWM input can be used to control the brightness of the LED. Logic high (greater than 2V) enables the output. Logic low (less than 0.4V) disables the output regardless of the EN state. Do not drive the DIM pin above VIN. Do not leave floating.
8	CTIMER	Timer Capacitor. A capacitor is required from CTIMER to ground sets the target switching frequency using the equation $C_{TIMER}=2.22*10^{-4} / F_{SW}$
9	PGND	Power Ground. Ground for the power MOSFET gate driver. The current loop for the power ground should be as small as possible and separate from the analog ground loop. See "PCB Layout Recommendations."
10	DRV	Gate Drive Output. Connect to the gate of an external N-channel MOSFET. The drain of the external MOSFET connects directly to the inductor and provides the switching current necessary to operate in hysteretic mode.
EP	ePAD	Exposed Pad. Must be connected to a GND plane for best thermal performance.

Absolute Maximum Ratings [1]

V_{IN} to PGND ..... –0.3V to +42V
V_{INS} to PGND ..... –0.3V to (V_{IN}+0.3V)
V_{CC} to PGND ..... –0.3V to +6.0V
CS to PGND ..... –0.3V to (V_{IN} + 0.3V)
EN to AGND ..... –0.3V to (V_{IN} + 0.3V)
DIM to AGND ..... –0.3V to (V_{IN} + 0.3V)
CTIMER to AGND ..... –0.3V to (V_{CC} + 0.3V)
DRV to PGND ..... –0.3V to (V_{CC} + 0.3V)
PGND to AGND ..... –0.3V to + 0.3V
Junction Temperature ..... 150°C
Storage Temperature Range ..... –60°C to +150°C
Lead Temperature (Soldering, 10sec) ..... 260°C
ESD Ratings [3]
HBM 1.5kV
MM 200V

Operating Ratings [2]

Supply Voltage (V_{IN}) ..... 4.5V to 40V
Enable Voltage (V_{EN}) ..... 0V to V_{IN}
Dimming Voltage (V_{DIM}) ..... 0V to V_{IN}
Junction Temperature (T_J) ..... –40°C to +125°C
Junction Thermal Resistance
10-pin 3x3 MLF (θ_{JA}) ..... 60.7°C/W
10-pin 3x3 MLF (θ_{JC}) ..... 28.7°C/W

Electrical Characteristics [4]

V_{IN} = V_{EN} = V_{DIM} = 12V; C_{VCC} = 4.7µF; T_J = 25°C; **bold** values indicate –40°C ≤ T_J ≤ +125°C, unless noted.

Symbol	Parameter	Condition	Min.	Typ.	Max.	Units
Input Supply						
V_{IN}	Input Voltage Range (V_{IN})		**4.5**		**40**	V
I_S	Supply Current	DRV = Open		1.3	**3**	mA
I_{SD}	Shutdown Current	V_{EN} = 0V			**2**	µA
UVLO	V_{IN} UVLO Threshold	V_{IN} Rising	**3.2**	4	**4.5**	V
$UVLO_{HYS}$	V_{IN} UVLO Hysteresis			600		mV
VCC Supply						
V_{CC}	V_{CC} Output Voltage	V_{IN} = 12V, I_{CC} = 5mA	**4.5**	5	**5.5**	V
Current Sense						
ΔV_{CS}	Average Current Sense Threshold	$\Delta V_{CS} = V_{INS} - V_{CS}$	190	200	210	mV
			188	200	**212**	mV
Δt_{CS}	Current Sense Response Time	V_{CS} Rising		50		ns
		V_{CS} Falling		70		ns
I_{CS}	CS Input Current	V_{IN} = V_{CS}		0.5	**10**	µA
ΔV_{HYS}	Sense Voltage Hysteresis [5]	V_{IN} =12V, V_{LED} =3V, L=47µH, F_{SW} =250kHz, V_D = 0.7V, I_{LED} = 1A		46		mV
Frequency						
I_{TIMER}	CTIMER Pull-up Current			66		µA
V_{CTREF}	CTIMER Threshold			1.189		V
$(4*I_{TIMER})/V_{CTREF}$	Frequency Coefficient [6]		**1.776×10^{-4}**	2.22×10^{-4}	**2.664×10^{-4}**	A/V

Electrical Characteristics [4] (Continued)

V_{IN} = V_{EN} = V_{DIM} = 12V; C_{VCC} = 4.7µF; T_J = 25°C; **bold** values indicate –40°C ≤ T_J ≤ +125°C, unless noted.

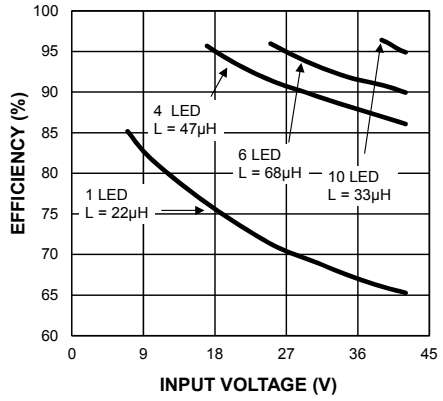
Symbol	Parameter	Condition	Min.	Typ.	Max.	Units
Enable Input						
EN_{HI}	EN Logic Level High		**2.0**			V
EN_{LO}	EN Logic Level Low				**0.4**	V
I_{EN}	EN Bias Current	V_{EN} = 12V		20	**60**	µA
		V_{EN} = 0V			1	µA
t_{START}	Start-Up Time	From EN pin going high to DRV going high		65		µs
Dimming Input						
DIM_{HI}	DIM Logic Level High		**2.0**			V
DIM_{LO}	DIM Logic Level Low				**0.4**	V
I_{DIM}	DIM Bias Current	V_{DIM} = 12V		20	**50**	µA
		V_{DIM} = 0V			1	µA
t_{DIM}	DIM Delay Time	From DIM pin going high to DRV going high		450		ns
f_{DIM}	Maximum Dimming Frequency	% of switching frequency		2		%
External FET Driver						
R_{ON}	DRV On-Resistance	Pull-Up, I_{SOURCE} = 10mA		4		Ω
		Pull-Down, I_{SINK} = -10mA		1.5		Ω
t_{DRV}	DRV Transition Time	Rise Time, C_{LOAD} = 1000pF		13		ns
		Fall Time, C_{LOAD} = 1000pF		7		ns
Thermal Protection						
T_{LIM}	Overtemperature Shutdown	T_J Rising		160		°C
T_{LIMHYS}	Overtemperature Shutdown Hysteresis			20		°C

Notes:

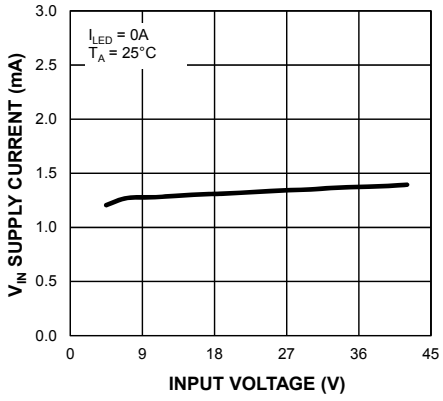
1. Exceeding the absolute maximum rating can damage the device.
2. The device is not guaranteed to function outside its operating rating.
3. Devices are ESD sensitive. Handling precautions are recommended. Human body model, 1.5kΩ in series with 100pF.
4. Specification for packaged product only.
5. See “Sense Voltage Hysteresis Range” in the “Application Information” section.
6. See “Frequency of Operation” in the “Application Information” section.

Typical Characteristics

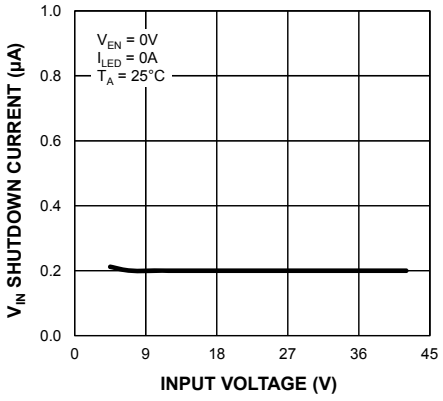
Efficiency (I_{LED} = 1A) vs. Input Voltage



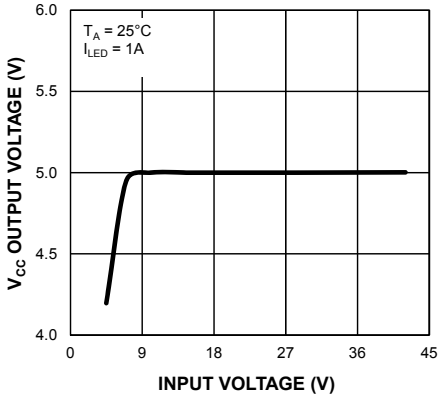
V_{IN} Supply Current vs. Input Voltage



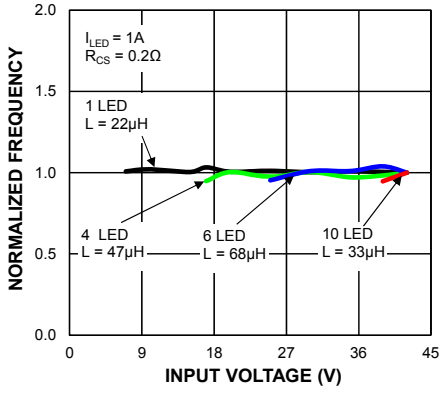
V_{IN} Shutdown Current vs. Input Voltage



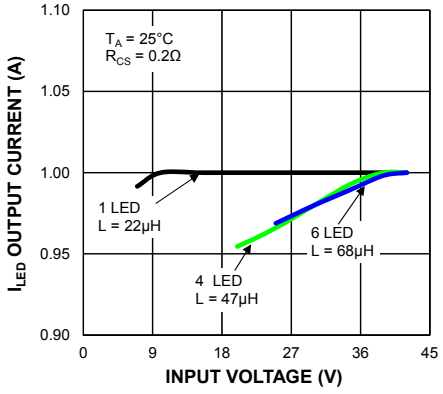
V_{CC} Output Voltage vs. Input Voltage



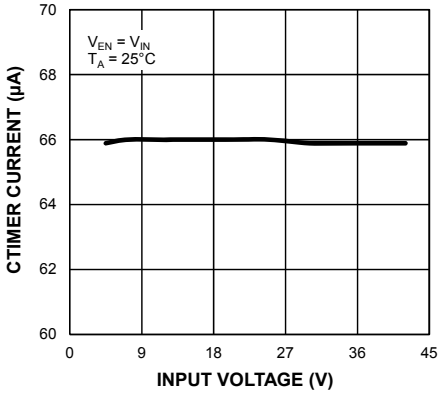
Normalized Switching Frequency vs. Input Voltage



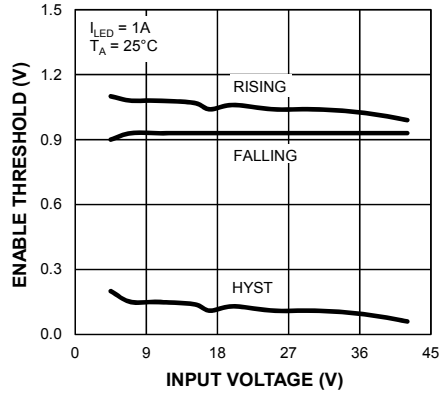
I_{LED} Output Current vs. Input Voltage



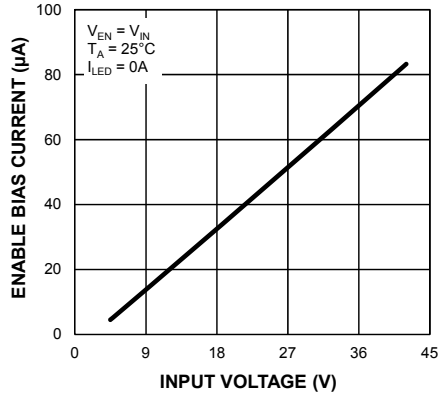
CTIMER Current vs. Input Voltage



Enable Threshold vs. Input Voltage

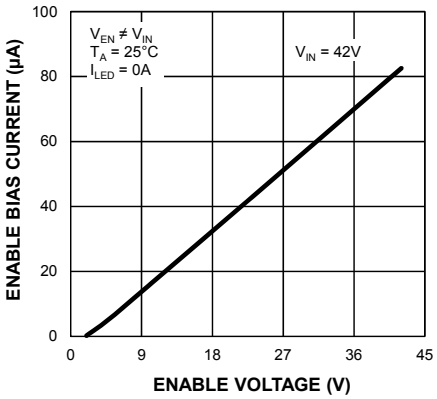


Enable Bias Current vs. Input Voltage

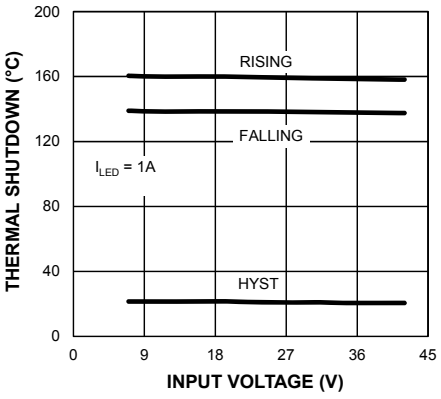


Typical Characteristics (Continued)

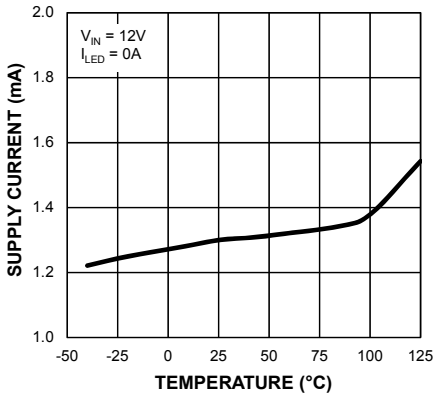
Enable Bias Current vs. Enable Voltage



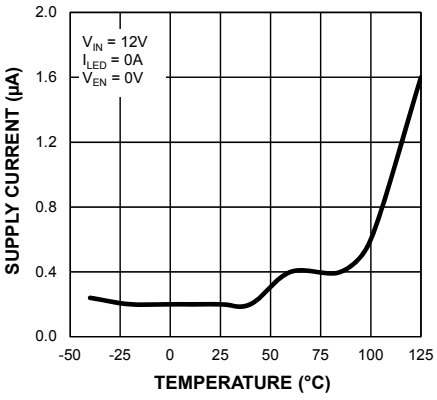
Thermal Shutdown vs. Input Voltage



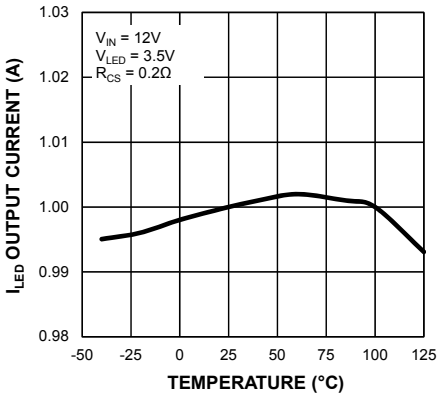
V_{IN} Supply Current vs. Temperature



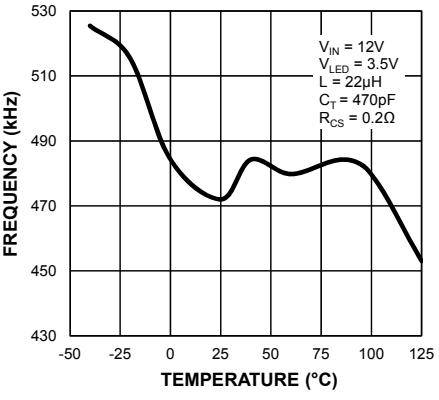
V_{IN} Shutdown Current vs. Temperature



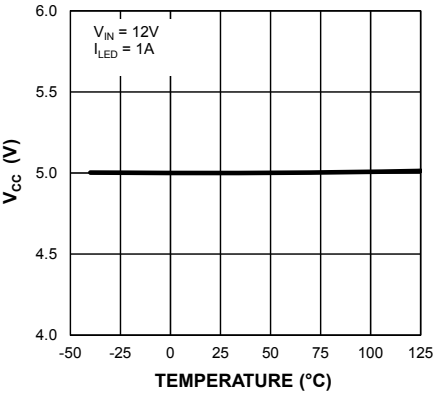
I_{LED} Output Current vs. Temperature



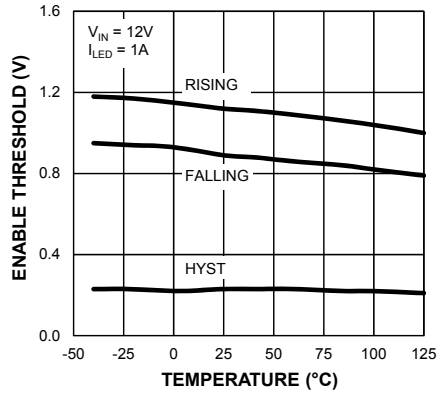
Switching Frequency vs. Temperature



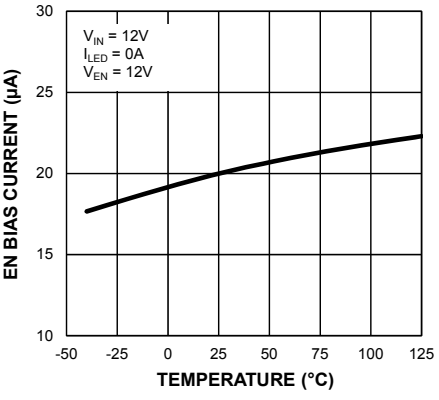
V_{CC} vs. Temperature



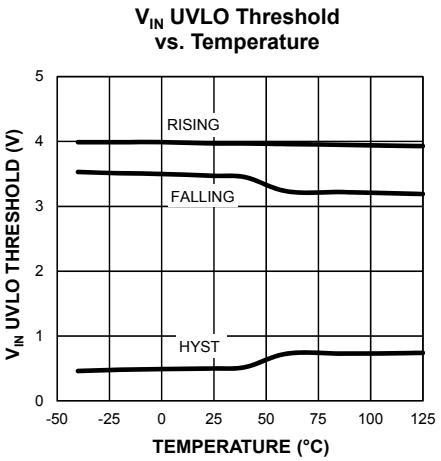
Enable Threshold vs. Temperature



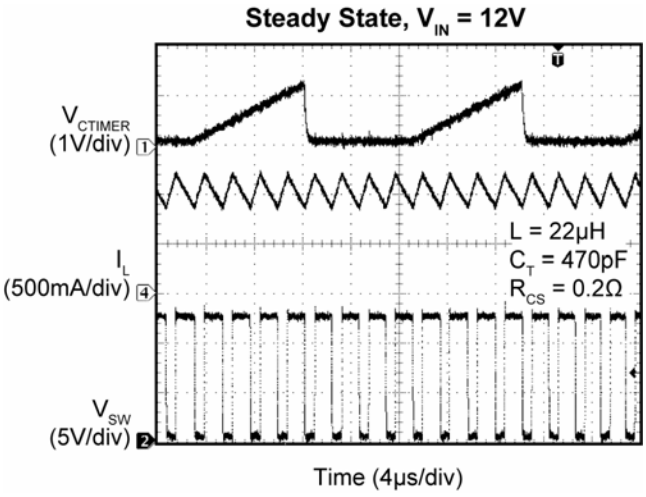
Enable Bias Current vs. Temperature

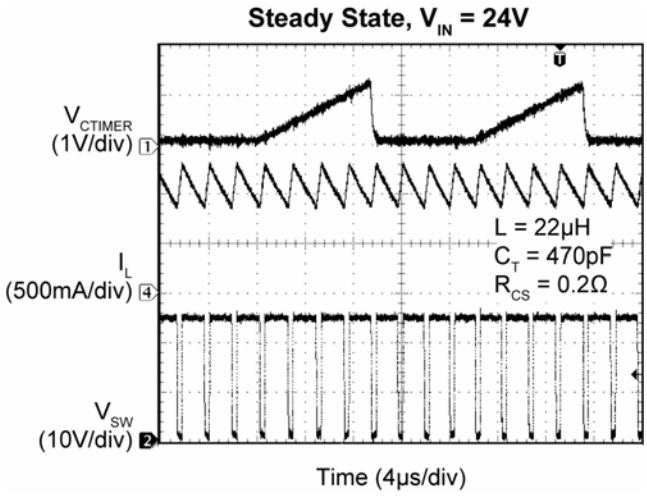


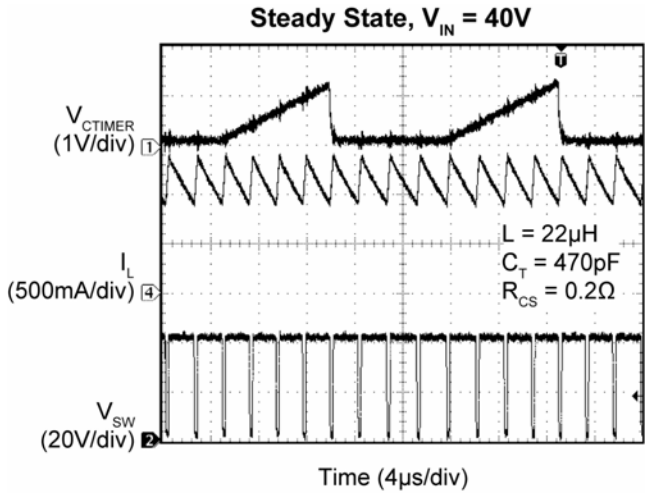
Typical Characteristics (Continued)

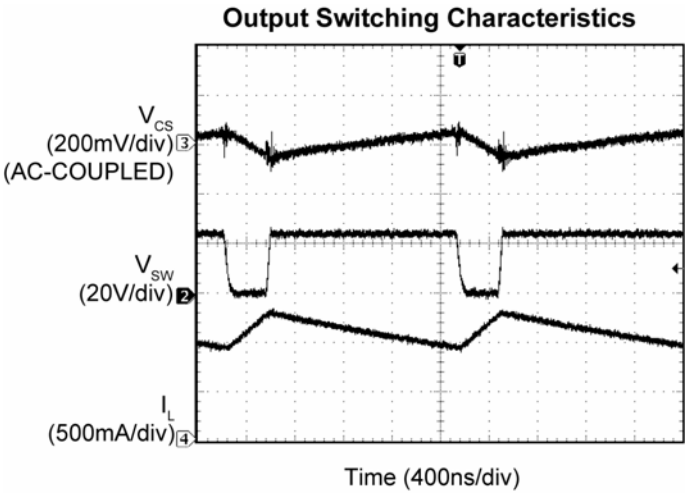


Functional Characteristics

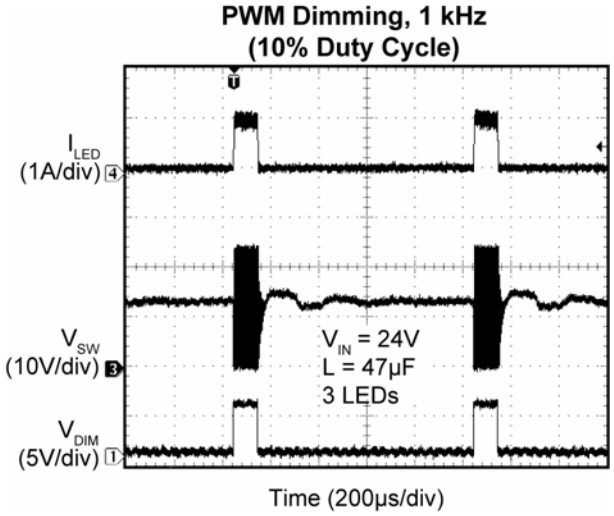


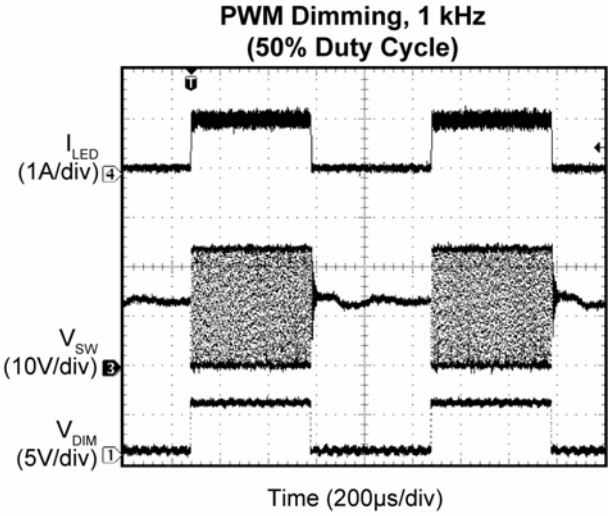


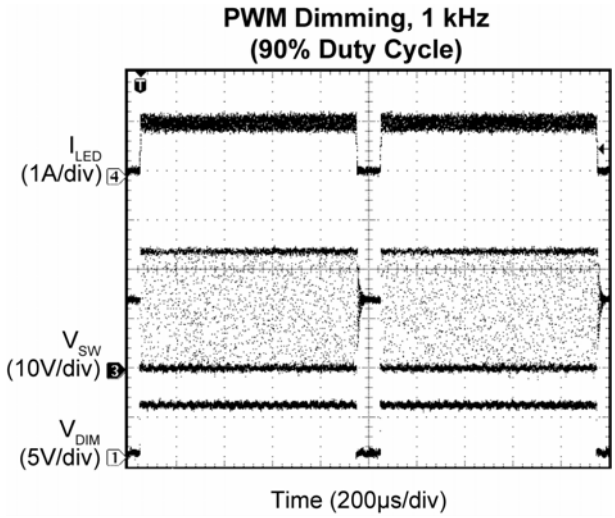




Functional Characteristics (Continued)







Functional Diagram

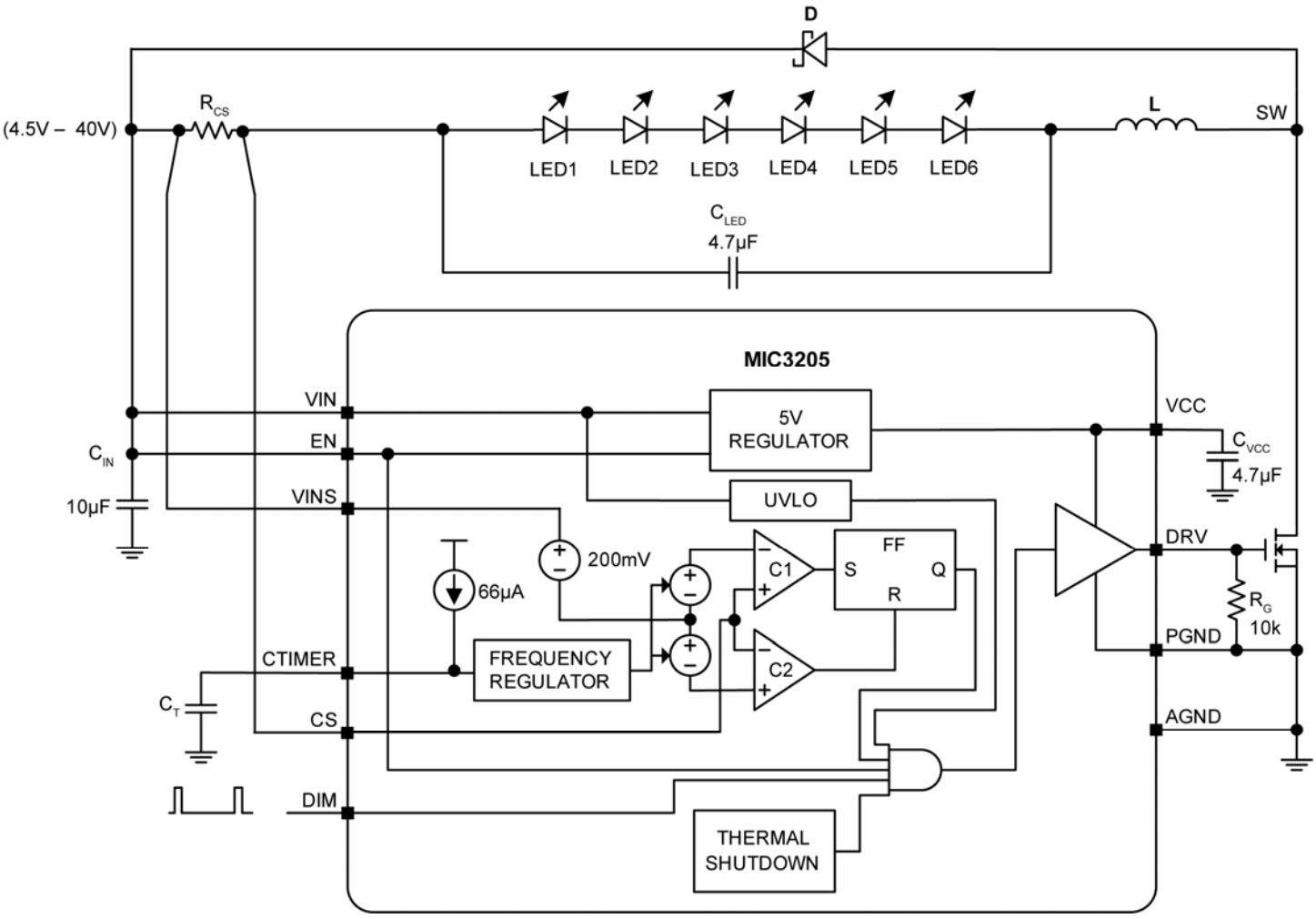


Figure 1. MIC3205 Block Diagram

Functional Description

The MIC3205 is a hysteretic step-down driver that regulates the LED current with a patent pending frequency regulation scheme. This scheme maintains a fixed operating frequency over a wide input voltage range.

Theory of Operation

The device operates from a 4.5V to 40V input MOSFET voltage. At turn-on, after the VIN input voltage crosses 4.5V, the DRV pin is pulled high to turn on an external MOSFET. The inductor and series LED current builds up linearly. This rising current results in a rising differential voltage across the current sense resistor (R_{CS}). When this differential voltage reaches an upper threshold, the DRV pin is pulled low, the MOSFET turns off, and the Schottky diode takes over and returns the series LEDs and inductor current to V_{IN}. Then, the current through the inductor and series LEDs starts to decrease. This decreasing current results in a decreasing differential voltage across R_{CS}. When this differential voltage reaches a lower threshold, the DRV pin is pulled high, the MOSFET is turned on, and the cycle repeats. The average of the CS pin voltage is 200mV below V_{IN} voltage. This is the average current sense threshold (ΔV_{CS}). Thus, the CS pin voltage switches about V_{IN} – 200mV with a peak-to-peak hysteresis that is the product of the peak-to-peak inductor current times the current sense resistor (R_{CS}). The average LED current is set by R_{CS}, as explained in the "Application Information" section.

MIC3205 dynamically adjusts hysteresis to accommodate fixed-frequency operation. Average frequency is programmed using an external capacitor connected to the CTIMER pin, as explained in the "Frequency of Operation" subsection in the "Application Information" section. The internal frequency regulator dynamically adjusts the inductor current hysteresis every eight switching cycles to make the average switching frequency a constant. If the instantaneous frequency is higher than the programmed average value, the hysteresis is increased to lower the frequency and vice versa. In other hysteretic control systems, current sense hysteresis is constant and frequency can change with input voltage, inductor value, series LEDs voltage drop, or LED current. However, with this patent pending frequency regulation scheme, the MIC3205 changes inductor current hysteresis and keeps the frequency fixed even upon changing input voltage, inductor value, series LEDs voltage drop, or LED current.

The MIC3205 has an on-board 5V regulator, which is for internal use only. Connect a 4.7µF capacitor on VCC pin to analog ground.

The MIC3205 has an EN pin that gives the flexibility to enable and disable the output with logic high and low signals. The maximum EN voltage is V_{IN}.

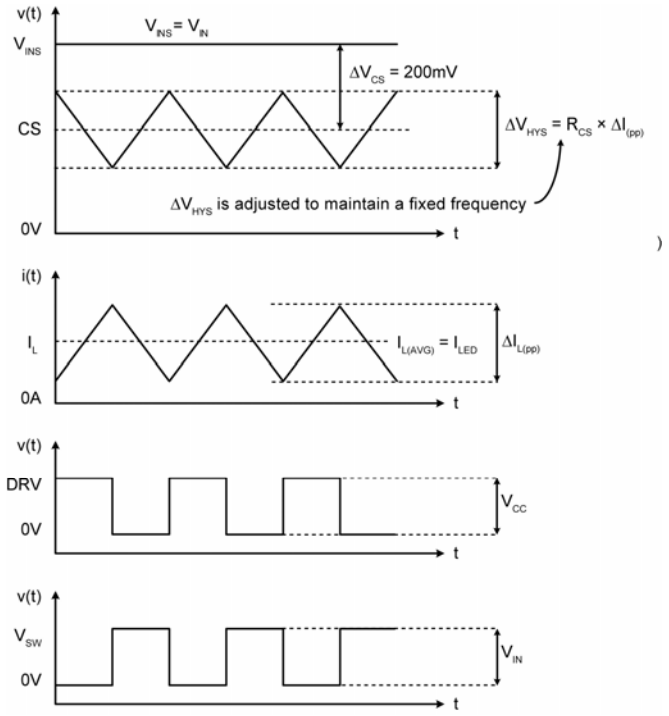


Figure 2. Theory of Operation

LED Dimming

The MIC3205 LED driver can control the brightness of the LED string through the use of pulse width modulated (PWM) dimming. A DIM pin is provided, which can turn on and off the LEDs if EN is in an active-high state. This DIM pin controls the brightness of the LED by varying the duty cycle of DIM pin from 1% to 99%.

An input signal from DC up to 20kHz can be applied to the DIM pin (see "Typical Application") to pulse the LED string on and off. A logic signal can be applied on the DIM pin for dimming, independent of input voltage (V_{IN}). Using PWM dimming signals above 120Hz is recommended to avoid any recognizable flicker by the human eye. Maximum allowable dimming frequency is 2% of operating frequency that is set by the external capacitor on the CTIMER pin (see "Frequency of Operation"). See "Functional Characteristics" on page 9 for PWM dimming waveforms. Maximum DIM voltage is V_{IN}.

PWM dimming is the preferred way to dim an LED to prevent color/wavelength shifting. Color/wavelength shifting occurs with analog dimming. By using PWM dimming, the output current level remains constant during each DIM pulse. The hysteretic buck converter switches only when the DIM pin is high. When the DIM pin is low, no LED current flows and the DRV pin is low turning the MOSFET off.

Application Information

The internal block diagram of the MIC3205 is shown in Figure 1. The MIC3205 is composed of a current-sense comparator, voltage reference, frequency regulator, 5V regulator, and MOSFET driver. Hysteretic mode control, also called bang-bang control, is a topology that does not use an error amplifier, instead using an error comparator.

The frequency regulator dynamically adjusts hysteresis for the current sense comparator to regulate frequency. The inductor current is sensed by an external sense resistor (R_{CS}) and controlled within a hysteretic window. It is a simple control scheme with no oscillator and no loop compensation. The control scheme does not need loop compensation. This makes design easy, and avoids instability problems.

Transient response to load and line variation is very fast and depends only on propagation delay. This makes the control scheme very popular for certain applications.

LED Current and R_{CS}

The main feature in MIC3205 is that it controls the LED current accurately within ±5% of set current. Choosing a high-side R_{CS} resistor is helpful for setting constant LED current regardless of wide input voltage range. The following equation and Table 1 give the R_{CS} value for required LED current:

$$R_{CS} = \frac{200mV}{I_{LED}} \qquad \text{Eq. 1}$$

R_{CS} (Ω)	I_{LED} (A)	I^2R (W)	Size (SMD)
1.33	0.15	0.03	0603
0.56	0.35	0.07	0805
0.4	0.5	0.1	0805
0.28	0.7	0.137	0805
0.2	1.0	0.2	1206
0.13	1.5	0.3	1206
0.1	2.0	0.4	2010
0.08	2.5	0.5	2010
0.068	3.0	0.6	2010

Table 1. R_{CS} for LED Current

Frequency of Operation

The patent pending frequency regulation scheme allows for operating frequency to be programmed by an external capacitor from the CTIMER pin to AGND. The frequency co-efficient (typically 2.22×10^{-4} A/F) divided by the value of this external capacitor connected to the CTIMER pin, gives the average frequency of operation, as seen in the following equation:

$$F_{SW} = \frac{2.22 \times 10^{-4}}{C_T} \qquad \text{Eq. 2}$$

The actual average frequency can vary depending on the variation of the frequency co-efficient and the parasitic board capacitances in parallel to the external capacitor C_T. As shown in the Electrical Characteristics table, part to part variation for the frequency co-efficient is ±20% over temperature, from the target frequency co-efficient of 2.22×10^{-4}.

Switching frequency selection is based on the trade-off between efficiency and system size. Higher frequencies result in smaller, but less efficient, systems and vice versa.

The operating frequency is independent of input voltage, inductor value, series LEDs voltage drop, or LED current, as long as $40mv \le \Delta V_{HYS} \le 100mV$ is maintained as explained in the next sections.

Sense Voltage Hysteresis Range

The frequency regulation scheme requires that the hysteresis remain in a controlled window. Components and operating conditions must be such that the hysteresis on the CS pin is between 40mV and 100mV.

Hysteresis less than 40mV or more than 100mV can result in loss of frequency regulation.

After average LED current (I_{LED}) has been set by R_{CS} and operating frequency has been set by external capacitor C_T, the hysteresis ΔV_{HYS} is calculated as follows:

As seen in Figure 2, for the inductor,

$$\Delta I_L = \frac{\Delta V_{HYS}}{R_{CS}} \qquad \text{Eq. 3}$$

where:

ΔI_L = inductor ripple current

ΔV_{HYS} = hysteresis on CS pin

For rising inductor current (MOSFET is on):

$$t_r = \frac{L \times \Delta I_L}{V_{L_RISE}} \qquad \text{Eq. 4}$$

where:

$V_{L_RISE} = V_{IN} - I_{LED} \times R_{CS} - V_{LED}$

V_{LED} is the total voltage drop of the LED string

V_{IN} is the input voltage

R_{CS} is the current sense resistor

I_{LED} is the average LED current

t_r is the MOSFET ON-time
L is the inductor

For falling inductor current (MOSFET is off):

$$t_f = \frac{L \times \Delta I_L}{V_{L_FALL}} \quad \text{Eq. 5}$$

where:

$V_{L_FALL} = V_D + I_{LED} \times R_{CS} + V_{LED}$
V_D is the freewheeling diode forward drop
t_f is the MOSFET OFF-time

Operating frequency and time period are given by:

$$F_{SW} = \frac{1}{T} \quad \text{Eq. 6}$$

$$T = t_r + t_f \quad \text{Eq. 7}$$

Using Equations 3, 4, 5, 6, and 7:

$$\Delta V_{HYS} = \frac{(V_{IN} - I_{LED} \times R_{CS} - V_{LED}) \times (V_D + I_{LED} \times R_{CS} + V_{LED}) \times R_{CS}}{(V_{IN} + V_D) \times L \times F_{SW}} \quad \text{Eq. 8}$$

The value of ΔV_{HYS} calculated in this way must be between 40mV and 100mV to ensure frequency regulation.

Inductor

According to the above equations, the inductor value can be calculated once average LED current, operating frequency and an appropriate hysteresis ΔV_{HYS} value have been chosen.

Thus, inductor L is given by:

$$L = \frac{(V_{IN} - I_{LED} \times R_{CS} - V_{LED}) \times (V_D + I_{LED} \times R_{CS} + V_{LED}) \times R_{CS}}{(V_{IN} + V_D) \times \Delta V_{HYS} \times F_{SW}} \quad \text{Eq. 9}$$

Table 2, Table 3, and Table 4 give reference inductor values for an operating frequency of 400 kHz, for a given LED current, freewheeling diode forward drop, and number of LEDs. By selecting ΔV_{HYS} in the 55mV to 75mV range, we get the following inductor values:

R_{CS} (Ω)	I_{LED} (A)	V_{IN} (V)	L (µH)	ΔV_{HYS} (mV)
0.56	0.35	5	22	64.1
0.56	0.35	12	68	57.7
0.28	0.7	5	10	70.5
0.28	0.7	12	33	59.4
0.2	1.0	5	6.8	72.6
0.2	1.0	12	22	62.4
0.1	2.0	5	3.6	68.5
0.1	2.0	12	10	68.6

Table 2. Inductor for F_{SW} = 400 kHz, V_D = 0.4V, 1 LED

R_{CS} (Ω)	I_{LED} (A)	V_{IN} (V)	L (µH)	ΔV_{HYS} (mV)
0.56	0.35	24	150	55.8
0.56	0.35	36	220	56.8
0.28	0.7	24	68	61.6
0.28	0.7	36	100	62.5
0.2	1.0	24	47	62.4
0.2	1.0	36	68	64.3
0.1	2.0	24	22	66.6
0.1	2.0	36	33	66.2

Table 3. Inductor for F_{SW} = 400 kHz, V_D = 0.4V, 4 LED

R_{CS} (Ω)	I_{LED} (A)	V_{IN} (V)	L (µH)	ΔV_{HYS} (mV)
0.56	0.35	36	150	58.4
0.56	0.35	40	220	54.3
0.28	0.7	36	68	64.4
0.28	0.7	40	100	59.6
0.2	1.0	36	47	65.2
0.2	1.0	40	68	61.4
0.1	2.0	36	22	69.6
0.1	2.0	40	33	63.3

Table 4. Inductor for F_{SW} = 400 kHz, V_D = 0.4V, 8 LED

Given an inductor value, the size of the inductor can be determined by its RMS and peak current rating.

Because LEDs are in series with the inductor,

$$I_L = I_{LED} \quad \text{Eq. 10}$$

From Equations 1, 3, and 10:

$$\frac{\Delta I_L}{I_L} = \frac{\Delta V_{HYS}}{200m} \quad \text{Eq. 11}$$

With 40mv ≤ ΔV_{HYS} ≤ 100mV:

$$I_{L(RMS)} = \sqrt{I_L^2 + \frac{1}{12}\Delta I_L^2} \approx I_L \quad \text{Eq. 12}$$

$$I_{L(PK)} = I_L(1 + \frac{\Delta V_{HYS}}{400m}) \quad \text{Eq. 13}$$

where:

I_L is the average inductor current

$I_{L(PK)}$ is the peak inductor current

Select an inductor with a saturation current rating at least 30% higher than the peak current.

For space-sensitive applications, smaller inductors with higher switching frequency could be used but regulator efficiency will be reduced.

MOSFET

N-channel MOSFET selection depends on the maximum input voltage, output LED current, and switching frequency.

The selected N-channel MOSFET should have 30% margin on maximum voltage rating for high reliability requirements.

The MOSFET channel resistance (R_{DSON}) is selected such that it helps to get the required efficiency at the required LED currents and meets the cost requirement.

Logic level MOSFETs are preferred as the drive voltage is limited to 5V.

The MOSFET power loss has to be calculated for proper operation. The power loss consists of conduction loss and switching loss. The conduction loss can be found by:

$$P_{LOSS(CON)} = I_{RMS(FET)}^2 \times R_{DSON}$$

$$I_{RMS(FET)} = I_{LED} \times \sqrt{D}$$

$$D \approx \frac{V_{LED}}{V_{IN}}$$

The switching loss occurs during the MOSFET turn-on and turn-off transition and can be found by:

$$P_{LOSS(TRAN)} = \frac{V_{IN} \times I_{LED} \times F_{SW}}{I_{DRV}} \times (Q_{gs2} + Q_{gd})$$

$$I_{DRV} = \frac{V_{DRV}}{R_{GATE}}$$

where:

R_{GATE} is total MOSFET gate resistance; Q_{gs2} and Q_{gd} can be found in a MOSFET manufacturer data sheet.

A gate resistor can be connected between the MOSFET gate and the DRV pin to slow down MOSFET switching edges. A 2Ω resistor is usually sufficient.

The total power loss is:

$$P_{LOSS(TOT)} = P_{LOSS(CON)} + P_{LOSS(TRAN)}$$

The MOSFET junction temperature is given by:

$$T_J = P_{LOSS(TOT)} \times R_{\theta JA} + T_A$$

T_J must not exceed maximum junction temperature under any conditions.

Freewheeling Diode

The freewheeling diode should have a reverse voltage rating that is at least 20% higher than the maximum input supply voltage. The forward voltage drop should be small to get the lowest conduction dissipation for high efficiency. The forward current rating should be at least equal to the LED current. Schottky diodes with low forward voltage drop and fast reverse recovery are ideal choices and give the highest efficiency. The freewheeling diode average current (I_D) is given by:

$$I_D = (1 - D) \times I_{LED}$$

Diode power dissipation (P_D) is given by:

$$P_D = V_D \times I_D$$

Typically, higher current rating diodes have a lower V_D and have better thermal performance, improving efficiency.

Input Capacitor

The ceramic input capacitor is selected by voltage rating and ripple current rating. A 10µF ceramic capacitor is usually sufficient. Select a voltage rating that is at least 30% larger than the maximum input voltage.

LED Ripple Current

The LED current is the same as inductor current ΔI_L. A ceramic capacitor should be placed across the series LEDs to pass the ripple current. A 4.7µF capacitor is usually sufficient for most applications. Voltage rating should be the same as the input capacitor.

PCB Layout Guidelines

NOTE: To minimize EMI and output noise, follow these layout recommendations.

PCB layout is critical to achieve reliable, stable, and efficient performance. A ground plane is required to control EMI and minimize the inductance in power, signal, and return paths.

Follow these guidelines to ensure proper operation of the MIC3205.

IC

- Use thick traces to route the input and output power lines.
- Keep signal and power grounds separate and connect them at only one location.

Input Capacitor

- Place the input capacitors on the same side of the board and as close to the IC as possible.
- Keep both the VIN and PGND traces as short as possible.
- If the application requires vias to the ground plane, place them close to the input capacitor ground terminal, but not between the input capacitors and IC pins.
- Use either X7R or X5R dielectric input capacitors. Do not use Y5V or Z5U type capacitors.
- Do not replace the ceramic input capacitor with any other type of capacitor. Any type of capacitor can be placed in parallel with the ceramic input capacitor.
- If a tantalum input capacitor is placed in parallel with the ceramic input capacitor, it must be recommended for switching regulator applications and the operating voltage must be derated by 50%.
- In “Hot-Plug” applications, place a tantalum or electrolytic bypass capacitor in parallel to the ceramic capacitor to limit the overvoltage spike seen on the input supply when power is suddenly applied. In this case, an additional tantalum or electrolytic bypass input capacitor of 22µF or higher is required at the input power connection.

Inductor

- Keep the inductor connection to the switch node (MOSFET drain) short.
- Do not route any digital lines underneath or close to the inductor.
- To minimize noise, place a ground plane underneath the inductor.

LED Ripple Current Carrying Capacitor

- Place this ceramic capacitor as close to the LEDs as possible.
- Use either X7R or X5R dielectric capacitors. Do not use Y5V or Z5U type capacitors.

MOSFET

- To avoid trace inductance, place the N-channel MOSFET as close as possible to the MIC3205.
- Provide sufficient copper area on MOSFET ground to dissipate the heat.

Freewheeling Diode

- Place the Schottky diode on the same side of the board as the IC and input capacitor.
- Keep the connection from the Schottky diode’s anode to the switching node as short as possible.
- Keep the diode’s cathode connection to the R_{CS} as short as possible.

RC Snubber

- If an RC snubber is needed, place the RC snubber on the same side of the board and as close to the Schottky diode as possible. A 1.2Ω resistor in series with a 1nF capacitor is usually a good choice.

R_{CS} (Current-Sense Resistor)

- VINS pin and CS pin must be as close as possible to R_{CS}.
- Make a Kelvin connection to the VINS and CS pin, respectively, for current sensing. For low values of ΔV_{HYS} (around 40mV) the switching noise could cause faulty switching on the DRV pin. If this occurs, place two 30Ω resistors and a 1nF capacitor, as shown in Figure 3, to filter out switching noise for low values of ΔV_{HYS}. Alternatively, as seen in Equation 8, a smaller inductor value can be used to increase ΔV_{HYS} and make the system more noise tolerant.

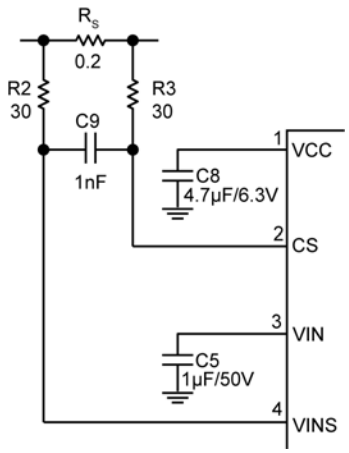


Figure 3. Input Filter for Low Values of ΔV_{HYS}

Trace Routing Recommendation

Keep the power traces as short and wide as possible. There is one current flowing loop during the MOSFET ON-time; the traces connect the input capacitor (C_{IN}), R_{CS}, the LEDs, the inductor, the MOSFET, and back to C_{IN}. There is another current flowing loop during the MOSFET OFF-time; the traces for this loop connect R_{CS}, the LED, the inductor, the freewheeling diode, and back to R_{CS}. These two loop areas should kept as small as possible to minimize noise interference

Keep all analog signal traces away from the switching node and its connecting traces.

Design Example

SPECIFICATIONS:

F_{SW} = 400 kHz

V_{SUPPLY} = 24V rectified AC

I_{LED} = 1A

Voltage drop per LED = 3.5V

Number of LEDs = 4

Schottky diode drop at 1A = 0.4V

1. CURRENT SENSE RESISTOR

From Equation 1: $R_{CS} = \frac{200mV}{I_{LED}}$

For I_{LED} = 1A

R_{CS} = 0.2Ω

2. SWITCHING FREQUENCY

From Equation 2: $F_{SW} = \frac{2.22 \times 10^{-4}}{C_T}$

For F_{SW} = 400 kHz

C_T = 550pF

The actual frequency may vary as explained in "Frequency of Operation" in the "Application Information" section.

3. INDUCTOR SELECTION

From Equation 9:

$$L = \frac{(V_{IN} - I_{LED} \times R_{CS} - V_{LED}) \times (V_D + I_{LED} \times R_{CS} + V_{LED}) \times R_{CS}}{(V_{IN} + V_D) \times \Delta V_{HYS} \times F_{SW}}$$

Given V_{SUPPLY} = 24V rectified AC

The peak voltage = $\sqrt{2}$ x V_{SUPPLY}

Thus for MIC3205, $V_{IN} \approx$ 34V

V_{LED} = 3.5 x 4 = 14, V_D = 0.4V

Select ΔV_{HYS} = 60mV

Thus, L = 70µH

Chose L = 68µH as closest available value.

As a side note, for this example, L = 68µH can be used even if V_{SUPPLY} = 24V DC. This is because ΔV_{HYS} calculates to around 44mV (with V_{IN} = V_{SUPPLY} = 24V) which is acceptable.

From Equations 12 and 13:

$I_{L(PK)}$ = 1.15A

Thus, we choose L = 68µH with an RMS saturation current of 1.5A or higher.

4. MOSFET SELECTION

For this example, V_{IN} = 34V, a 50V rating or greater N-channel MOSFET is required. A high current rating MOSFET is a good choice because it has lower R_{DSON}.

A 60V, 12A MOSFET with 10mΩ R_{DSON} is a good choice.

5. CAPACITOR SELECTION

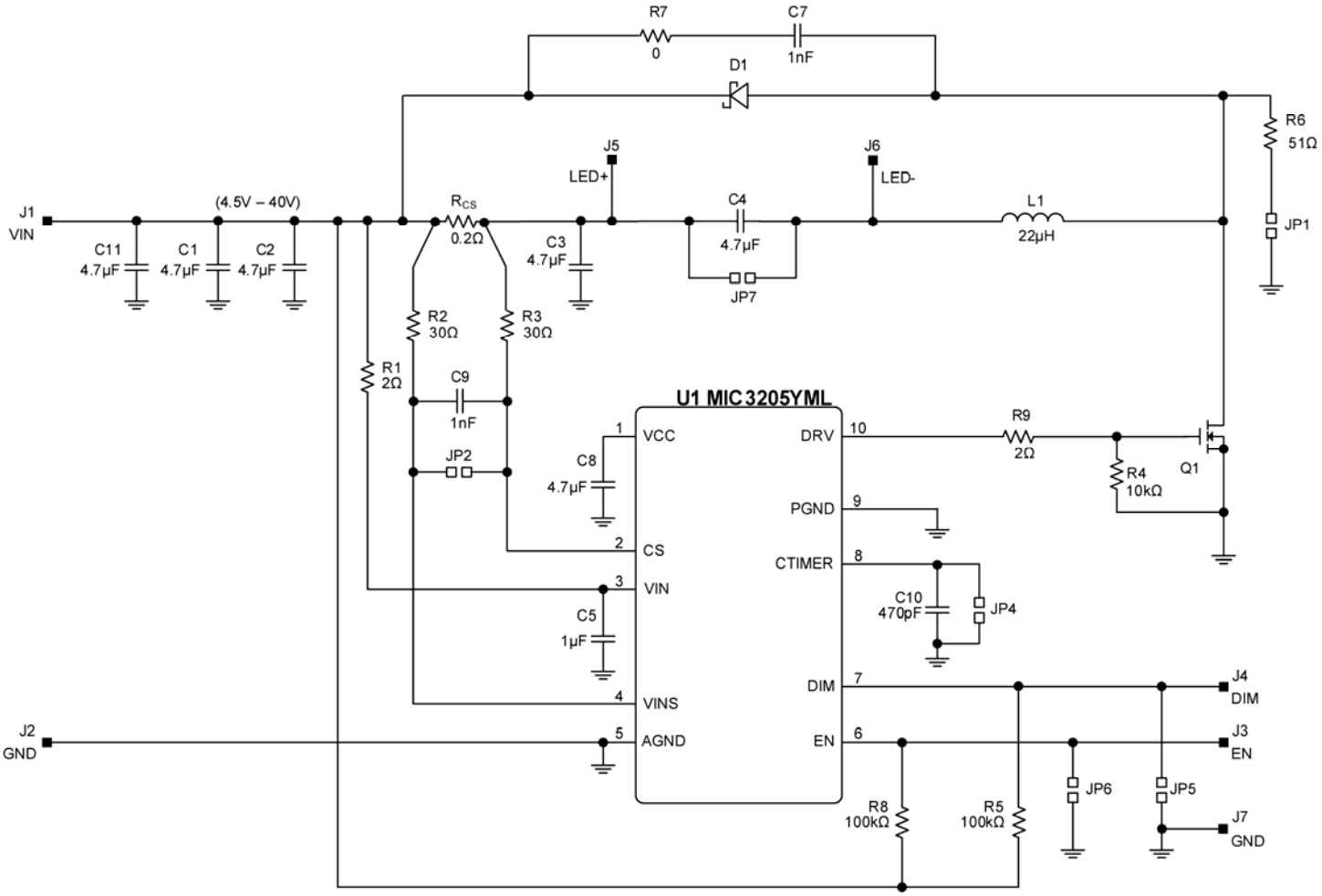
Use a 10µF/50V X7R type ceramic capacitor for the input capacitor.

Use a 4.7µF/50V X5R type ceramic capacitor for the LED ripple current carrying capacitor connected across the series connection of 4 LEDs

6. FREEWHEELING DIODE SELECTION

With V_{IN} = 34V, choose a 2A, 60V Schottky diode with a forward drop voltage of 0.4V at 1A forward current.

Evaluation Board Schematic



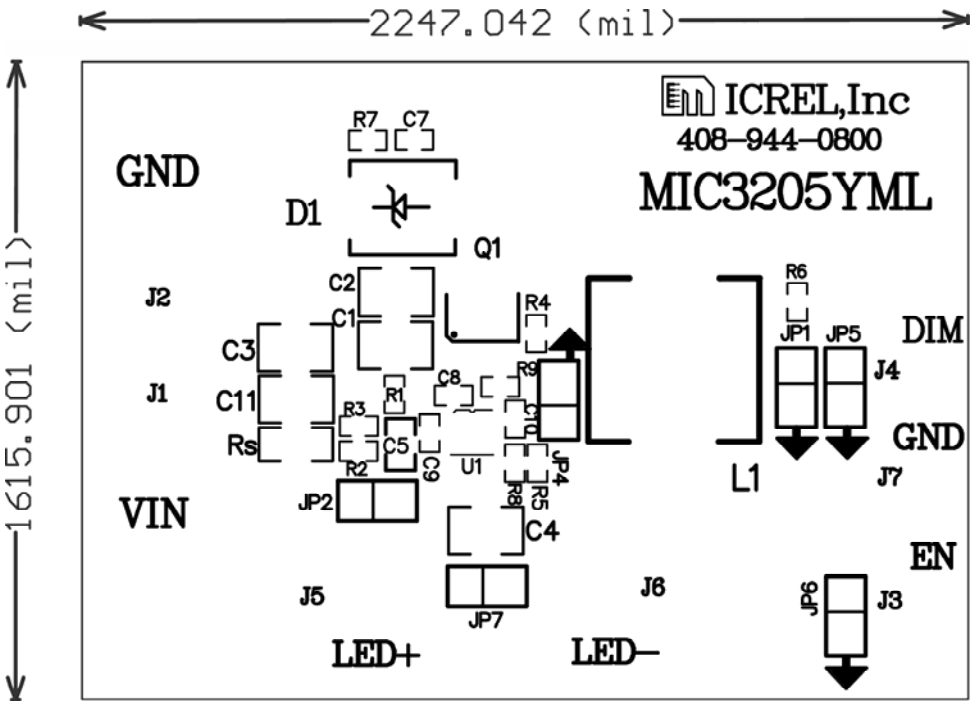
Bill of Materials

Item	Part Number	Manufacturer	Description	Qty.
C1, C2,C3,C4,C11	12105C475KAZ2A	AVX[1]	4.7µF/50V, Ceramic Capacitor, X7R, Size 1210	5
	GRM32ER71H475KA88L	Murata[2]		
	CGA6P3X7R1H475K	TDK[3]		
C5	GRM21BR71H105KA12L	Murata	1µF/50V, Ceramic Capacitor, X7R, Size 0805	1
	CGA4J3X7R1H105K	TDK		
C10	06035C471K4T2A	AVX	470pF/50V, Ceramic Capacitor, X7R, Size 0603	1
	GRM188R71H471KA01D	Murata		
	C1608X7R1H471K	TDK		
C8	06036D475KAT2A	AVX	4.7µF/6.3V, Ceramic Capacitor, X5R, Size 0603	1
	GRM188R60J475KE19J	Murata		
	CGA3E1X5R0J475K	TDK		
C7,C9	06035C102KAT2A	AVX	1nF/50V, Ceramic Capacitor, X7R, Size 0603	2
	GRM188R71H102KA01D	Murata		
	C1608X7R1H102K	TDK		
D1	SK36-TP	MCC[4]	60V, 3A, SMC, Schottky Diode	1
	SK36	Fairchild[5]		
	SK36-7-F	Diodes, Inc.[6]		
L1	SLF10145T-220M1R9-PF	TDK	22µH, 2.1A, 0.0591Ω, SMT, Power Inductor	1
M1	FDS5672	Fairchild	MOSFET, N-CH, 60V, 12A, SO-8	1
R_{CS}	CSR1206FKR200	Stackpole Electronics, Inc.[7]	0.2Ω Resistor, 1/2W, 1%, Size 1206	1
R5, R8	CRCW0603100KFKEA	Vishay Dale[8]	100kΩ Resistor, 1%, Size 0603	2
R2, R3	CRCW060330R0FKEA	Vishay Dale	30Ω Resistor, 1%, Size 0603	2
R1, R9	CRCW06032R00FKEA	Vishay Dale	2Ω Resistor, 1%, Size 0603	2
R4	CRCW060310K0FKEA	Vishay Dale	10kΩ Resistor, 1%, Size 0603	1
R6	CRCW060351R0FKEA	Vishay Dale	51Ω Resistor, 1%, Size 0603	1
R7	CRCW06030000Z0EA	Vishay Dale	0Ω Resistor, Size 0603	1
U1	**MIC3205YML**	**Micrel, Inc.[9]**	**High-Brightness LED Driver Controller with Fixed Frequency Hysteretic Control**	1

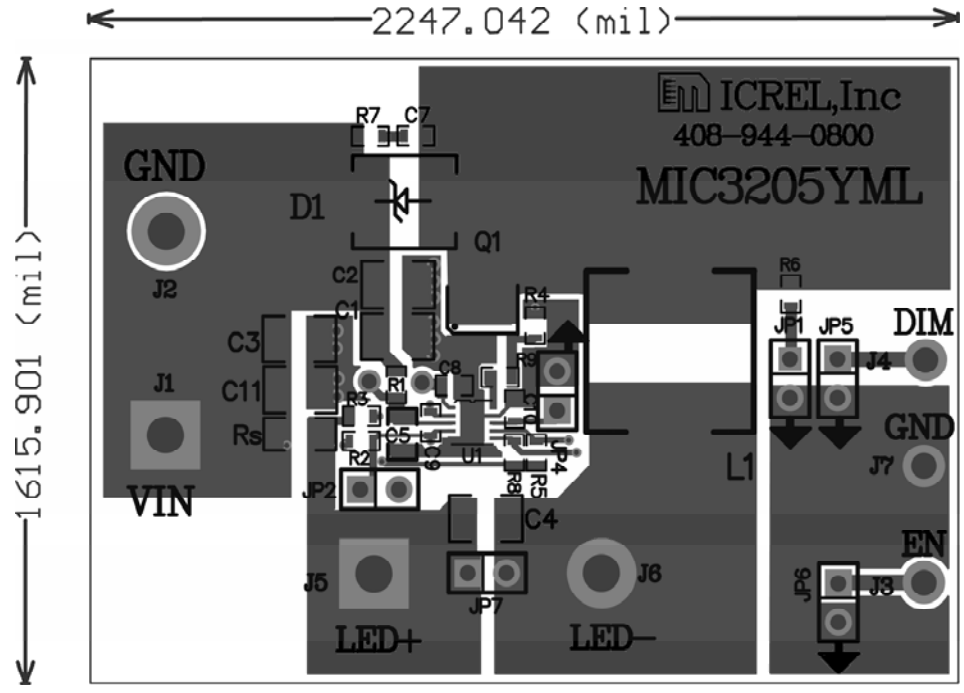
Notes:

1. AVX: www.avx.com.
2. Murata: www.murata.com.
3. TDK: www.tdk.com.
4. MCC: www.mccsemi.com.
5. Fairchild: www.fairchildsemi.com.
6. Diodes Inc.: www.diodes.com.
7. Stackpole Electronics: www.seielect.com.
8. Vishay Dale: www.vishay.com.
9. **Micrel, Inc.: www.micrel.com.**

PCB Layout Recommendations

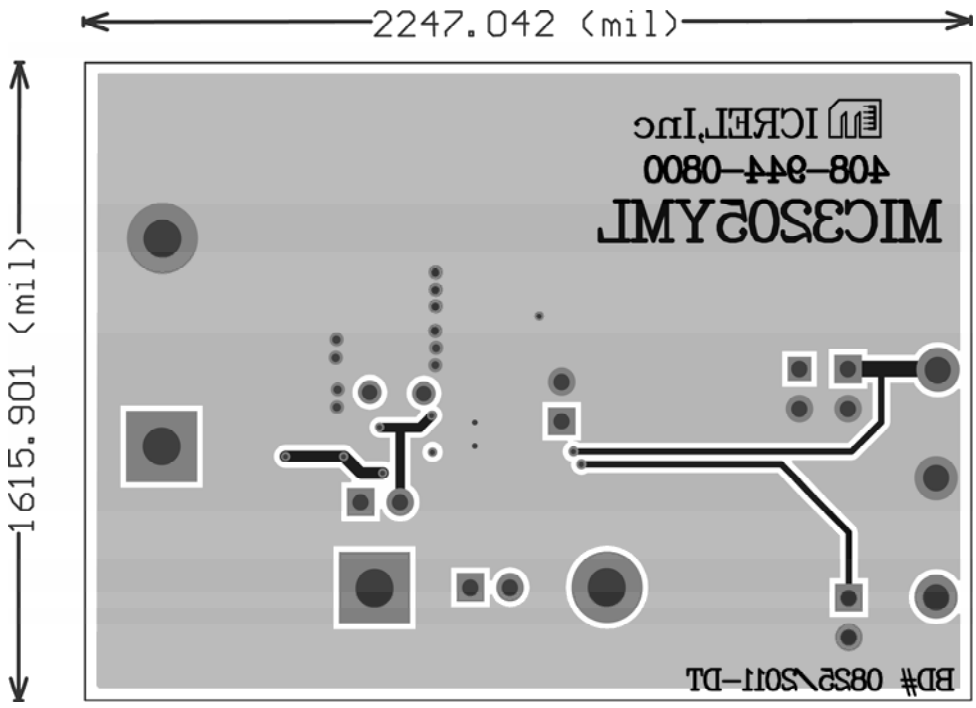


Top Assembly



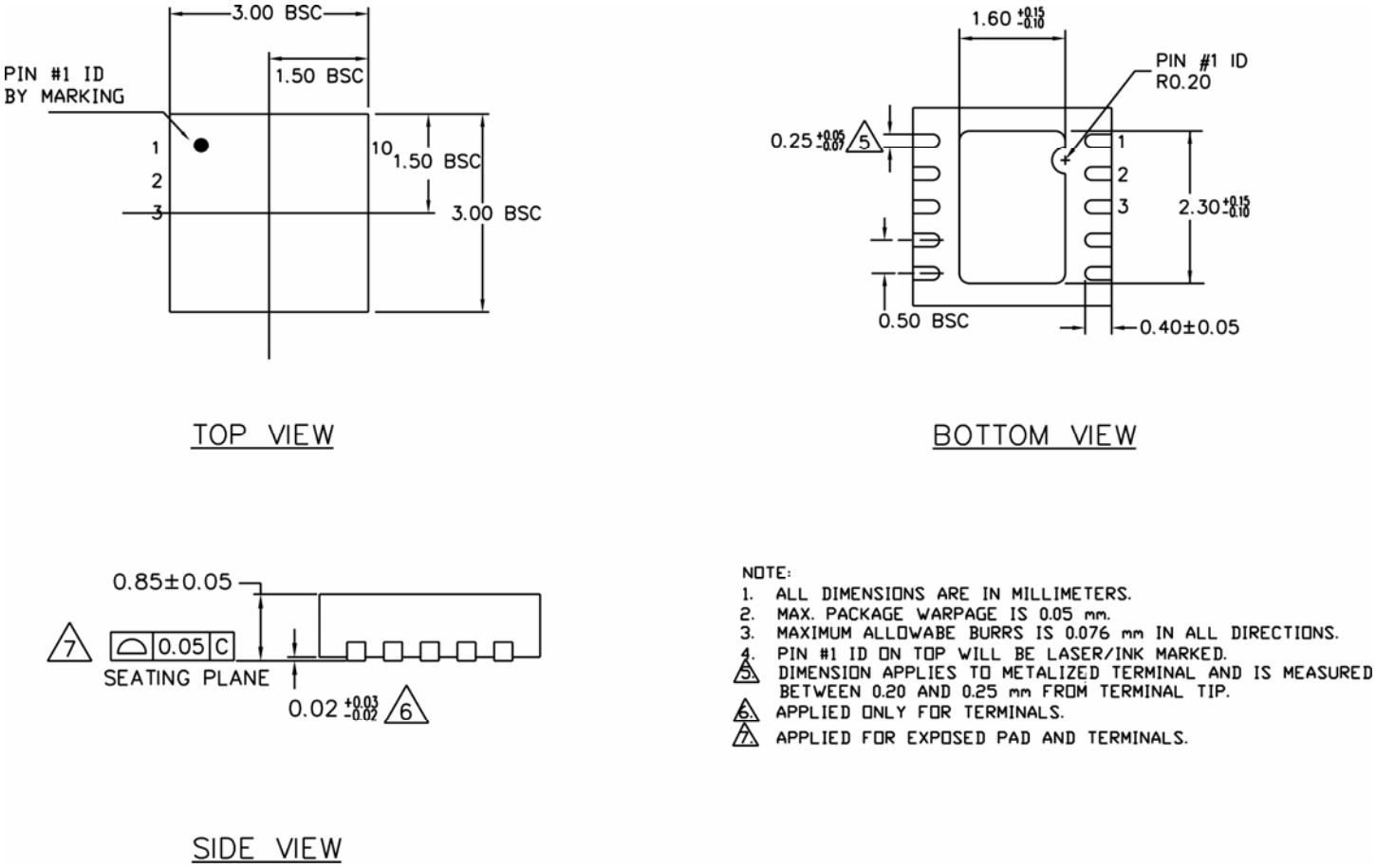
Top Layer

PCB Layout Recommendations (Continued)



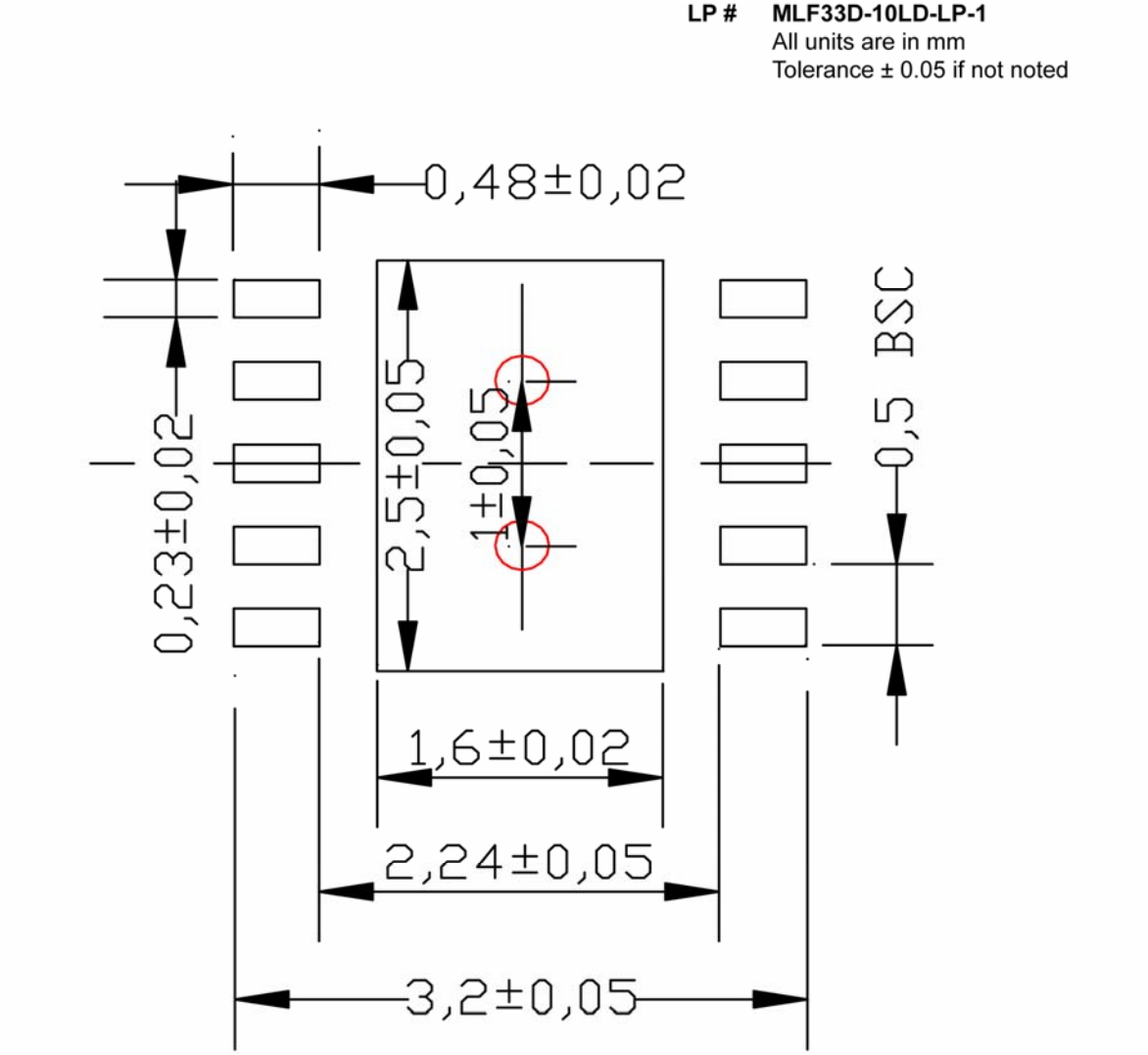
Bottom Layer

Package Information



10-Pin 3mm x 3mm MLF (ML)

Recommended Landing Pattern



Red circle indicates Thermal Via. Size should be 0.300-0.350mm in diameter and it should be connected to GND plane for maximum thermal performance.

10-Pin 3mm x 3mm MLF (ML) Land Pattern

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