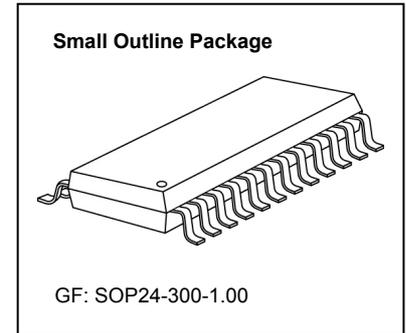


**16-Channel PWM-Embedded LED Driver****Features**

- Backward compatible with MBI5026 in package
- 16 constant-current output channels
- 12-bit grayscale PWM control
- Scrambled-PWM technology to improve refresh rate
- Open-Circuit Detection to detect individual LED errors
- 8-bit programmable output current gain
- Constant output current range:
 - 5 ~ 45mA at 3.3V supply voltage
 - 5 ~ 60mA at 5.0V supply voltage
- Output current accuracy:
 - between channels: $<\pm 3\%$ (max.), and
 - between ICs: $<\pm 6\%$ (max.)
- Staggered output delay
- Maximum data clock frequency: 25MHz
- Schmitt trigger input
- 3.0V-5.5V supply voltage

**Product Description**

MBI5031 is designed for LED video applications using internal Pulse Width Modulation (PWM) control with 12-bit gray scales. MBI5031 features a 16-bit shift register which converts serial input data into each 12-bit pixel gray scale of output port. At MBI5031 output port, sixteen regulated current ports are designed to provide uniform and constant current sinks for driving LEDs with a wide range of V_f variations. The output current can be preset through an external resistor. Moreover, the preset current of MBI5031 can be further programmed up or down to 128 gain steps for LED global brightness adjustment.

With Scrambled-PWM (S-PWMTM) technology, MBI5031 enhances Pulse Width Modulation by scrambling the “on” time into several “on” periods. The enhancement equivalently increases the visual refresh rate. When building a 12-bit gray scale video, S-PWMTM reduces the flickers and improves the fidelity. MBI5031 offloads the signal timing generation of the host controller which just needs to feed data into drivers. MBI5031 drives the corresponding LEDs to the brightness specified by image data. With MBI5031, all output channels can be built with 12-bit color depths (4,096 gray scales).

Block Diagram

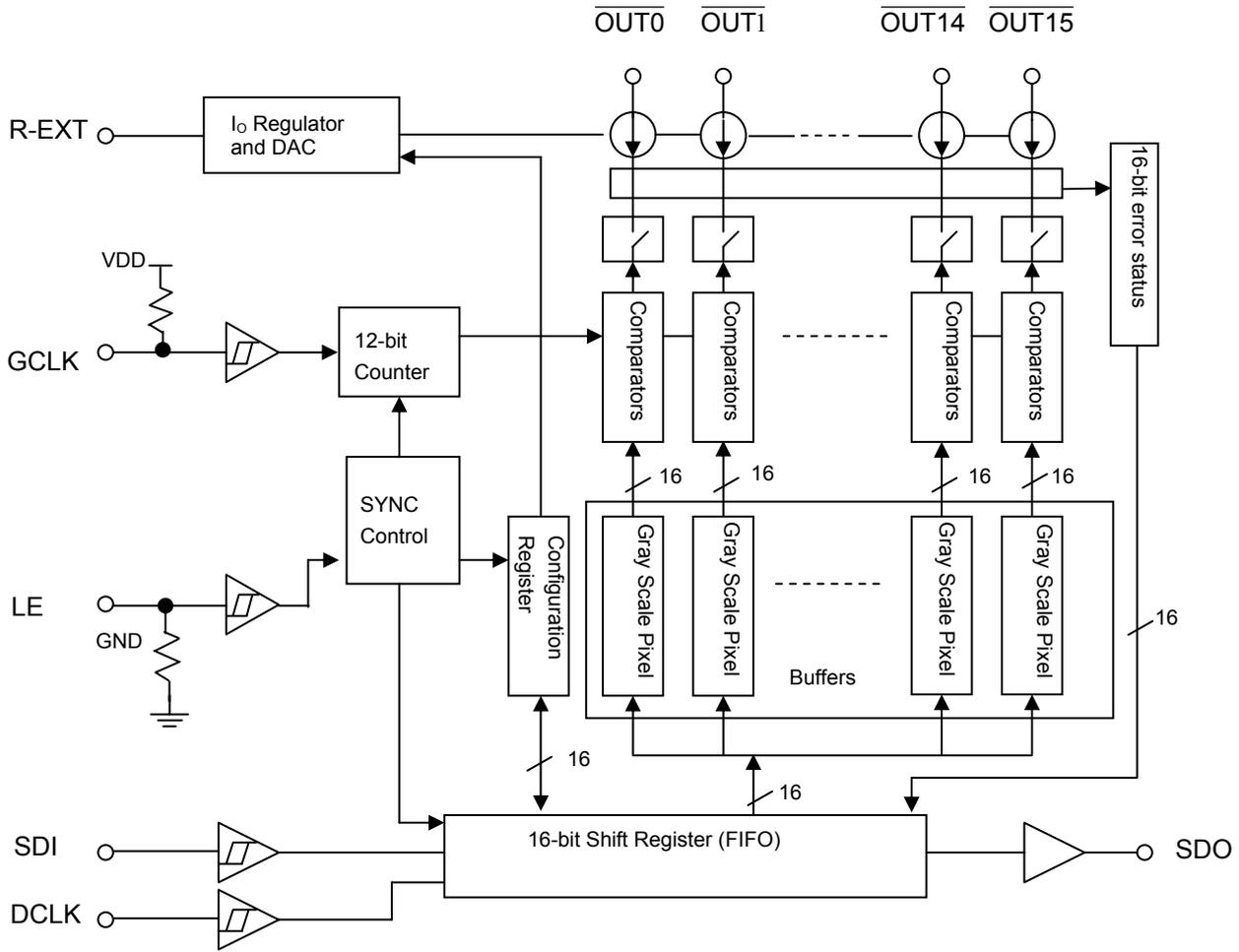
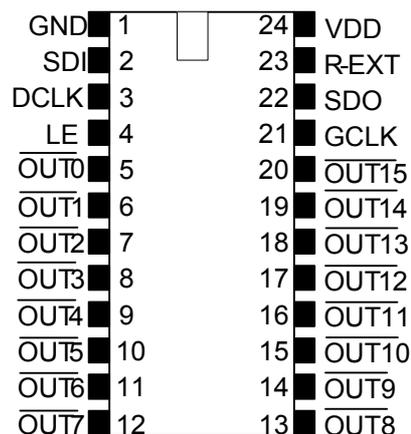


Figure 1

Terminal Description

Pin Configuration

Pin Name	Function
GND	Ground terminal for control logic and current sink
SDI	Serial-data input to the shift register
DCLK	Clock input terminal used to shift data on rising edge and carries command information when LE is asserted.
LE	Data strobe terminal and controlling command with DCLK
$\overline{\text{OUT0}} \sim \overline{\text{OUT15}}$	Constant current output terminals
GCLK	Gray scale clock terminal Clock input for gray scale. The gray scale display is counted by gray scale clock comparing with input data.
SDO	Serial-data output to the receiver-end SDI of next driver IC
R-EXT	Input terminal used to connect an external resistor for setting up output current for all output channels
VDD	3.3V/5V supply voltage terminal



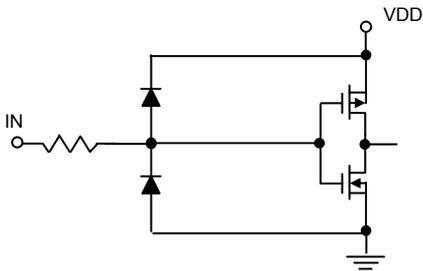
Maximum Ratings

Characteristic	Symbol	Rating	Unit
Supply Voltage	V_{DD}	7	V
Input Pin Voltage (SDI)	V_{IN}	-0.4 ~ $V_{DD} + 0.4$	V
Output Current	I_{OUT}	+60	mA
Sustaining Voltage at OUT Port	V_{DS}	17	V
Data Clock Frequency*	F_{DCLK}	+25	MHz
Gray Scale Clock Frequency	F_{GCLK}	+8	MHz
GND Terminal Current	I_{GND}	+1000	mA
Power Dissipation (On PCB, $T_a=25^\circ\text{C}$)	GF Type P_D	2.39	W
Thermal Resistance (On PCB, $T_a=25^\circ\text{C}$)	GF Type $R_{th(j-a)}$	52.37	$^\circ\text{C/W}$
Operating Temperature	T_{opr}	-40 ~ +85	$^\circ\text{C}$
Storage Temperature	T_{stg}	-55 ~ +150	$^\circ\text{C}$

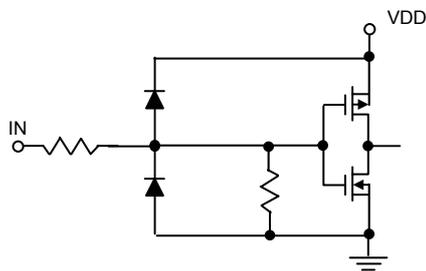
* Supply Voltage is 5V.

Equivalent Circuits of Inputs and Outputs

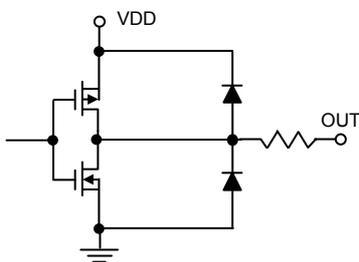
GCLK, DCLK, SDI terminal



LE terminal



SDO terminal



Electrical Characteristics (V_{DD} = 5.0V)

Characteristics		Symbol	Condition	Min.	Typ.	Max.	Unit
Supply Voltage		V _{DD}	-	4.5	5.0	5.5	V
Sustaining Voltage at OUT Ports		V _{DS}	$\overline{\text{OUT0}} \sim \overline{\text{OUT15}}$	-	-	17.0	V
Output Current		I _{OUT}	Refer to "Test Circuit for Electrical Characteristics"	5	-	60	mA
		I _{OH}	SDO	-	-	-1.0	mA
		I _{OL}	SDO	-	-	1.0	mA
Input Voltage	"H" level	V _{IH}	Ta = -40~85°C	0.7*V _{DD}	-	V _{DD}	V
	"L" level	V _{IL}	Ta = -40~85°C	GND	-	0.3*V _{DD}	V
Output Leakage Current		I _{OH}	V _{DS} = 17.0V	-	-	0.5	μA
Output Voltage	SDO	V _{OL}	I _{OL} = +1.0mA	-	-	0.4	V
		V _{OH}	I _{OH} = -1.0mA	4.6	-	-	V
Current Skew		dI _{OUT}	I _{OUT} = 10.5mA V _{DS} = 1.0V R _{ext} = 920Ω	-	-	±3	%
Output Current vs. Output Voltage Regulation		%/dV _{DS}	V _{DS} within 1.0V and 3.0V, R _{ext} = 460Ω@21mA	-	±0.1	-	% / V
Output Current vs. Supply Voltage Regulation		%/dV _{DD}	V _{DD} within 4.5V and 5.5V, R _{ext} = 460Ω@21mA	-	±1.0	-	% / V
LED Open Detection Threshold		V _{DS,TH}	-	-	0.15	0.20	V
Pull-down Resistor		R _{IN(down)}	LE	200	430	700	KΩ
Supply Current	"Off"	I _{DD(off) 1}	R _{ext} = Open, $\overline{\text{OUT0}} \sim \overline{\text{OUT15}} = \text{Off}$	-	3.5	5.3	mA
		I _{DD(off) 2}	R _{ext} = 920Ω, $\overline{\text{OUT0}} \sim \overline{\text{OUT15}} = \text{Off}$	-	7.1	10.7	
		I _{DD(off) 3}	R _{ext} = 460Ω, $\overline{\text{OUT0}} \sim \overline{\text{OUT15}} = \text{Off}$	-	7.5	11.3	
	"On"	I _{DD(on) 1}	R _{ext} = 920Ω, $\overline{\text{OUT0}} \sim \overline{\text{OUT15}} = \text{On}$	-	11.0	16.5	
		I _{DD(on) 2}	R _{ext} = 460Ω, $\overline{\text{OUT0}} \sim \overline{\text{OUT15}} = \text{On}$	-	11.5	17.3	

Electrical Characteristics ($V_{DD} = 3.3V$)

Characteristics		Symbol	Condition	Min.	Typ.	Max.	Unit	
Supply Voltage		V_{DD}	-	3.0	3.3	3.6	V	
Sustaining Voltage at OUT Ports		V_{DS}	$\overline{OUT0} \sim \overline{OUT15}$	-	-	17.0	V	
Output Current		I_{OUT}	Refer to "Test Circuit for Electrical Characteristics"	5	-	45	mA	
		I_{OH}	SDO	-	-	-1.0	mA	
		I_{OL}	SDO	-	-	1.0	mA	
Input Voltage	"H" level	V_{IH}	$T_a = -40 \sim 85^\circ C$	$0.7 \cdot V_{DD}$	-	V_{DD}	V	
	"L" level	V_{IL}	$T_a = -40 \sim 85^\circ C$	GND	-	$0.3 \cdot V_{DD}$	V	
Output Leakage Current		I_{OH}	$V_{DS} = 17.0V$	-	-	0.5	μA	
Output Voltage	SDO	V_{OL}	$I_{OL} = +1.0mA$	-	-	0.4	V	
		V_{OH}	$I_{OH} = -1.0mA$	2.9	-	-	V	
Current Skew		dI_{OUT}	$I_{OUT} = 10.5mA$ $V_{DS} = 1.0V$	$R_{ext} = 920\Omega$	-	-	± 3	%
Output Current vs. Output Voltage Regulation		$\% / dV_{DS}$	V_{DS} within 1.0V and 3.0V, $R_{ext} = 460\Omega @ 21mA$	-	± 0.1	-	% / V	
Output Current vs. Supply Voltage Regulation		$\% / dV_{DD}$	V_{DD} within 3.0V and 3.6V, $R_{ext} = 460\Omega @ 21mA$	-	± 1.0	-	% / V	
LED Open Detection Threshold		$V_{DS,TH}$	-	-	0.15	0.20	V	
Pull-down Resistor		$R_{IN(down)}$	LE	200	430	700	K Ω	
Supply Current	"Off"	$I_{DD(off) 1}$	$R_{ext} = \text{Open}, \overline{OUT0} \sim \overline{OUT15} = \text{Off}$	-	2.2	3.3	mA	
		$I_{DD(off) 2}$	$R_{ext} = 920\Omega, \overline{OUT0} \sim \overline{OUT15} = \text{Off}$	-	4.4	6.6		
		$I_{DD(off) 3}$	$R_{ext} = 460\Omega, \overline{OUT0} \sim \overline{OUT15} = \text{Off}$	-	6.3	9.5		
	"On"	$I_{DD(on) 1}$	$R_{ext} = 920\Omega, \overline{OUT0} \sim \overline{OUT15} = \text{On}$	-	6.7	10.1		
		$I_{DD(on) 2}$	$R_{ext} = 460\Omega, \overline{OUT0} \sim \overline{OUT15} = \text{On}$	-	7.1	10.7		

Test Circuit for Electrical Characteristics

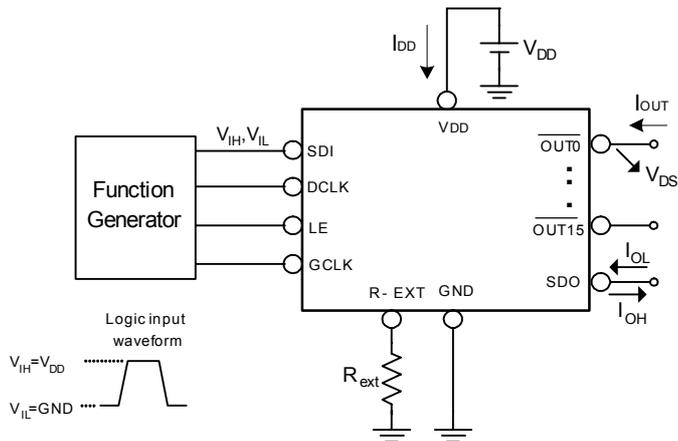


Figure 2

Switching Characteristics (V_{DD} = 5.0V)

Characteristics		Symbol	Condition	Min.	Typ.	Max.	Unit
Setup Time	SDI - DCLK ↑	t _{SU0}	V _{DD} =5.0V V _{IH} =V _{DD} V _{IL} =GND R _{ext} =460Ω V _{LED} =4.5V R _L =152Ω C _L =10pF C ₁ =100nF C ₂ =10 μF	1	-	-	ns
	LE ↑ - DCLK ↑	t _{SU1}		1	-	-	ns
	LE ↓ - DCLK ↑	t _{SU2}		5	-	-	ns
Hold Time	DCLK ↑ - SDI	t _{H0}		3	-	-	ns
	DCLK ↑ - LE ↓	t _{H1}		7.0	-	-	ns
Propagation Delay Time	DCLK - SDO	t _{PD0}		15.0	22.0	35.0	ns
	GCLK - $\overline{\text{OUT}}_{4n}^*$	t _{PD1}		-	130	-	ns
	LE - SDO**	t _{PD2} **		16.0	24.0	37.0	ns
Stagger Delay Time	$\overline{\text{OUT}}_{4n+1}^*$	t _{DL1}		-	30.0	-	ns
	$\overline{\text{OUT}}_{4n+2}^*$	t _{DL2}		-	60.0	-	ns
	$\overline{\text{OUT}}_{4n+3}^*$	t _{DL3}		-	90.0	-	ns
Pulse Width	LE	t _{w(L)}		5.0	-	-	ns
	DCLK	t _{w(DCLK)}		20.0	-	-	ns
	GCLK	t _{w(GCLK)}	125.0	-	-	ns	
Output Rise Time of Output Ports		t _{OR}	-	90.0	-	ns	
Output Fall Time of Output Ports		t _{OF}	-	70.0	-	ns	
Error Detection Minimum Duration		t _{EDD} ***	-	2.0	-	μs	

*There will be one GCLK latency at the first PWM output data. Refer to the Timing Waveform, where n=0, 1, 2, 3.

**In timing of “Read Configuration” and “Read Error Status Code”, the next DCLK rising edge should be t_{PD2} after the falling edge of LE.

***Refer to Figure 6.

Switching Characteristics ($V_{DD} = 3.3V$)

Characteristics	Symbol	Condition	Min.	Typ.	Max.	Unit
Setup Time	SDI - DCLK \uparrow	t_{SU0}	1.0	-	-	ns
	LE \uparrow - DCLK \uparrow	t_{SU1}	1.0	-	-	ns
	LE \downarrow - DCLK \uparrow	t_{SU2}	5.0	-	-	ns
Hold Time	DCLK \uparrow - SDI	t_{H0}	3.0	-	-	ns
	DCLK \uparrow - LE \downarrow	t_{H1}	7.0	-	-	ns
Propagation Delay Time	DCLK - SDO	t_{PD0}	-	40.0	-	ns
	GCLK - $\overline{OUT4n}^*$	t_{PD1}	-	150	-	ns
	LE - SDO	t_{PD2}^{**}	-	40.0	-	ns
Stagger Delay Time	$\overline{OUT4n+1}^*$	t_{DL1}	-	30.0	-	ns
	$\overline{OUT4n+2}^*$	t_{DL2}	-	60.0	-	ns
	$\overline{OUT4n+3}^*$	t_{DL3}	-	90.0	-	ns
Pulse Width	LE	$t_{w(L)}$	5.0	-	-	ns
	DCLK	$t_{w(DCLK)}$	25.0	-	-	ns
	GCLK	$t_{w(GCLK)}$	125.0	-	-	ns
Output Rise Time of Output Ports		t_{OR}	-	90.0	-	ns
Output Fall Time of Output Ports		t_{OF}	-	70.0	-	ns
Error Detection Minimum Duration		t_{EDD}^{***}	-	2.0	-	μs

$V_{DD}=3.3V$
 $V_{IH}=V_{DD}$
 $V_{IL}=GND$
 $R_{ext}=460\Omega$
 $V_{LED}=4.5V$
 $R_L=152\Omega$
 $C_L=10pF$
 $C_1=100nF$
 $C_2=10\mu F$

*There will be one GCLK latency at the first PWM output data. Refer to the Timing Waveform, where n=0, 1, 2, 3.

**In timing of "Read Configuration" and "Read Error Status Code", the next DCLK rising edge should be t_{PD2} after the falling edge of LE.

***Refer to Figure 6.

Test Circuit for Switching Characteristics

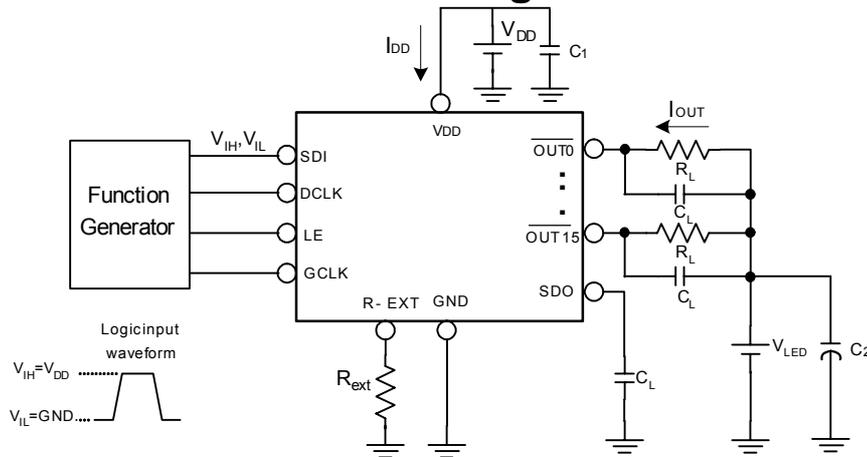
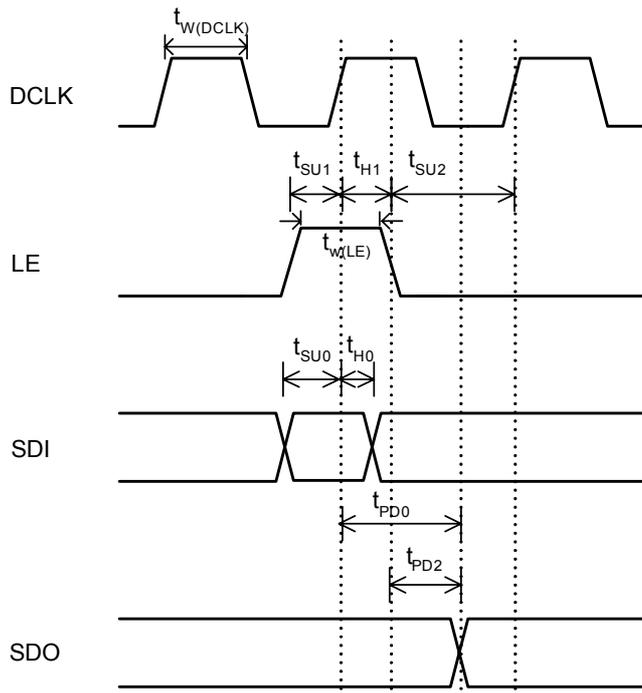


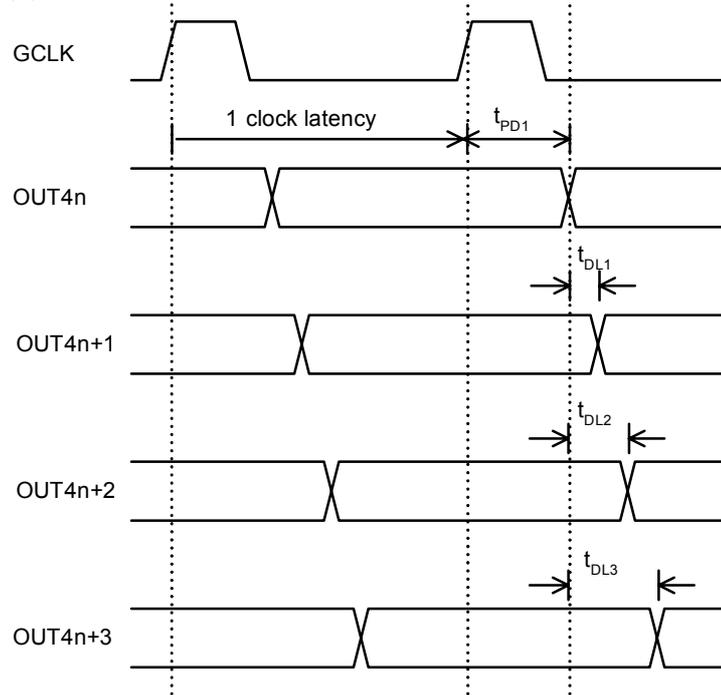
Figure 3

Timing Waveform

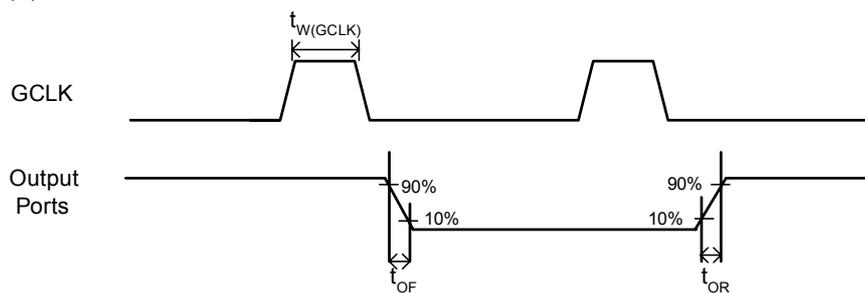
(1)



(2)



(3)

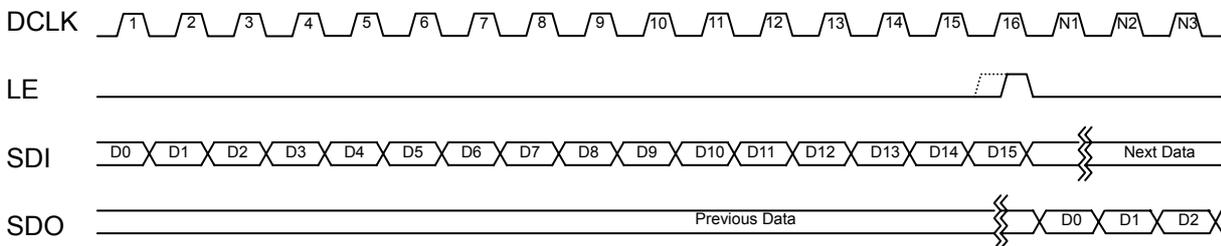


Principle of Operation

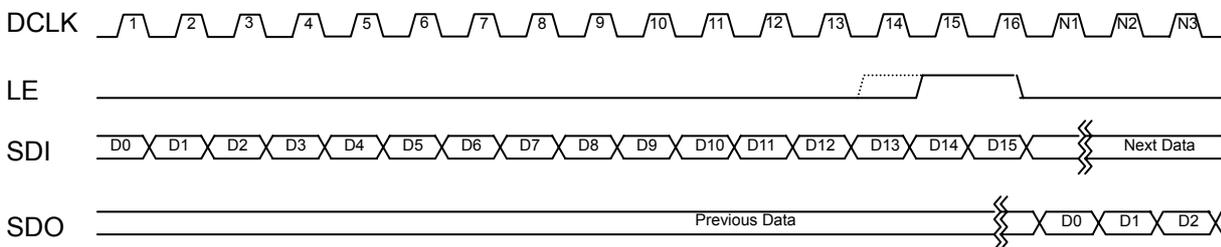
Control Command

Command Name	Signals Combination		Description
	LE	Number of DCLK Rising Edge when LE is asserted	
Data Latch	High	0 or 1	Serial data are transferred to the buffers
Global Latch	High	2 or 3	Buffer data are transferred to the comparators
Read Configuration	High	4 or 5	Move out "configuration register" to the shift registers
Enable "Error detection"	High	6 or 7	Enable "open circuit detection" of each output's LED
Read "Error status code"	High	8 or 9	Move out "error status code" of 16 outputs to the shift registers
Write Configuration	High	10 or 11	Serial data are transferred to the "configuration register"

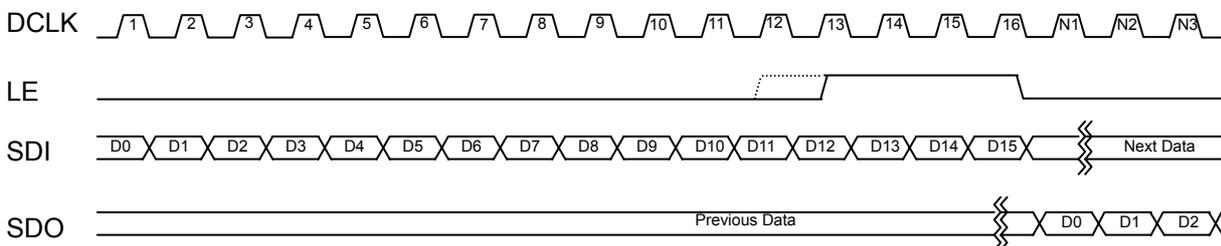
Data Latch



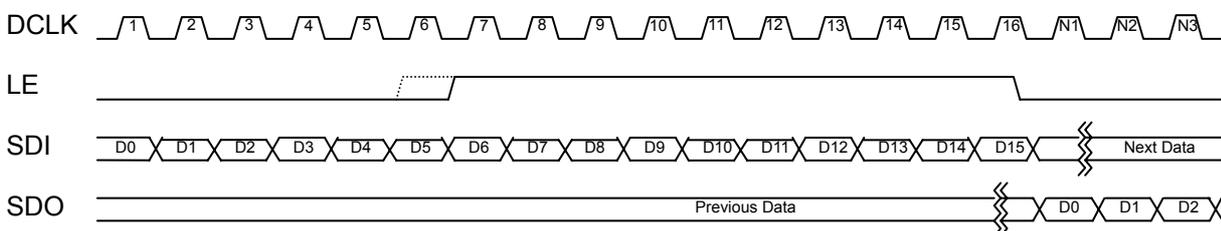
Global Latch



Read Configuration



Write Configuration



Setting Gray Scales of Pixels

MBI5031 implements the gray level of each output port using the S-PWM™ control algorithm. With the 16-bit data, all output channels can be built with 4,096 gray scales. The 16-bit input shift register latches 15 times of the gray scale data into each data buffer with a “data latch” command sequentially. With a “global latch” command for the 16th gray scale data, the 256-bit data buffers will be clocked in with the MSB first, loading the data from port 15 to port 0.

Full Timing for Data Loading

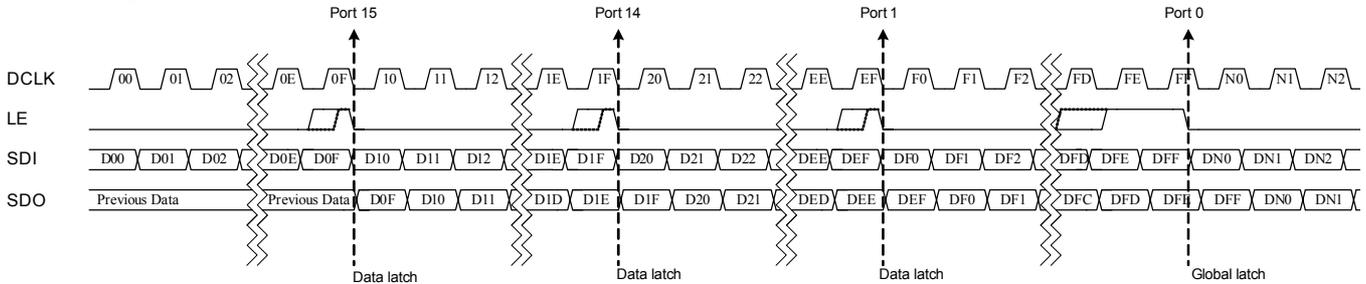


Figure 4

Open-Circuit Detection Principle

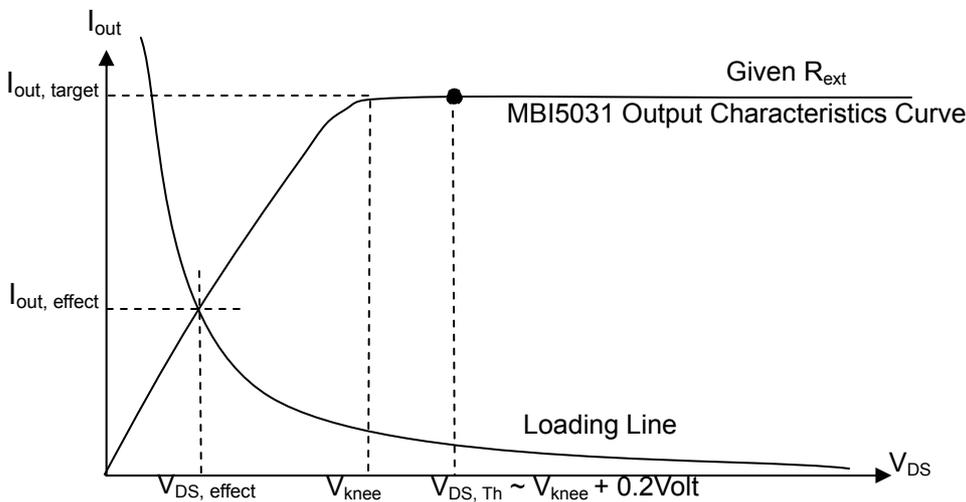


Figure 5

The principle of MBI5031 LED Open-Circuit Detection is based on the fact that the LED loading status is judged by comparing the effective current value ($I_{out, effect}$) of each output port with the target current ($I_{out, target}$) set by R_{ext} . As shown in the above figure, the knee voltage (V_{knee}) is the one between triode region and saturation region. The cross point between the loading line and MBI5031 output characteristics curve is the effective output point ($V_{DS, effect}, I_{out, effect}$). Thus, after the command of “enabling error detection”, the output ports of MBI5031 will be turned on for a while. It is required to obtain the stable error status result for 2 μ second. Then, the error status saved in the built-in register would be shifted out through SDO pin bit by bit by sending the command of “Read Error Status Code”. Thus, to detect the status of LED correctly, the output ports of MBI5031 must be turned on. The relationship between the Error Status code and the effective output point is shown below:

State of Output Port	Condition of Effective Output Point	Detected Open-Circuit Error Status Code	Meaning
Off	$I_{out, effect} = 0$	“0”	-
On	$I_{out, effect} \leq I_{out, target}$ and $V_{out, effect} < V_{DS, Th}$	“1”	Open Circuit
	$I_{out, effect} = I_{out, target}$ and $V_{out, effect} \geq V_{DS, Th}$	“0”	Normal

Note: the threshold voltage $V_{DS, Th}$ is around $V_{knee} + 0.2\text{ Volt}$

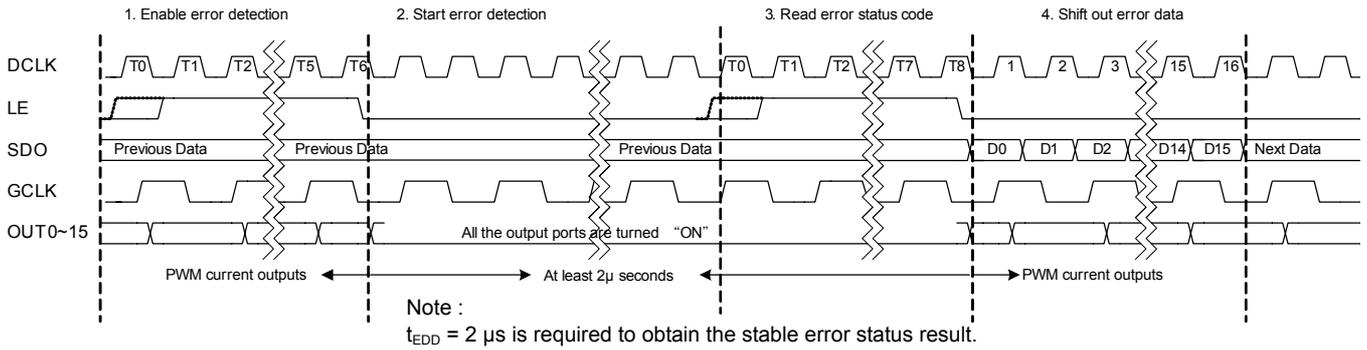


Figure 6

Definition of Configuration Register

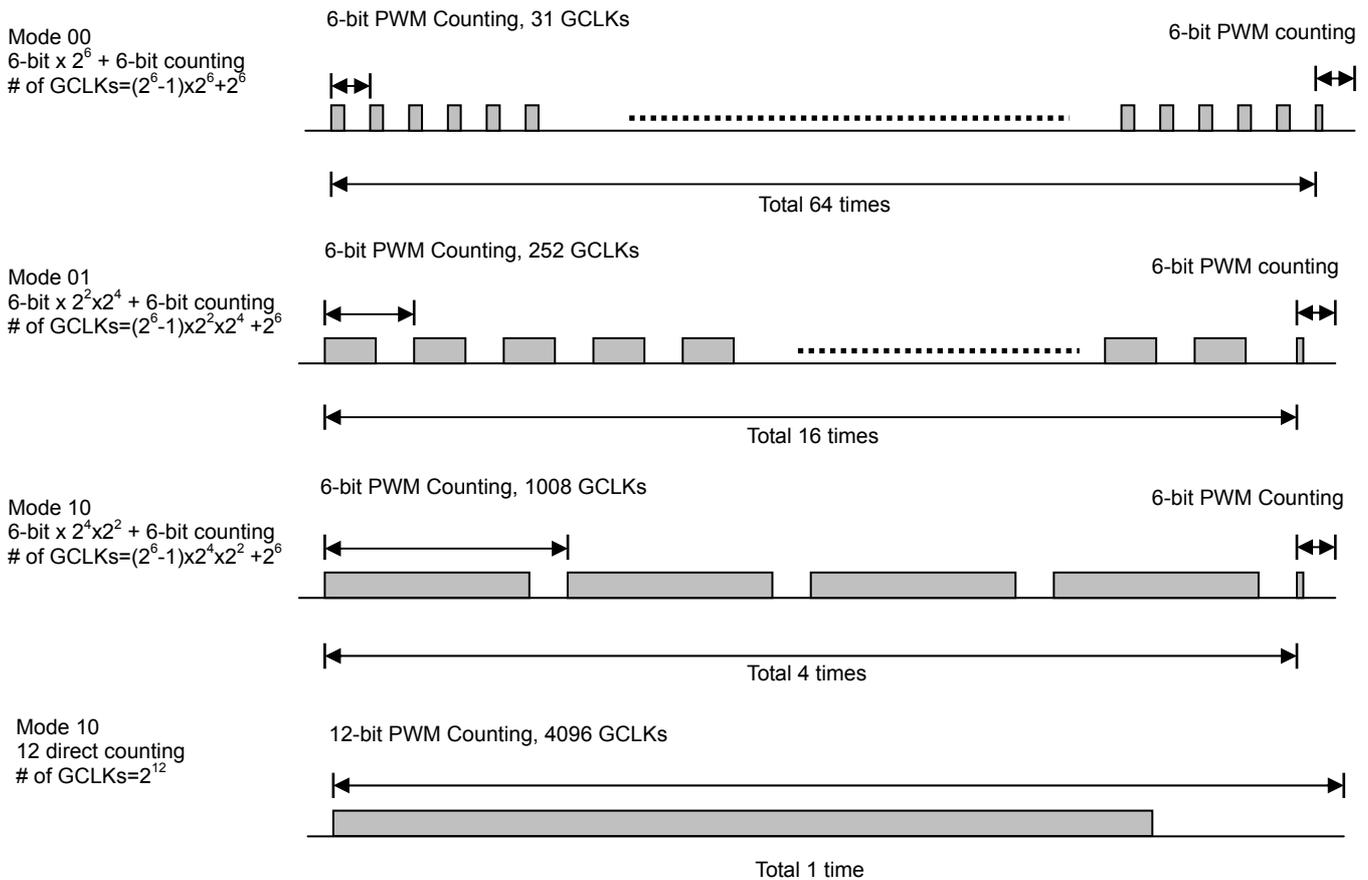
Bit	Attribute	Definition	Value	Function
F	X	X	X	Reserved bit
E	X	X	X	Reserved bit
D	X	X	X	Reserved bit
C	Write	PWM counting mode selection	00 (Default)	64 times of 6-bit PWM counting and once of PWM 6-bit counting
B			01	16 times of 6-bit PWM counting by 1/4 GCLK and once of 6-bit PWM counting
			10	4 times of 6-bit PWM counting by 1/16 GCLK and once of 6-bit PWM counting
			11	12-bit PWM counting
A	Write	PWM data synchronization mode	0	Auto-synchronization
			1 (Default)	Self-synchronization
9~2	Write	Current gain adjustment	00000000 ~ 11111111	8'b10101011 (Default)
1	X	X	X	Reserved bit
0	Write	Time-out alert of GCLK disconnection	0 (Default)	Enable
			1	Disable

Setting the PWM Gray Scale Counter

MBI5031 provides a 12-bit color depth. The value of each 16-bit serial data input will be valid only for 12 bits and implemented according 12-bit PWM counter.

Setting the PWM Counting Mode

MBI5031 defines the different counting algorithms that support S-PWM™, scrambled PWM, technology. With S-PWM™, the total PWM cycles can be broken down into MSB (Most Significant Bits) and LSB (Least Significant Bits) of gray scale cycles, and the MSB information can be dithered across many refresh cycles to achieve overall same high bit resolution. MBI5031 also allows changing different counting algorithms and provides the better output linearity when there are fewer transitions of output.



Synchronization for PWM Counting

Between the data frame and the video frame, when the bit “A” is set to “0”, MBI5031 will automatically handle the synchronization of previous data and next data for PWM counting. The next image data will be updated to output buffers and start PWM counting when the previous data has finished one internal PWM cycle. It will prevent the lost count of image data resolution and guarantee the data accuracy. In this mode, system controller only needs to provide a continuous running GCLK for PWM counter. The output will be renewed after finishing one of MSB PWM cycles.

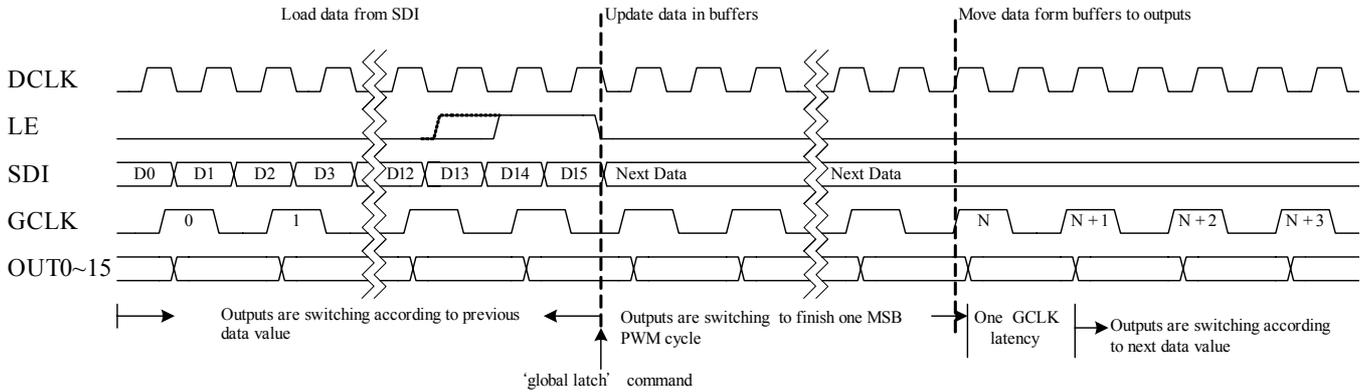


Figure 7

When the bit “A” is set to “1” (Default), MBI5031 will update the next image data into output buffer immediately, no matter the counting status of previous image data is. In this mode, system controller will synchronize the GCLK according image data outside MBI5031 by itself. Otherwise, the conflict of previous image data and next image data will cause the data lost.

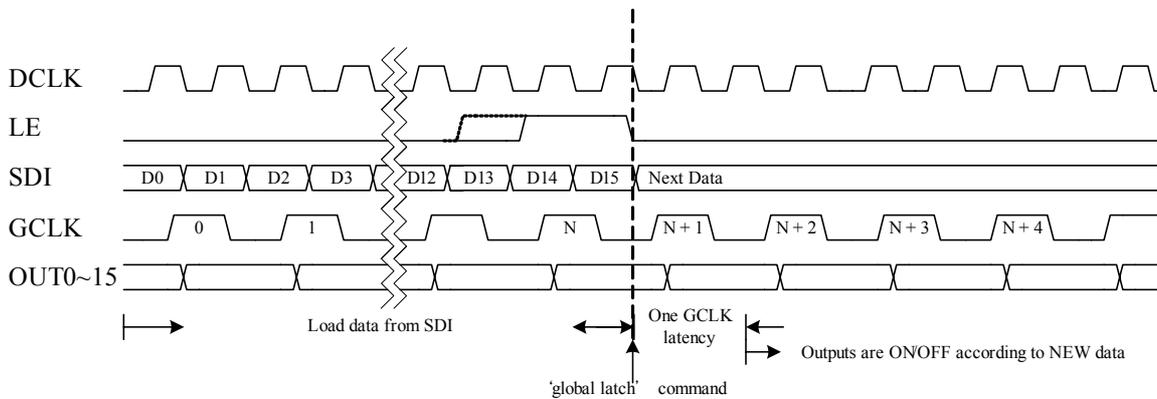


Figure 8

Time-Out Alert of GCLK Disconnection

When signal of GCLK is disconnected for around 1 second period, the all output ports will be turned off automatically. This function will protect the LED display system to stay on always and prevent a big current to damage the power system. The default is set to ‘enable’ when bit “0” is 0. When the GCLK is active again, the driver resumes to work after resetting the internal counters and comparators.

Setting Output Current

The output current (I_{OUT}) is set by an external resistor, R_{ext} . The default relationship between I_{OUT} and R_{ext} is shown in the following figure.

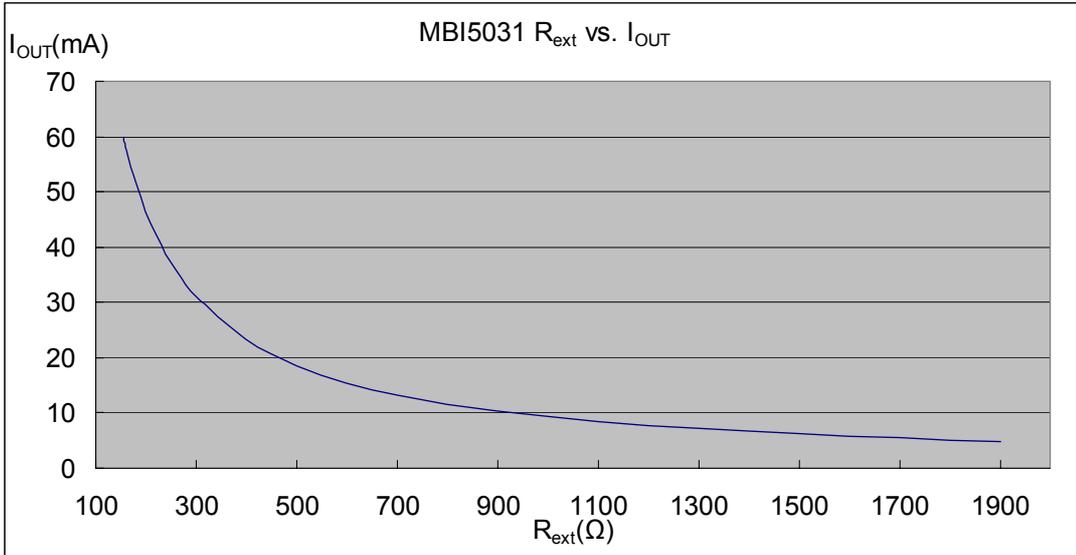


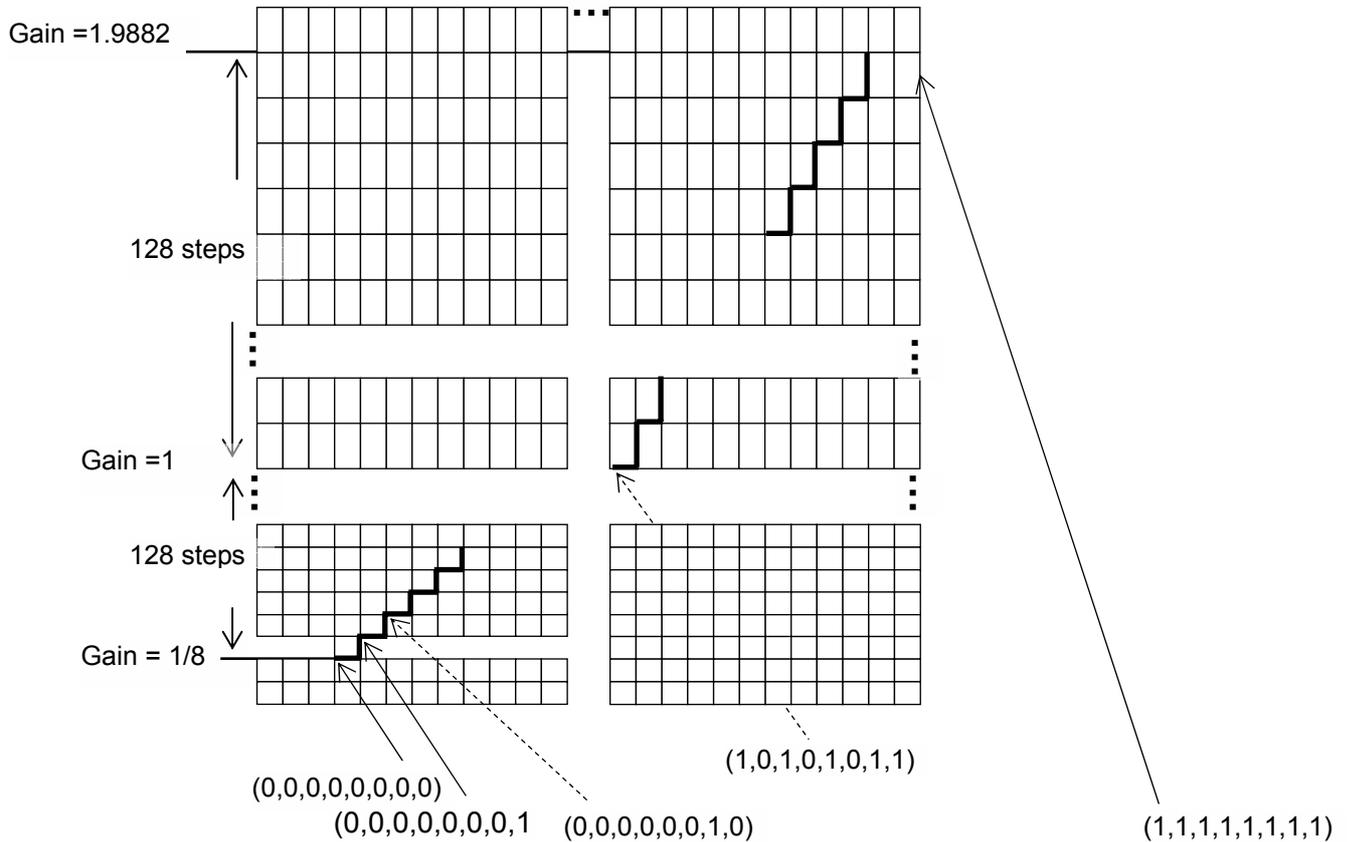
Figure 9

Also, the output current can be calculated from the equation:

$$V_{R-EXT} = 0.625 \text{ Volt} \times G; I_{OUT} = (V_{R-EXT} / R_{ext}) \times 15.5$$

Whereas R_{ext} is the resistance of the external resistor connected to R-EXT terminal and V_{R-EXT} is its voltage. G is the digital current gain, which is set by the bit9 – bit2 of the configuration register. The default value of G is 1. For your information, the output current is about 21mA when $R_{ext} = 460 \Omega$ and 10.5mA when $R_{ext} = 920 \Omega$ if G is set to default value 1. The formula and setting for G are described in next section.

● Current Gain Adjustment



The bit 9 to bit 2 of the configuration register set the gain of output current, i.e., G. As totally 8-bit in number, i.e., ranged from 8'b00000000 to 8'b11111111, these bits allow the user to set the output current gain up to 256 levels. These bits can be further defined inside Configuration Register as follows:

F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0
-	-	-	-	-	-	HC	DA6	DA5	DA4	DA3	DA2	DA1	DA0	-	-

1. Bit 9 is HC bit. The setting is in low current band when HC=0, and in high current band when HC=1.
2. Bit 8 to bit 2 are DA6 ~ DA0.

The relationship between these bits and current gain G is:

$$G = [(1+3xHC)/4]x[(1+3xD/128)/2]$$

Whereas HC is 1 or 0 and

$$D = DA6x2^6 + DA5x2^5 + DA4x2^4 + DA3x2^3 + DA2x2^2 + DA1x2^1 + DA0x2^0$$

In other words, these bits can be looked as a floating number with 1-bit exponent HC and 7-bit mantissa DA6~DA0.

For example,

1. When the bit9 to bit2 of configuration register are set to 8'b11111111, the current gain G becomes $[(1+3x1)/4]x[(1+3x127/128)/2]=1.9882$
2. When the bit9 to bit2 of configuration register are set to 8'b10000000, the current gain G becomes $[(1+3x1)/4]x[(1+3x0/128)/2]=0.5$
3. when the bit9 to bit2 of configuration register are set to 8'b00000000, the current gain G becomes $[(1+3x0)/4]x[(1+3x0/128)/2]=1/8$

Delay Time of Staggered Output

MBI5031 has a built-in staggered circuit to perform delay mechanism. Among output ports exist a graduated 30ns delay time among $\overline{OUT4n}$, $\overline{OUT4n+1}$, $\overline{OUT4n+2}$, and $\overline{OUT4n+3}$, by which the output ports will be divided to four groups at a different time so that the instant current from the power line will be lowered.

Package Power Dissipation (PD)

The maximum allowable package power dissipation is determined as $P_D (max) = (T_j - T_a) / R_{th(j-a)}$. When 16 output channels are turned on simultaneously, the actual package power dissipation is $P_D (act) = (I_{DD} \times V_{DD}) + (I_{OUT} \times Duty \times V_{DS} \times 16)$. Therefore, to keep $P_D (act) \leq P_D (max)$, the allowable maximum output current as a function of duty cycle is:

$$I_{OUT} = \{ [(T_j - T_a) / R_{th(j-a)}] - (I_{DD} \times V_{DD}) \} / V_{DS} / Duty / 16, \text{ where } T_j = 150^\circ\text{C}.$$

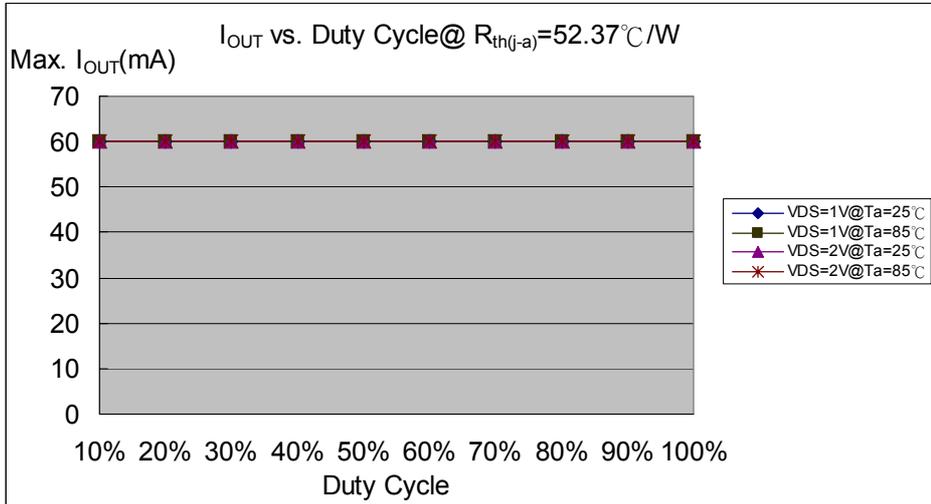


Figure 10

Condition: I _{OUT} =60mA, 16 output channels	
Device Type	R _{th(j-a)} (°C /W)
GF	52.37

The maximum power dissipation, $P_D (max) = (T_j - T_a) / R_{th(j-a)}$, decreases as the ambient temperature increases.

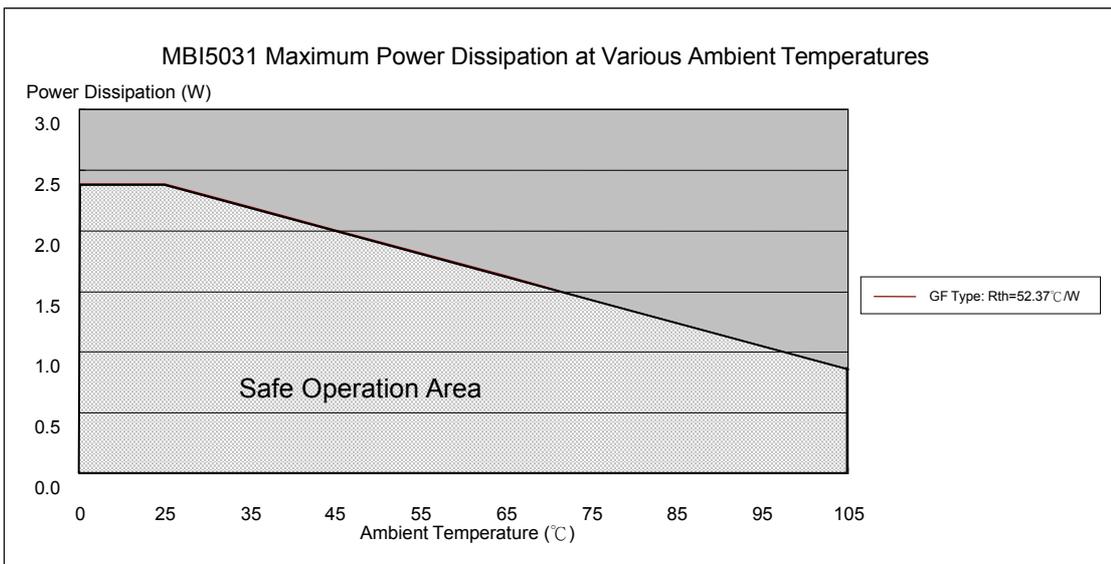


Figure 11

LED Supply Voltage (V_{LED})

MBI5031 are designed to operate with V_{DS} ranging from 0.4V to 0.8V (depending on $I_{OUT}=5\sim 60mA$) considering the package power dissipating limits. V_{DS} may be higher enough to make $P_{D(act)} > P_{D(max)}$ when $V_{LED} = 5V$ and $V_{DS} = V_{LED} - V_F$, in which V_{LED} is the load supply voltage. In this case, it is recommended to use the lowest possible supply voltage or to set an external voltage reducer, V_{DROP} .

A voltage reducer lets $V_{DS} = (V_{LED} - V_F) - V_{DROP}$.

Resistors or Zener diode can be used in the applications as shown in the following figures.

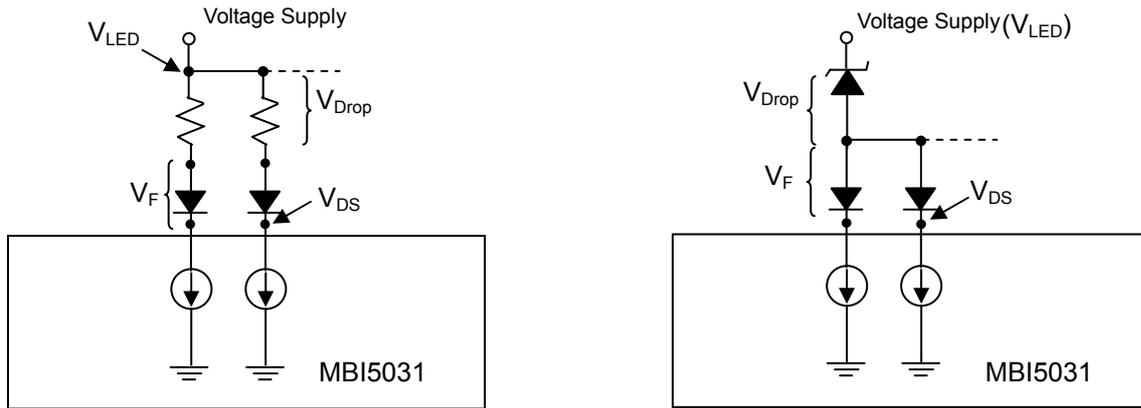
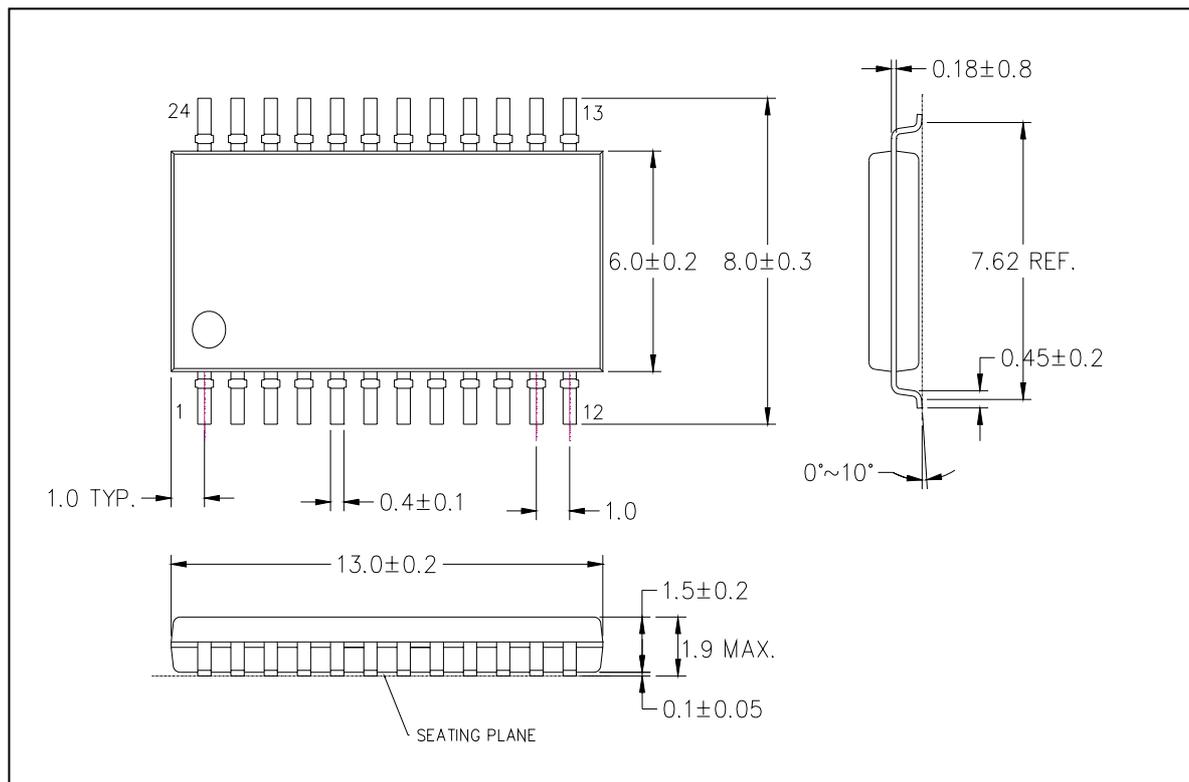


Figure 12

Switching Noise Reduction

LED drivers are frequently used in switch-mode applications which always behave with switching noise due to the parasitic inductance on PCB. To eliminate switching noise, refer to “Application Note for 8-bit and 16-bit LED Drivers-Overshoot”.

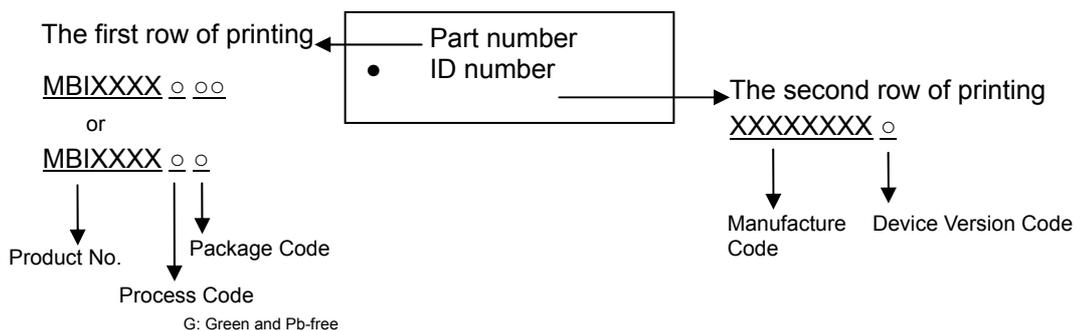
Package Outline



MBI5031GF Outline Drawing

Note: The unit for the outline drawing is mm.

Product Top Mark Information



Product Revision History

Datasheet version	Device Version Code
V1.00	A

Product Ordering Information

Part Number	“Pb-free & Green” Package Type	Weight (g)
MBI5031GF	SOP24-300-1.00	0.30