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High-Voltage Liquid Lens Driver

MAX14515B

General Description

The MAX14515B high-voltage liquid lens driver features a high-voltage differential output controlled through an I²C interface. The MAX14515B uses a charge-pump-based boost converter and integrated H-bridge to provide a compact lens driver solution with minimal external components to achieve a small overall footprint suitable for small space constraints inside camera modules.

The MAX14515B features an 8-bit monotonic DAC with a single differential high-voltage output controlled by a 2-wire I²C interface to set the amplitude. The high-voltage outputs are capable of delivering up to $48V_{RMS}$ (max) into a 200pF liquid lens load at 1.0kHz (min).

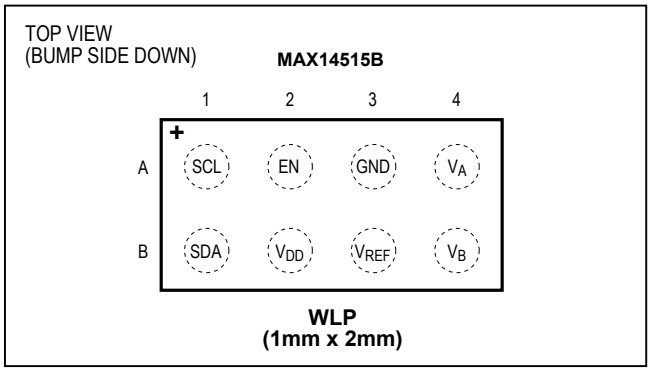
The MAX14515B also features two power-saving modes (shutdown mode and sleep mode) to minimize power consumption when the device is inactive. Shutdown mode places the device in a low-power state that resets all registers and disables the I²C interface to reduce current below 500nA (max). In sleep mode, the power-on reset circuit remains active. If no activity is detected on the I²C interface, current consumption is less than 3µA.

The MAX14515B operates over the +2.7V to +5.5V supply voltage range, ideal for portable applications using lithium-ion (Li+) battery sources. The MAX14515B is specified over the -40°C to +125°C extended temperature range and is available in a small (1mm x 2mm) 8-bump wafer-level package (WLP).

Applications

- Automotive Camera Systems
- Camera Actuators (Drones, Machine Vision)
- Security/Action/Mobile Robotic Camera Systems

Pin Configuration



Features

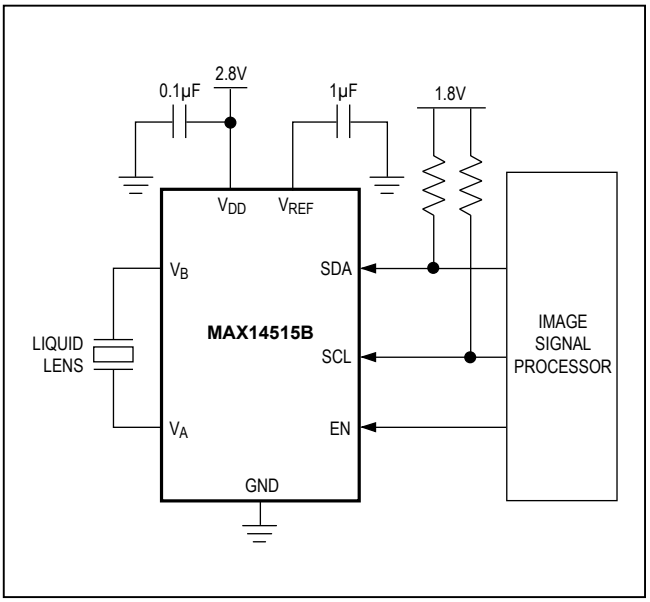
- Small Footprint for Placement Inside Camera Modules
- $48V_{RMS}$ Maximum Output (C_{LENS} = 200pF)
- I²C-Compatible Interface for Setting Output Voltage
- 8-Bit Output Voltage Resolution
- Guaranteed Monotonic Output
- ±15kV Human Body Model ESD Protection on Outputs
- Low 500nA (max) Shutdown Current
- +2.7V to +5.5V Input Voltage Range
- Space-Saving, 8-Bump WLP (1mm x 2mm) Package
- -40°C to +125°C Automotive Temperature Range
- Automotive Qualified AEC-Q100

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	TOP MARK
MAX14515BAWA/V+	-40°C to +125°C	8 WLP	+AAC

+Denotes a lead(Pb)-free/RoHS-compliant package.

Typical Application Circuit



19-102060; Rev 0; 6/26

Absolute Maximum Ratings

(All voltages referenced to GND.)
V_{DD} ..... -0.3V to +6.0V
V_A, V_B ..... -0.3V to +52V
V_{REF} ..... MAX (-0.3V, V_{DD} - 0.3V) to +6.0V
SDA, SCL, EN ..... -0.3V to +6.0V
Continuous Power Dissipation (T_A = +70°C)
8-Bump WLP (derate 13.4mW/°C above +70°C) 1071mW
Junction-to-Ambient Thermal Resistance (θ_{JA}) (Note 1)
8-Bump WLP ..... +74.65°C/W
Operating Temperature Range ..... -40°C to +125°C
Junction Temperature ..... +150°C
Storage Temperature Range ..... -65°C to +150°C
Soldering Temperature (reflow) ..... +260°C

Note 1: Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to **www.analog.com/en/resources/technical-articles/thermal-characterization-of-ic-packages.html**.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Electrical Characteristics

(V_{DD} = +2.7V to +5.5V, C_{VDD} = 0.1µF, C_{REF} = 1µF, C_{LENS} = 200pF ±30pF, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at V_{DD} = +2.8V and T_A = +25°C.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Input Voltage	V_{DD}			2.7		5.5	V
Input Supply Current	I_{DD}	Peak output voltage register (VP) = 0xFF, C_{LENS} = 200pF			9		mA
Reference Output Voltage	V_{REF}					5.5	V
Shutdown Supply Current	I_{SHDN}	EN = GND (T_A = +85°C)			1	500	nA
		EN = GND (T_A = +125°C)				10.5	µA
Sleep Supply Current	I_{SLEEP}	$\overline{SM}$ = 0, SDA = SCL	V_{EN} = 1.8V, V_{DD} = 4.2V		8		µA
			V_{EN} = V_{DD}, V_{DD} = 2.8V (T_A = +85°C)		1.2	3	
			V_{EN} = V_{DD}, V_{DD} = 2.8V (T_A = +125°C)			10.5	
POR Threshold	V_{TH_POR}					2.6	V
HIGH-VOLTAGE OUTPUTS (V_A, V_B)							
Peak Output Voltage (Note 3)	V_{PEAK}	VP = 0x01		15.7	17.3	18.5	V
		VP = 0xFF		49	50.5	52	
Output RMS Voltage	V_{RMS}	VP = 0x01		15.2	16.8	18	V
		VP = 0xFF, C_{LENS} = 200pF		42.9	45	48	
Output Voltage Ripple	V_{RPL}	C_{LENS} = 200pF			±100		mV
Pull-down Strength	RL_{PD}	$\overline{SM}$ = 0				2	kΩ
Output Switching Frequency	f_{LENS}			1	1.1	1.2	kHz
CONTROL INPUTS (SDA, SCL, EN)							
Input Logic-High Voltage	V_{IH}			1.5			V
Input Logic-Low Voltage	V_{IL}					0.5	V
Output Logic-Low Voltage	V_{OL}	I_{SINK} = 10mA				0.4	V
Input Low-Leakage Current	I_{IL}	EN = V_{CC}			0.01	7.5	µA
		EN = GND			0.01	0.5	
Input High-Leakage Current	I_{IH}				0.01	3	µA
Input Capacitance	C_{IN}				10		pF

Electrical Characteristics (continued)

(V_{DD} = +2.7V to +5.5V, C_{VDD} = 0.1µF, C_{REF} = 1µF, C_{LENS} = 200pF ±30pF, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at V_{DD} = +2.8V and T_A = +25°C.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
OUTPUT-VOLTAGE STATIC PERFORMANCE (V_A, V_B)						
Resolution	N			8		Bits
Least Significant Bit	LSB	(Note 4)	124	131	139	mV
Integral Nonlinearity	INL		-4		+4	LSB
Differential Nonlinearity	DNL	(Note 5)	-0.5		+0.5	LSB
OUTPUT-VOLTAGE DYNAMIC PERFORMANCE (V_A, V_B)						
Peak Output-Voltage Settling Time	t_{SV}	VP = any value to any other value transition; time to settle within 7 LSBs of final value, Figure 1			1	ms
Output Slew Rate	SR_V	Peak output voltage register = FFh			5	V/µs
Wake-Up Time	t_{WAKE}	Time to settle within 7 LSBs of peak value, Figure 1			2	ms
Shutdown Time	t_{SHDN}	Figure 2		100		µs
I^2C INTERFACE (Figure 3)						
Serial-Clock Frequency	f_{SCL}				1000	kHz
Bus Free Time Between START and STOP Condition	t_{BUF}		0.5			µs
Hold Time for Repeated START Condition	$t_{HD:STA}$		0.26			µs
Low Period for SCL Clock	t_{LOW}		0.5			µs
High Period for SCL Clock	t_{HIGH}		0.26			µs
Setup Time for Repeated START Condition	$t_{SU:STA}$		0.26			µs
Data Hold Time	$t_{HD:DAT}$		0		0.9	µs
Data Setup Time	$t_{SU:DAT}$		50			ns
Rise Time of Both SDA and SCL Signals	t_R				120	ns
Fall Time of Both SDA and SCL Signals	t_F				120	ns
Setup Time for STOP Condition	$t_{SU:STO}$		0.26			µs
Capacitive Load for Each Bus Line	C_B				400	pF
ESD PROTECTION						
V_A, V_B		Human Body Model		±15		kV
		IEC 61000-4-2		±4		
All Other Pins		Human Body Model		±2		kV

Note 2: All devices are tested at T_A = -40°C, +25°C, and +125°C. All temperature limits are guaranteed by design.
Note 3: V_{PEAK} is the average peak output voltage of V_A or V_B.
Note 4: LSB is defined as: V_{PEAK} (code = xFF) - V_{PEAK} (code = x01)/254; LSB for output RMS voltage is always smaller than V_{PEAK} = 17.3V + (N - 1) x LSB. (N = 1:255, accuracy ±3%).
Note 5: Guaranteed monotonic.

Timing Diagrams

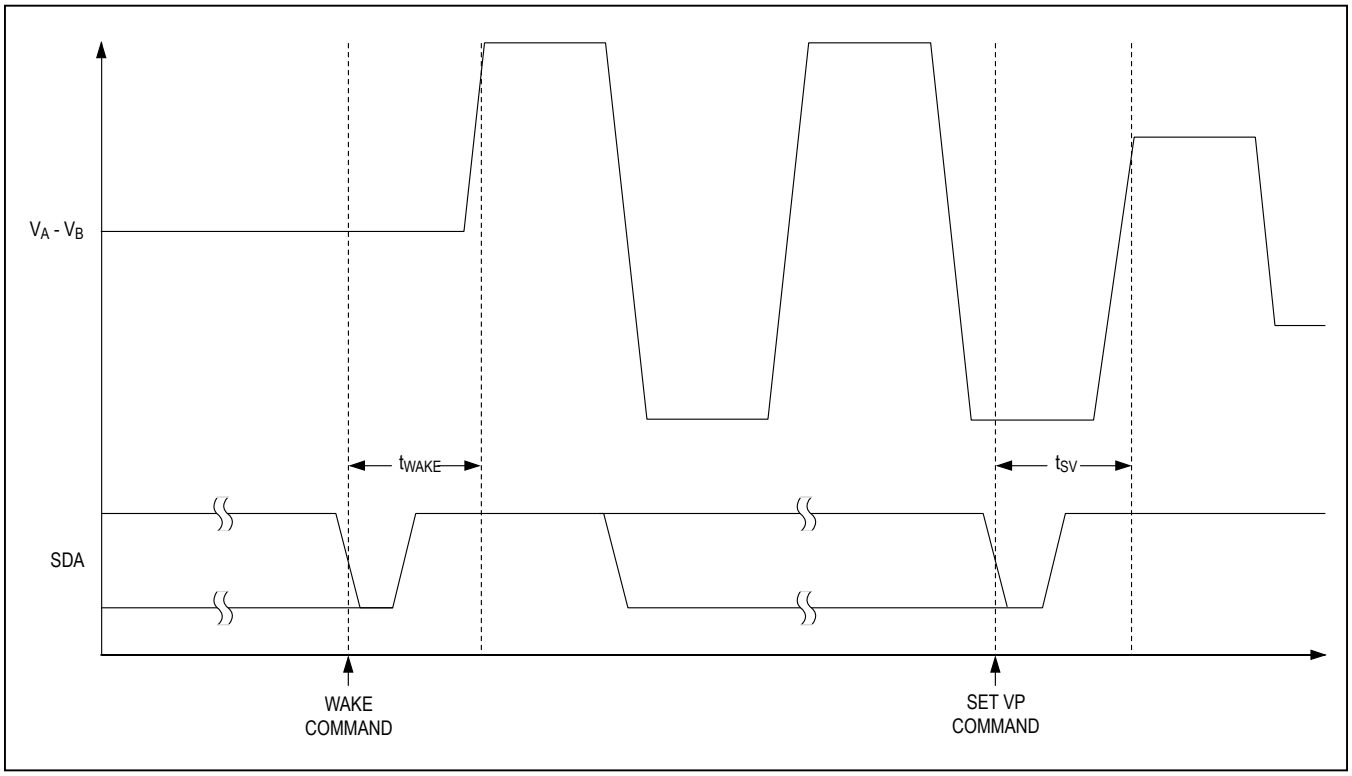


Figure 1. Wake-up and Peak Output-Voltage Settling Timing Diagram

Timing Diagrams (continued)

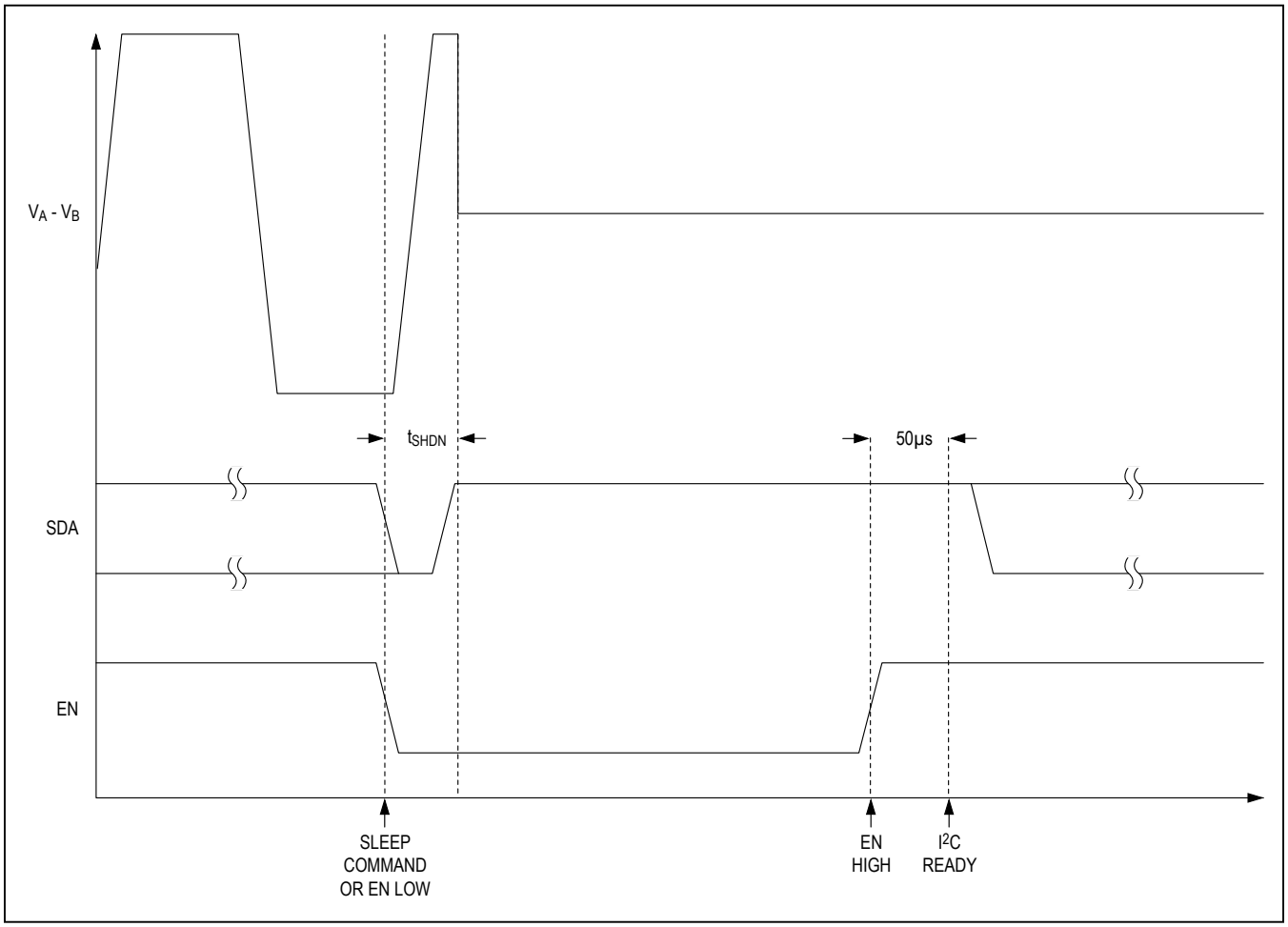
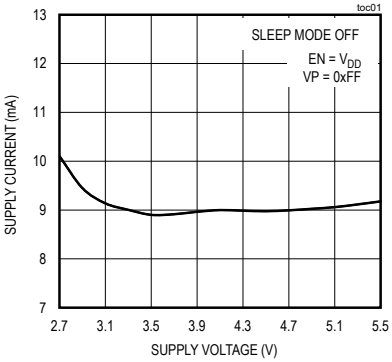


Figure 2. Shutdown/Sleep Mode Timing Diagram

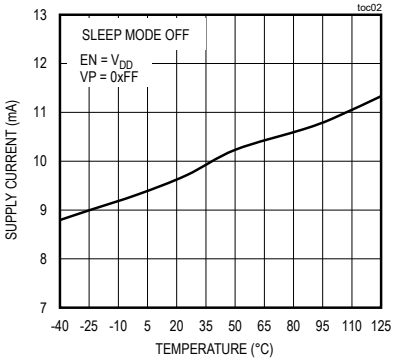
Typical Operating Characteristics

(V_{DD} = +2.8V, T_A = +25°C, C_{LENS} = 200pF, unless otherwise noted.)

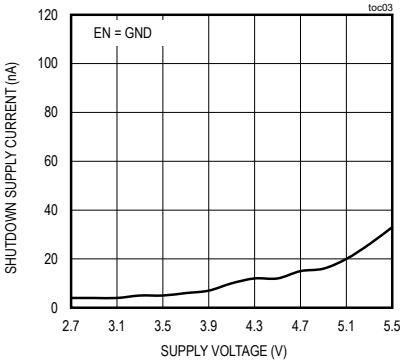
SUPPLY CURRENT vs. SUPPLY VOLTAGE



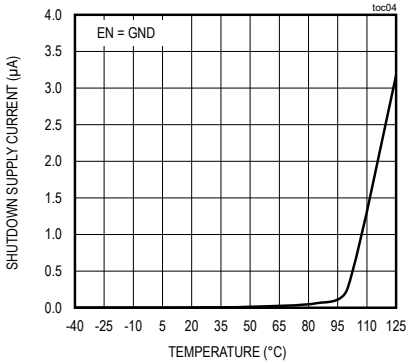
SUPPLY CURRENT vs. TEMPERATURE



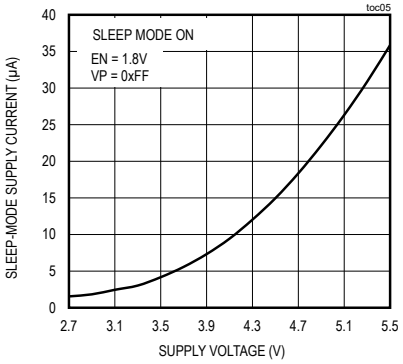
SHUTDOWN SUPPLY CURRENT vs. SUPPLY VOLTAGE



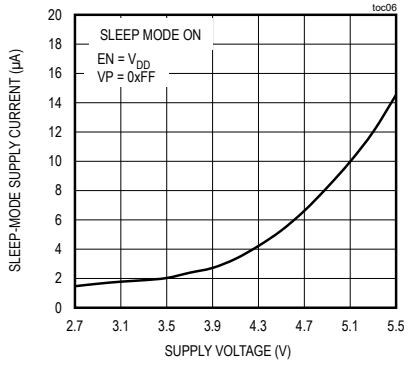
SHUTDOWN SUPPLY CURRENT vs. TEMPERATURE



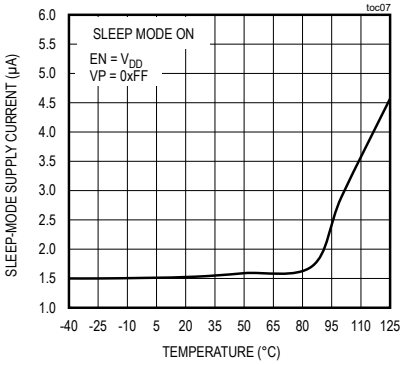
SLEEP-MODE SUPPLY CURRENT vs. SUPPLY VOLTAGE



SLEEP-MODE SUPPLY CURRENT vs. SUPPLY VOLTAGE



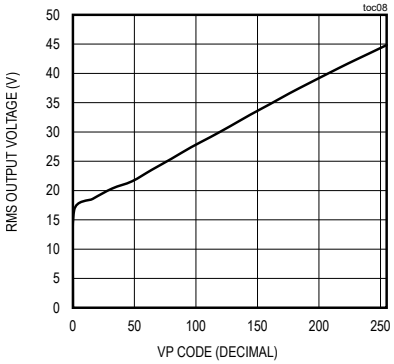
SLEEP-MODE SUPPLY CURRENT vs. TEMPERATURE



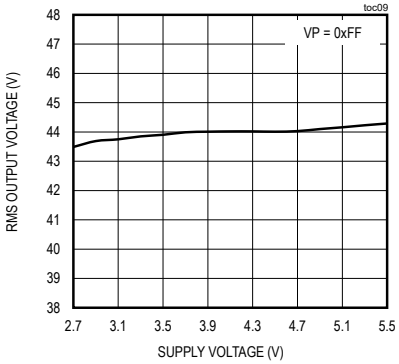
Typical Operating Characteristics (continued)

(V_{DD} = +2.8V, T_A = +25°C, C_{LENS} = 200pF, unless otherwise noted.)

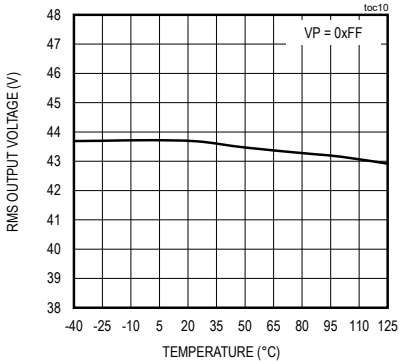
RMS OUTPUT VOLTAGE vs. VP CODE



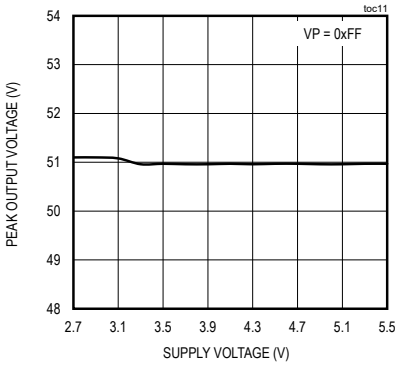
RMS OUTPUT VOLTAGE vs. SUPPLY VOLTAGE



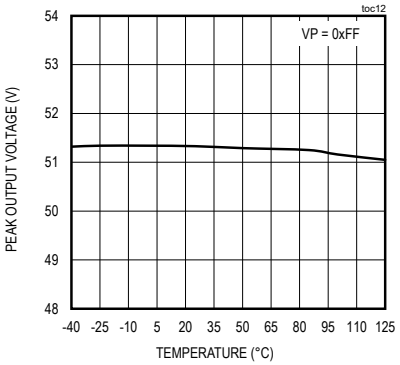
RMS OUTPUT VOLTAGE vs. TEMPERATURE



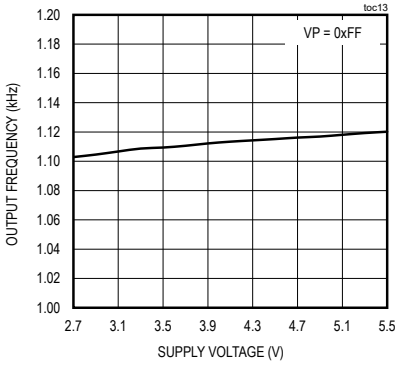
PEAK OUTPUT VOLTAGE vs. SUPPLY VOLTAGE



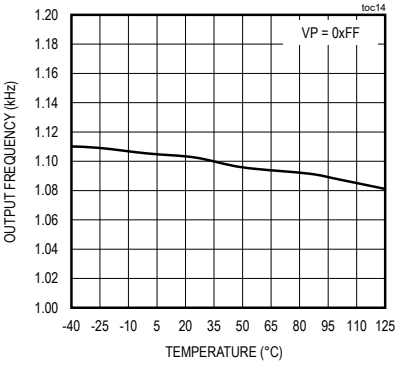
PEAK OUTPUT VOLTAGE vs. TEMPERATURE



OUTPUT FREQUENCY vs. SUPPLY VOLTAGE



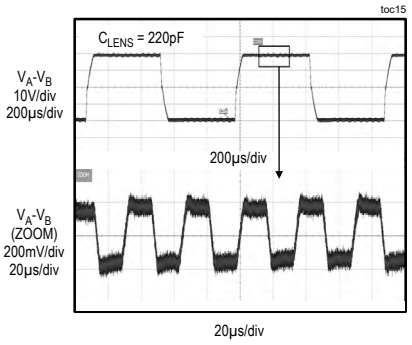
OUTPUT FREQUENCY vs. TEMPERATURE



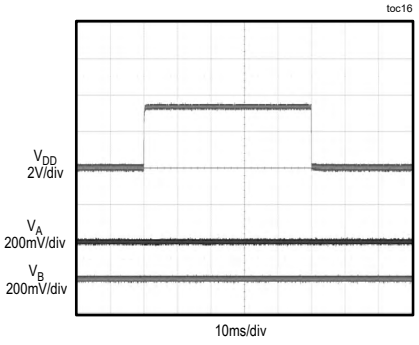
Typical Operating Characteristics (continued)

(V_{DD} = +2.8V, T_A = +25°C, C_{LENS} = 200pF, unless otherwise noted.)

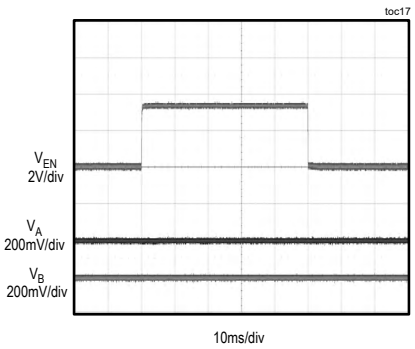
OUTPUT-VOLTAGE RIPPLE



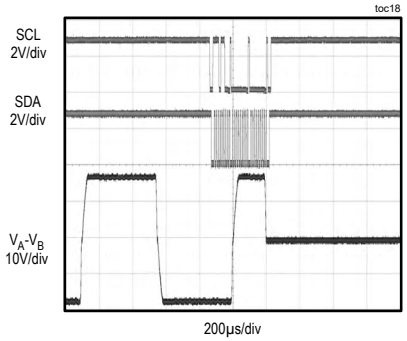
POWER UP/DOWN



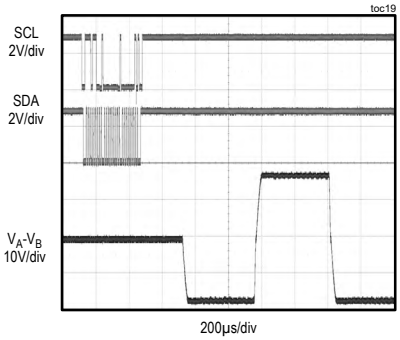
POWER UP/DOWN



SLEEP MODE ON



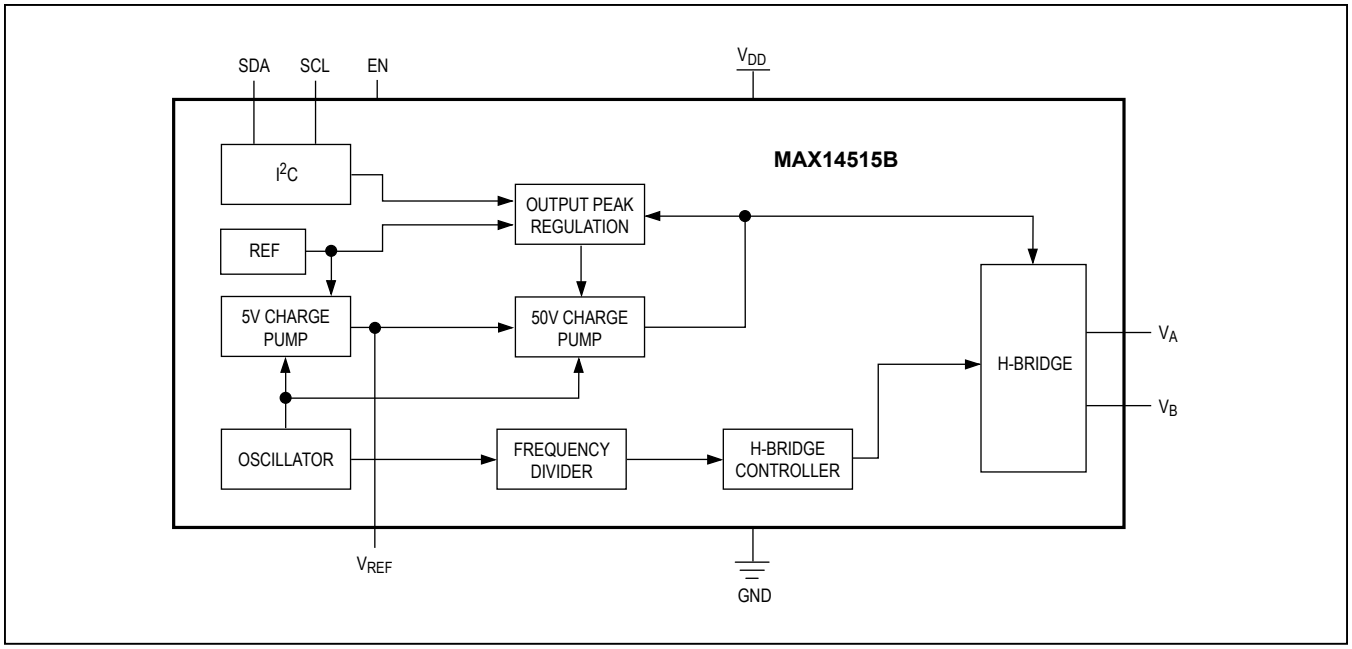
SLEEP MODE OFF



Pin Description

PIN	NAME	FUNCTION
A1	SCL	I²C Open-Drain Serial-Clock Input
A2	EN	Enable Input. Drive EN high for normal operation. Drive EN low to enter shutdown mode.
A3	GND	Ground
A4	V_A	High-Voltage Output. Connect to terminal 1 of liquid lens.
B1	SDA	I²C Open-Drain Serial-Data Input/Output
B2	V_{DD}	Input Supply Voltage. Bypass V_{DD} to GND with a 0.1µF capacitor as close as possible to the device.
B3	V_{REF}	Reference Voltage. Connect a 1µF ceramic capacitor from V_{REF} to GND as close as possible to the device. V_{REF} is nominally +5V. Do not use V_{REF} to drive external circuitry.
B4	V_B	High-Voltage Output. Connect to terminal 2 of liquid lens.

Functional Diagram



Detailed Description

The MAX14515B high-voltage liquid lens driver utilizes a charge-pump-based boost converter and integrated H-bridge to provide a compact lens driver solution with minimal external components. This device features an 8-bit monotonic DAC controlled by a simple 2-wire I²C interface to set the peak amplitude of the high-voltage output.

Power-On Reset

When the MAX14515B initially powers up, all the registers are cleared and the device is in sleep mode.

High-Voltage Outputs (V_A, V_B)

Connect a liquid lens between the high-voltage outputs (V_A, V_B) of the MAX14515B. The peak output voltage of V_A and V_B is controlled by the value set in the high-voltage output register (VP) (see *Table 1*). The internal H-bridge that drives V_A and V_B switches at 1.1kHz (typ).

Reference Output (V_{REF})

V_{REF} is the internal 5V charge-pump reference voltage of the MAX14515B. Connect a 1µF ceramic capacitor from V_{REF} to GND. V_{REF} is not intended to drive external circuitry.

Shutdown Mode (EN)

The MAX14515B features a shutdown mode that reduces supply current to less than 500nA (max). In shutdown, all registers are in a reset state, and the I²C interface is disabled. Drive EN low to place the device in shutdown mode. Drive EN high for normal operation. Driving EN rail-to-rail minimizes power consumption.

Sleep Mode

When EN is high and the sleep mode bit ($\overline{SM}$) in the power mode register (see *Table 1*) is reset, the device is in sleep mode. During sleep mode, only the power-on reset circuit remains active. If no activity is detected on the I²C interface, current consumption is less than 3µA.

I²C Serial Interface

Serial Addressing

The MAX14515B operates as a target device that sends and receives data through an I²C-compatible 2-wire interface. The interface uses a serial-data line (SDA) and a serial-clock line (SCL) to achieve bidirectional communication between controller(s) and target(s). A controller (typically a microcontroller) initiates all data transfers to and from the MAX14515B, and generates the SCL clock that synchronizes the data transfer. The SDA line operates as both an input and an open-drain output. A pull-up resistor is required on SDA. The SCL line operates only

Table 1. Register Definition

DEVICE ADDRESS				WRITE	0xEC
				READ	0xED
FIELD NAME	**READ WRITE**	**BITS**	**POWER-ON RESET**	**DESCRIPTION**	
POWER MODE (I²C ADDRESS = 0x00)					
RSVD	Read/Write	[7:1]	0000 000	Reserved. All bits must be set to 0.	
$\overline{SM}$	Read/Write	0	0	Sleep Mode Bit 0 = Sleep Mode 1 = Normal Operation All the registers keep the same values as before sleep unless a POR occurs.	
HIGH-VOLTAGE OUTPUT LEVEL (I²C ADDRESS = 0x01)					
VP[7:1]	Read/Write	[7:0]	0000 0000	Code 0x00 = $0V_{PEAK}$ Code 0x01 = $17.3V_{PEAK}$ Code 0xFF = $50.5V_{PEAK}$, linear scale $V_{OUT(PEAK)}$ = 17.3V + (N - 1) x LSB (N = 1:255, Accuracy ±3%)	

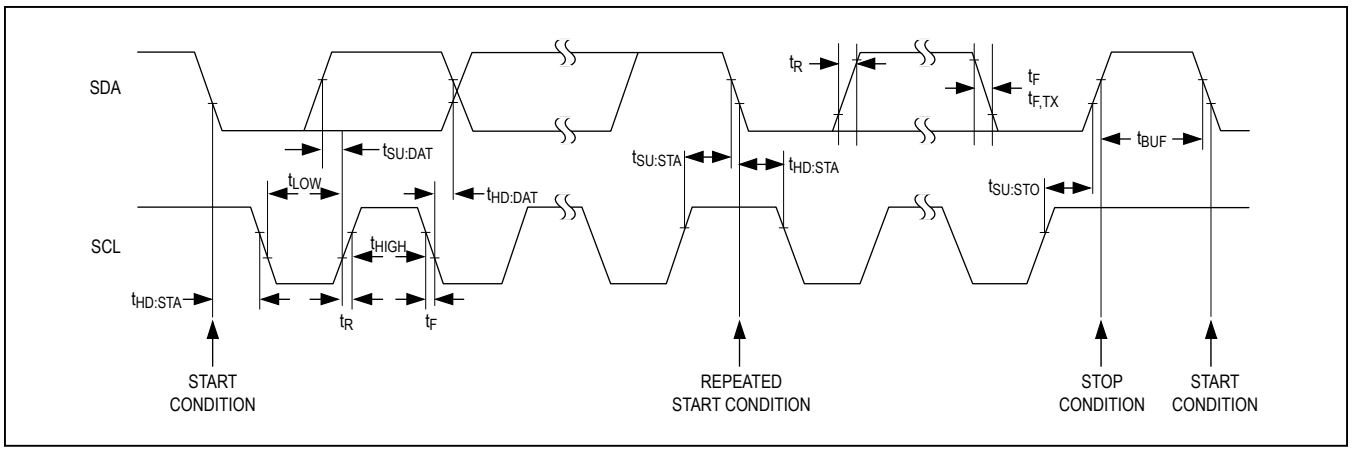


Figure 3. I²C Interface Timing Diagram

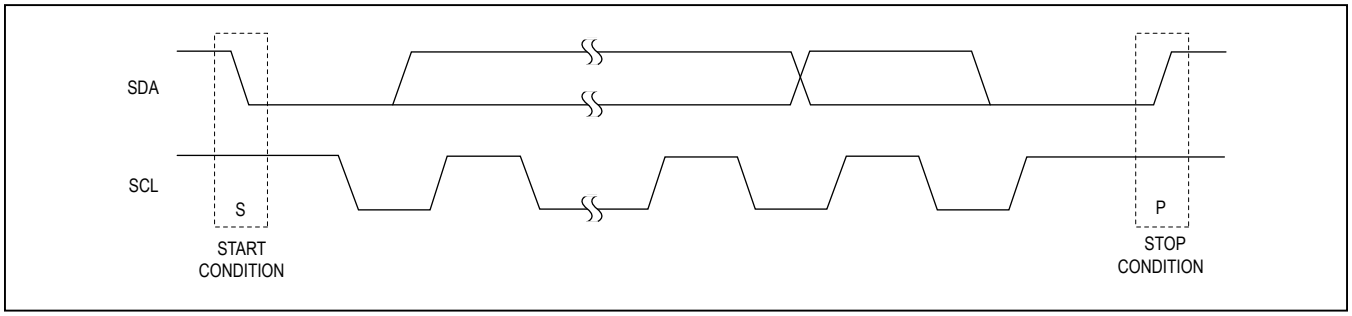


Figure 4. START and STOP Conditions

as an input. A pull-up resistor is required on SCL if there are multiple controllers on the 2-wire interface, or if the controller in a single-controller system has an open-drain SCL output. Each transmission consists of a START condition sent by a controller, followed by the MAX14515B's 7-bit target address plus R/$\overline{W}$ bit, a register address byte, 1 or more data bytes, and finally a STOP condition.

START and STOP Conditions

Both SCL and SDA remain high when the interface is not busy. A controller signals the beginning of a transmission with a START (S) condition by transitioning SDA from high to low while SCL is high (Figure 4). When the controller has finished communicating with the target, it issues a STOP (P) condition by transitioning SDA from low to high while SCL is high. The bus is then free for another transmission.

Bit Transfer

One data bit is transferred during each clock pulse (Figure 5). The data on SDA must remain stable while SCL is high.

Acknowledge

The acknowledge bit is a clocked 9th bit (Figure 6), which the recipient uses to handshake receipt of each byte of data. Thus, each byte transferred effectively requires 9 bits. The controller generates the 9th clock pulse, and the recipient pulls down SDA during the acknowledge clock pulse. The SDA line is stable low during the high period of the clock pulse. When the controller is transmitting to the MAX14515B, it generates the acknowledge bit because the MAX14515B is the recipient. When the MAX14515B is transmitting to the controller, the controller generates the acknowledge bit because the controller is the recipient.

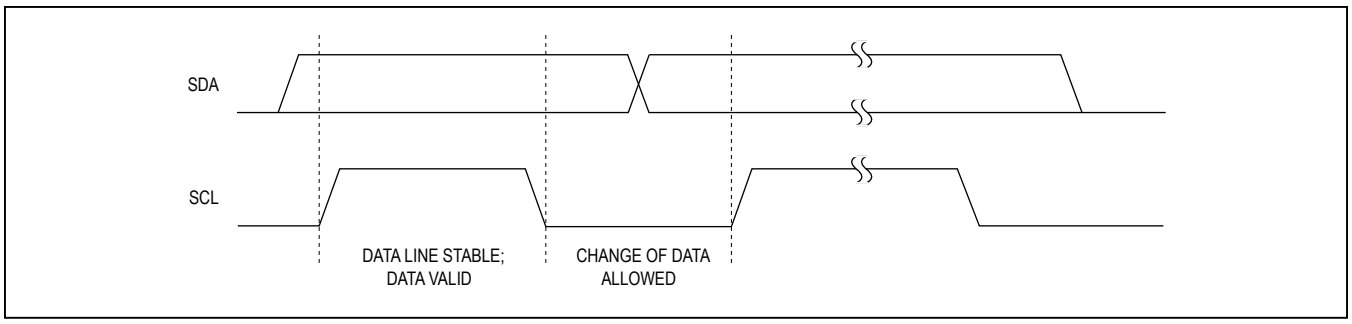


Figure 5. Bit Transfer

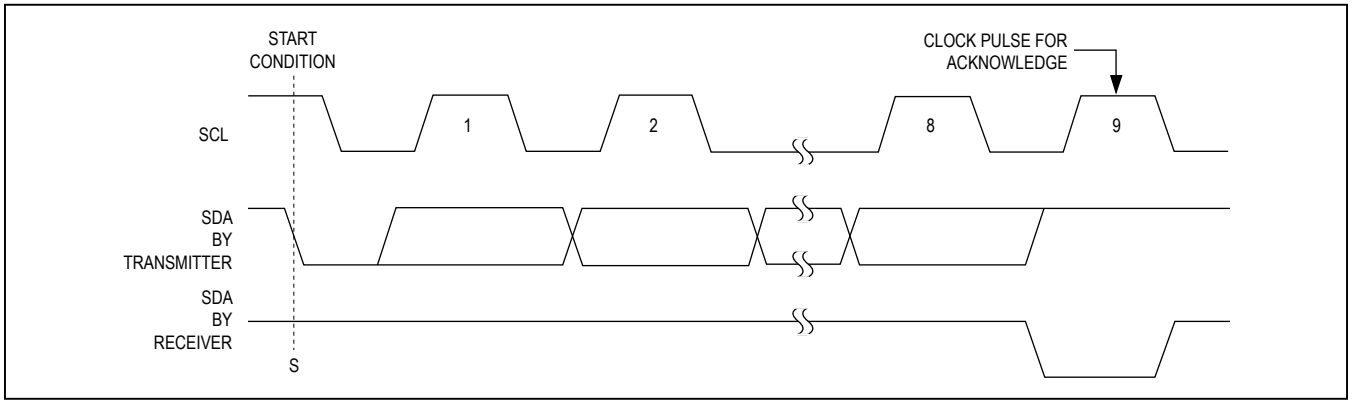


Figure 6. Acknowledge

Slave Address

The MAX14515B has a 7-bit long target address. The bit following a 7-bit target address is the R/$\overline{W}$ bit, which is low for a write command and high for a read command. The target address is 0xEC for write commands and 0xED for read commands (Figure 7).

Format for Writing

A write to the MAX14515B comprises the transmission of the target address with the R/W bit set to zero, followed by at least 1 byte of information. The first byte of information is the register address or command byte. The register address determines which register of the MAX14515B is to be written by the next byte, if received. If a STOP condition is detected after the register address is received, then the MAX14515B takes no further action beyond storing the register address (Figure 8). Any bytes received after the register address are data bytes. The first data byte goes into the register selected by the register address and subsequent data bytes go into subsequent registers (Figure 9).

If multiple data bytes are transmitted before a STOP condition, these bytes are stored in subsequent registers because the register address autoincrements.

Format for Reading

The MAX14515B is read using the internally stored register address as an address pointer, the same way the stored register address is used as an address pointer for a write. The pointer autoincrements after each data byte is read using the same rules as for a write. Thus, a read is initiated by first configuring the register address by performing a write (Figure 10). The controller can now read consecutive bytes from the MAX14515B, with the first data byte being read from the register address pointed by the previously written register address. Once the controller sounds a NACK, the MAX14515B stops sending valid data.

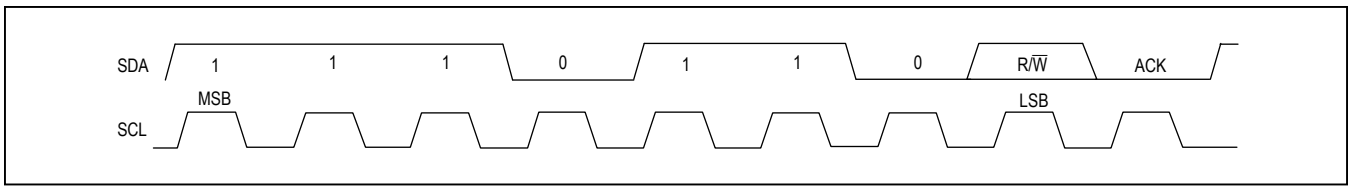


Figure 7. Target Address

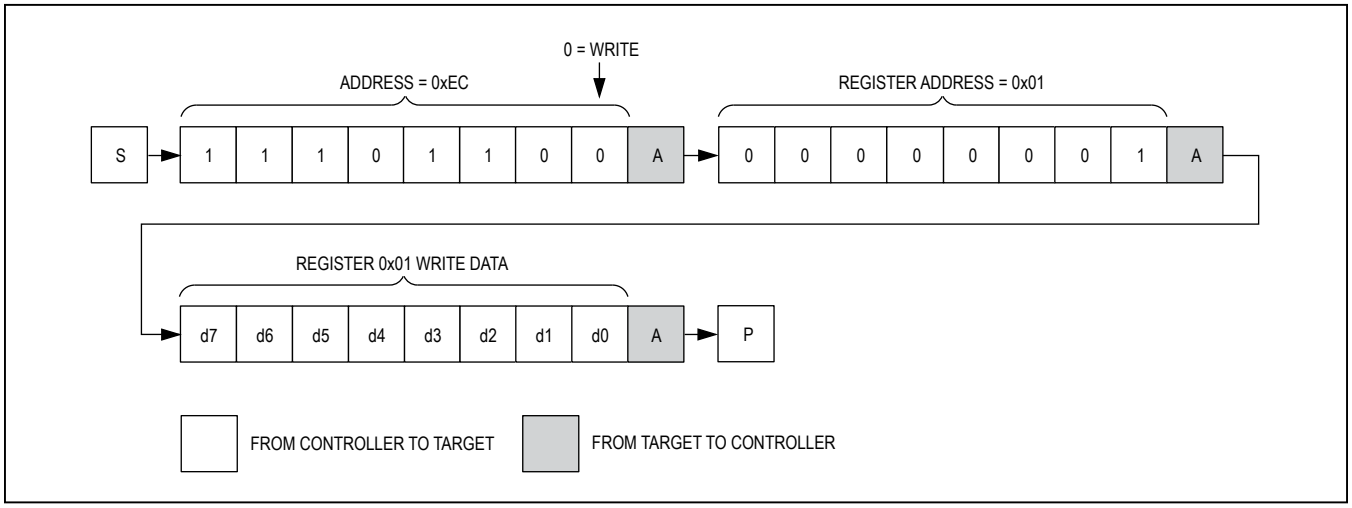


Figure 8. Format for I²C Write

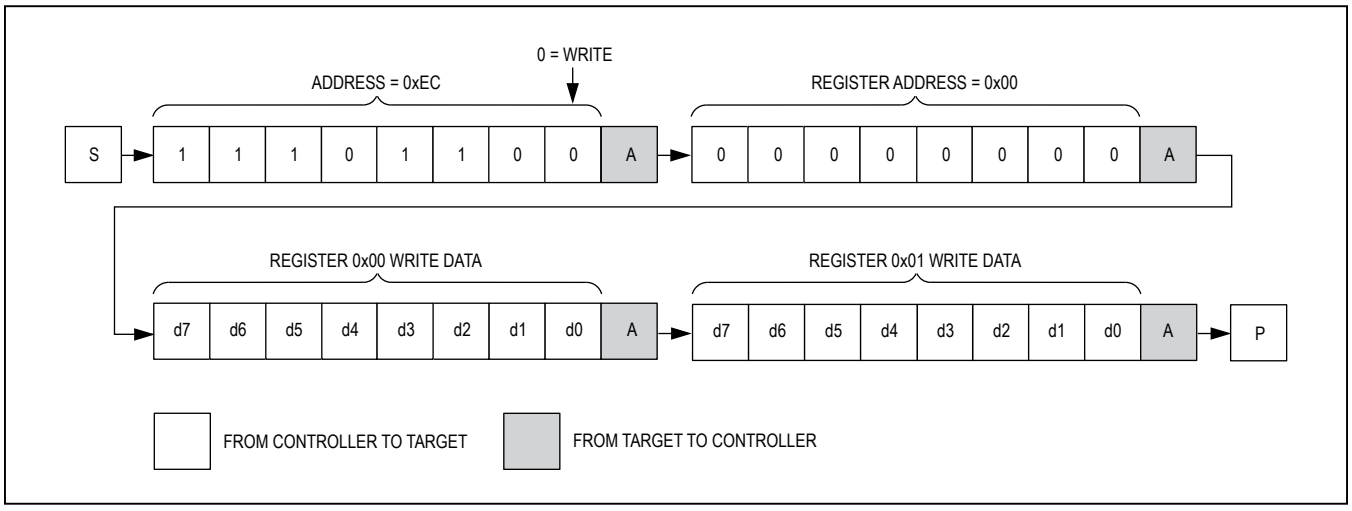


Figure 9. Format for Writing to Multiple Registers

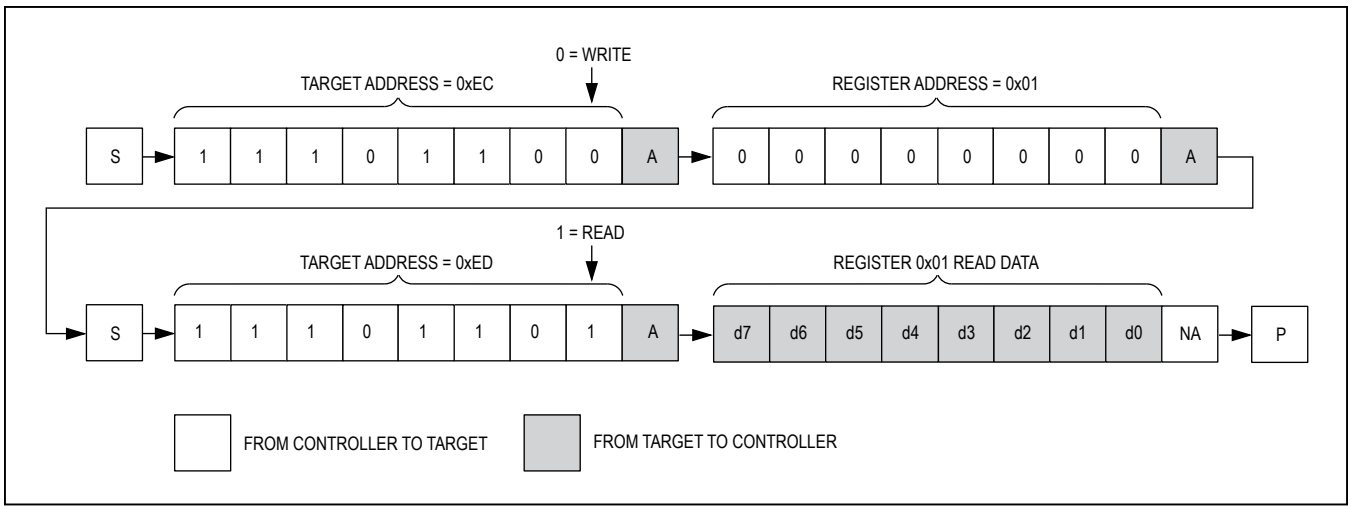


Figure 10. Format for Reading

Applications Information

Layout

Circuit board layout can significantly affect the performance of the MAX14515B. Ensure that bypass capacitors are as close to the device as possible. Keep PCB traces as short as possible and minimize trace inductances to V_{DD}. Use large ground planes where possible.

ESD Protection

ESD performance depends on a number of conditions. The MAX14515B is rated for ±15kV (Human Body Model) and ±4kV (IEC 61000-4-2 Contact) typical ESD resistance on V_A and V_B. All other pins are rated for ±2kV (Human Body Model) typical ESD resistance.

Human Body Model

Figure 11 shows the Human Body Model, and Figure 12 shows the current waveform it generates when discharged into a low impedance. This model consists of a 100pF capacitor charged to the ESD voltage of interest that is then discharged into the device through a 1.5kΩ resistor.

IEC 61000-4-2

The main difference between tests done using the Human Body Model and IEC 61000-4-2 is higher peak current in IEC 61000-4-2. Because series resistance is lower in the IEC 61000-4-2 ESD test model (Figure 13), the ESD-withstand voltage measured to this standard is generally lower than that measured using the Human Body Model. Figure 14 shows the current waveform for the IEC 61000-4-2 Level 4 ESD Contact Discharge test.

Chip Information

PROCESS: CMOS

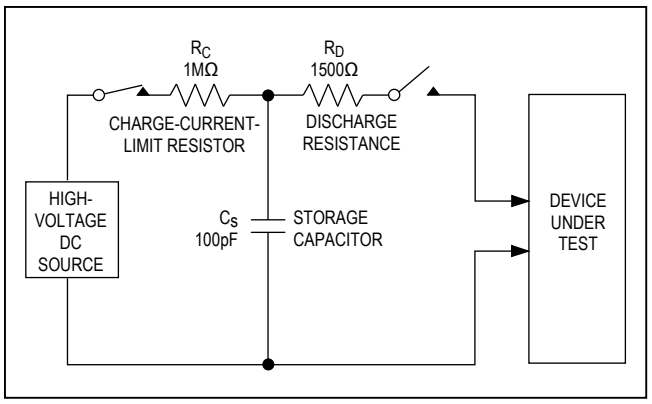


Figure 11. Human Body ESD Test Model

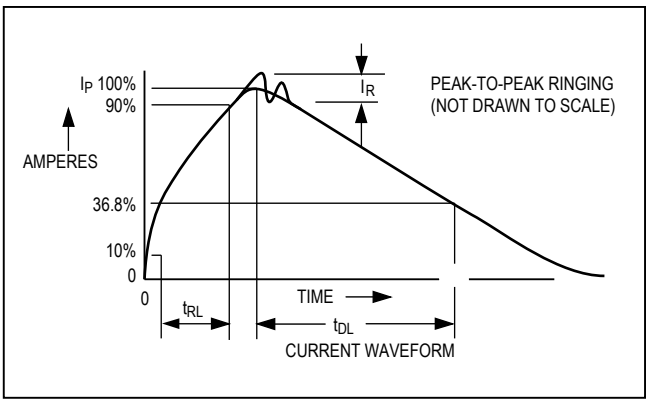


Figure 12. Human Body Current Waveform

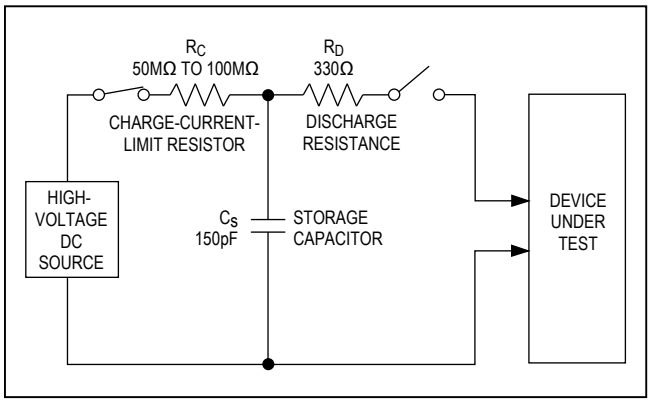


Figure 13. IEC 61000-4-2 ESD Test Model

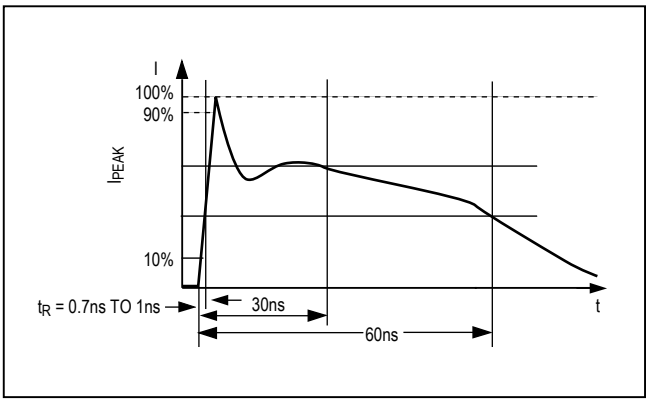


Figure 14. IEC 61000-4-2 ESD Generator Current Waveform

Package Information

For the latest package outline information and land patterns (footprints), go to **www.analog.com/en/resources/packaging-quality-symbols-footprints/package-index.html**. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	DOCUMENT NO.
WLCSP	W81A2+3	21-100812

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	6/26	Initial release	—