



# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

## General Description

The MAX8540/MAX8541 pulse-width-modulated (PWM) controllers for forward/flyback isolated DC-to-DC converters provide maximum flexibility to power-supply designers and reduce external component count. These controllers allow common PC board layout for current-mode (MAX8540) and voltage-mode (MAX8541) designs.

Both controllers feature adjustable switching frequency and external synchronization from 200kHz to 1MHz. Active-high and active-low enable, undervoltage protection (UVP), and overvoltage protection (OVP) reduce external component count.

Maximum duty cycle is adjustable, and the feed-forward function scales the maximum duty cycle with input voltage to limit the maximum volt-seconds applied to the transformer primary. The MAX8540 allows the user to select the value of slope compensation to further optimize magnetics design. The MAX8541 features user-adjustable ramp magnitude for the PWM comparator.

A cycle-by-cycle current-limit function controls the peak primary current during overload and short circuit. Both controllers can be set to latch off or to hiccup when a short circuit is detected. The number of current-limited cycles to initiate the hiccup mode and number of cycles skipped are user selectable to allow startup with high-capacitance loads and protect the converter against sustained short circuits.

The MAX8540/MAX8541 feature 9Ω internal gate drivers for low-power applications and are compatible with external gate drivers for high-power applications. Both devices are available in the space-saving 16-pin QSOP package.

The MAX8541 EV kit evaluates the MAX8540 and the MAX8541 to speed designs. Design examples are also available in application notes: *50W Voltage-Mode Forward Converter Design with the MAX8541* and *50W Current-Mode Forward Converter Design with the MAX8540*.

## Applications

- Isolated DC-to-DC Modules (Bricks)
- Cellular Base Stations
- Telecom and Network Systems
- High-Performance Off-Line AC/DC Converters

**Functional Diagrams and Typical Operating Circuit appear at end of data sheet.**



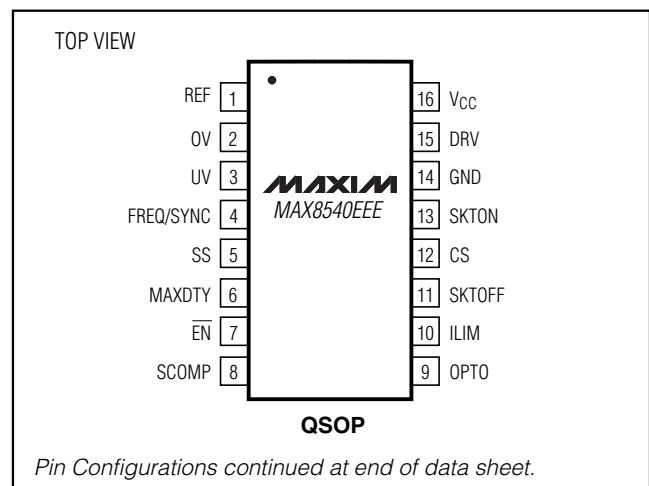
## Features

- ◆ 200kHz to 1MHz Adjustable Switching Frequency
- ◆ Synchronization to External Clock
- ◆ Programmable, Constant Maximum Volt-Second Simplifies Transformer Design
- ◆ Programmable Hiccup/Skip Cycles or Latch-Mode Protection
- ◆ Clean Startups with High-Capacitance Loads
- ◆ Programmable Under/Overvoltage Protection
- ◆ Current-Mode, Adjustable Slope Compensation (MAX8540)
- ◆ Voltage-Mode, Adjustable Ramp Magnitude (MAX8541)
- ◆ 10mA, 5V Regulator
- ◆ 75mV to 1.25mV Adjustable Current Limit Reduces External Components
- ◆ Internal Gate Driver for Low-Power Applications
- ◆ External Gate Driver for High-Power Applications

## Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX8540EEE	-40°C to +85°C	16 QSOP
MAX8541EEE	-40°C to +85°C	16 QSOP

## Pin Configurations



MAX8540/MAX8541

**For pricing, delivery, and ordering information, please contact Maxim/Dallas Direct! at 1-888-629-4642, or visit Maxim's website at [www.maxim-ic.com](http://www.maxim-ic.com).**

# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

## ABSOLUTE MAXIMUM RATINGS

V<sub>CC</sub> to GND .....-0.3V to +20V  
 OPTO, UV, OV,  $\overline{\text{EN}}$ , PRAMP, ILIM, REF to GND .....-0.3V to +6V  
 SCOMP, FREQ, CS, SKTON, SKTOFF, SS,  
 MAXDTY to GND .....-0.3V to V<sub>REF</sub> + 0.3V  
 DRV to GND .....-0.3V to V<sub>VCC</sub> + 0.3V  
 Continuous Power Dissipation (T<sub>A</sub> = +70°C)  
 16-Pin QSOP (derate 8.3mW/°C above +70°C).....667mW

Operating Temperature Range .....-40°C to +85°C  
 Junction Temperature .....+150°C  
 Storage Temperature Range .....-65°C to +150°C  
 Lead Temperature (soldering, 10s) .....+300°C

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<sub>VCC</sub> = 12V, C<sub>REF</sub> = 1μF, V<sub>UV</sub> = V<sub>OV</sub> = V<sub>OPTO</sub>, V<sub>ILIM</sub> = 2V, R<sub>FREQ/SYNC</sub> = 32.4kΩ, C<sub>SS</sub> = 0.1μF, R<sub>MAXDTY</sub> = 97.6kΩ, V $\overline{\text{EN}}$  = 0, R<sub>SCOMP</sub> = 68kΩ, R<sub>PRAMP</sub> = 25kΩ, C<sub>SKTON</sub> = 0.01μF, C<sub>SKTOFF</sub> = 0.1μF, V<sub>CS</sub> = 0.6V, C<sub>DRV</sub> = 10pF, T<sub>A</sub> = 0°C to +85°C, unless otherwise noted. Typical values are at T<sub>A</sub> = +25°C.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	
<b>V<sub>CC</sub></b>						
Operating Voltage Range	(Note 1)	7.6		18.0	V	
Undervoltage Lockout	V <sub>CC</sub> rising	7.6	8.0	8.4	V	
	V <sub>CC</sub> falling	6.6	7.0	7.4		
Undervoltage Lockout Hysteresis		0.9	1.0		V	
Supply Current	V <sub>REF</sub> is active, I <sub>REF</sub> = 0	No switching		3.5	4.2	mA
		Switching with no load		5	6.3	
Shutdown Current	V $\overline{\text{EN}}$ = 3V		0.5	0.9	mA	
<b>REF</b>						
Output Voltage	I <sub>REF</sub> = 0	4.9	5.0	5.1	V	
Load Regulation	I <sub>REF</sub> = 0 to 10 mA		20	50	mV	
Line Regulation	V <sub>VCC</sub> = 8.4V to 18V		5	20	mV	
Pulldown Resistor in Shutdown	V $\overline{\text{EN}}$ = 3V		10	30	Ω	
<b>UNDERVOLTAGE/OVERVOLTAGE (UV/OV)</b>						
UVLO Threshold	V <sub>UV</sub> rising, 120mV typical hysteresis	1.200	1.250	1.300	V	
	V <sub>UV</sub> falling	1.083	1.128	1.173		
Input Bias Current		-0.5	+0.01	+0.5	μA	
OVLO Threshold	V <sub>OV</sub> rising, 130mV typical hysteresis	2.9	3.021	3.1	V	
	V <sub>OV</sub> falling	2.778	2.894	3.010		
<b><math>\overline{\text{EN}}</math></b>						
Input Low Threshold	V <sub>IL</sub>			1.2	V	
Input High Threshold	V <sub>IH</sub>	2.6			V	
Pullup Current	V $\overline{\text{EN}}$ = 2.6V	5	17		μA	
<b>CURRENT LIMIT</b>						
V <sub>ILIM</sub> Range		0.075		1.250	V	
CS Current-Limit to DRV Turn-Off Delay	Includes leading-edge blanking time		110	150	ns	
V <sub>CS</sub> Cycle-by-Cycle Threshold Voltage	Accuracy when V <sub>ILIM</sub> = 0.075V		±10		%	
	V <sub>ILIM</sub> = 1.250V	1.175	1.250	1.330	V	

# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

## ELECTRICAL CHARACTERISTICS (continued)

( $V_{CC} = 12V$ ,  $C_{REF} = 1\mu F$ ,  $V_{UV} = V_{OV} = V_{OPTO}$ ,  $V_{ILIM} = 2V$ ,  $R_{FREQ/SYNC} = 32.4k\Omega$ ,  $C_{SS} = 0.1\mu F$ ,  $R_{MAXDTY} = 97.6k\Omega$ ,  $V_{EN} = 0$ ,  $R_{SCOMP} = 68k\Omega$ ,  $R_{PRAMP} = 25k\Omega$ ,  $C_{SKTON} = 0.01\mu F$ ,  $C_{SKTOFF} = 0.1\mu F$ ,  $V_{CS} = 0.6V$ ,  $C_{DRV} = 10pF$ ,  $T_A = 0^\circ C$  to  $+85^\circ C$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$ .)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
ILIM Leakage Current		-1		+1	$\mu A$
Hiccup Skip Off-Time	$C_{SKTOFF} = 0.1\mu F$ (Note 3)		90		ms
Hiccup Skip Off-Charging		0.9	1.5	2.1	$\mu A$
Hiccup Skip On-Time	$C_{SKTON} = 0.01\mu F$ (Note 3)		9		ms
Hiccup Skip On-Charging Current		1.5	2.5	3.5	$\mu A$
Hiccup SKTOFF Voltage Threshold		2.3	2.5	2.7	V
<b>OPTO</b>					
Input Bias Current	$V_{OPTO} = 3.5V$		30		$\mu A$
Minimum Input Voltage	Minimum voltage for duty-cycle control		0.6		V
Maximum Input Voltage	Maximum voltage for duty-cycle control		2.6		V
<b>DUTY CYCLE</b>					
Maximum Duty Cycle	$R_{MAXDTY} = 24.3k\Omega$ , $V_{UV} = 1.3V$		15		%
	$R_{MAXDTY} = 130k\Omega$ , $V_{UV} = 1.3V$		80		
	$V_{UV} = 1.3V$ , $R_{MAXDTY} = 97.6k\Omega$		60		
	Internally programmed limit for maximum duty cycle at all frequencies	79	80	82	
<b>SOFT-START</b>					
Source Current	$V_{SS} = 1V$	4.5	5.5	6.5	$\mu A$
Pulldown Resistance in Shutdown	$I_{SS} = 10mA$ , $V_{EN} = 3V$		10	30	$\Omega$
Time			440		ms/ $\mu F$
<b>FREQUENCY</b>					
Initial Accuracy	$R_{FREQ} = 32.4k\Omega$	280	300	320	kHz
Switching Frequency Range	$R_{FREQ} = 48.7k\Omega$		200		kHz
	$R_{FREQ} = 8.87k\Omega$		1000		
<b>SCOMP (MAX8540)</b>					
Slope Compensation	$R_{SCOMP} = 14k\Omega$		1.5		V
	$R_{SCOMP} = 204k\Omega$		0.1		
<b>PRAMP (MAX8541)</b>					
Ramp Voltage Amplitude	$R_{PRAMP} = 12.4k\Omega$		2.5		V
	$R_{PRAMP} = 21k\Omega$		1		
	$R_{PRAMP} = 42k\Omega$		0.5		
<b>DRV (MOSFET DRIVER)</b>					
Rise Time	$C_{DRV} = 500pF$ , 10% to 90% of $V_{CC}$		30		ns
	$C_{DRV} = 2000pF$ , 10% to 90% of $V_{CC}$		57		

# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

## ELECTRICAL CHARACTERISTICS (continued)

( $V_{CC} = 12V$ ,  $C_{REF} = 1\mu F$ ,  $V_{UV} = V_{OV} = V_{OPTO}$ ,  $V_{ILIM} = 2V$ ,  $R_{FREQ/SYNC} = 32.4k\Omega$ ,  $C_{SS} = 0.1\mu F$ ,  $R_{MAXDTY} = 97.6k\Omega$ ,  $V_{EN} = 0$ ,  $R_{SCOMP} = 68k\Omega$ ,  $R_{PRAMP} = 25k\Omega$ ,  $C_{SKTON} = 0.01\mu F$ ,  $C_{SKTOFF} = 0.1\mu F$ ,  $V_{CS} = 0.6V$ ,  $C_{DRV} = 10pF$ ,  $T_A = 0^\circ C$  to  $+85^\circ C$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$ .)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Fall Time	$C_{DRV} = 500pF$ , 90% to 10% of $V_{CC}$		27		ns
	$C_{DRV} = 2000pF$ , 90% to 10% of $V_{CC}$		53		
On-Resistance Pullup			9		$\Omega$
On-Resistance Pulldown			7		$\Omega$
<b>SYNC (EXTERNAL FREQUENCY SYNCHRONIZATION)</b>					
Frequency Range	Frequency syncs $\pm 30\%$ of frequency set by external R on FREQ pin	0.2		1.0	MHz
FREQ Input Threshold	(Note 4)	2		3	V
<b>THERMAL SHUTDOWN</b>					
Thermal Shutdown	$T_A$ rising, $20^\circ C$ hysteresis		170		$^\circ C$

## ELECTRICAL CHARACTERISTICS

( $V_{CC} = 12V$ ,  $C_{REF} = 1\mu F$ ,  $V_{UV} = V_{OV} = 2V$ ,  $R_{FREQ/SYNC} = 32.4k\Omega$ ,  $C_{SS} = 0.1\mu F$ ,  $R_{MAXDTY} = 97.6k\Omega$ ,  $V_{EN} = 0$ ,  $R_{SCOMP} = 68k\Omega$ ,  $R_{PRAMP} = 25k\Omega$ ,  $C_{SKTON} = 0.01\mu F$ ,  $C_{SKTOFF} = 0.1\mu F$ ,  $V_{OPTO} = 2V$ ,  $V_{ILIM} = 4V$ ,  $V_{CS} = 0.6V$ ,  $C_{DRV} = 10pF$ ,  $T_A = -40^\circ C$  to  $+85^\circ C$ , unless otherwise noted.) (Note 5)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
<b>V<sub>CC</sub></b>					
Operating Voltage Range	(Note 1)	7.6		18.0	V
Undervoltage Lockout	$V_{CC}$ rising	7.6		8.4	V
	$V_{CC}$ falling	6.6		7.4	
Undervoltage Lockout Hysteresis		0.9			V
Supply Current	$V_{REF} =$ is active, $I_{REF} = 0$	No switching		4.2	mA
		Switching with no load		6.3	
Shutdown Current	$V_{EN} = 3V$			0.9	mA
<b>REF</b>					
Output Voltage	$I_{REF} = 0$	4.9		5.1	V
Load Regulation	$I_{REF} = 0$ to 10mA			50	mV
Line Regulation	$V_{CC} = 8.4V$ to 18V			20	mV
Shutdown Resistor	$V_{EN} = 3V$			30	$\Omega$
<b>UNDERVOLTAGE/OVERVOLTAGE (UV/OV)</b>					
UVLO Threshold	$V_{UV}$ falling, 120mV typical hysteresis	1.200		1.300	V
	$V_{UV}$ rising	1.083		1.173	
Input Bias Current		-0.5		+0.5	$\mu A$
OVLO Threshold	$V_{OV}$ falling, 130 mV typical hysteresis	2.901		3.142	V
	$V_{OV}$ rising	2.778		3.010	

# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

## ELECTRICAL CHARACTERISTICS (continued)

( $V_{CC} = 12V$ ,  $C_{REF} = 1\mu F$ ,  $V_{UV} = V_{OV} = 2V$ ,  $R_{FREQ/SYNC} = 32.4k\Omega$ ,  $C_{SS} = 0.1\mu F$ ,  $R_{MAXDLY} = 97.6k\Omega$ ,  $V_{EN} = 0$ ,  $R_{SCOMP} = 68k\Omega$ ,  $R_{PRAMP} = 25k\Omega$ ,  $C_{SKTON} = 0.01\mu F$ ,  $C_{SKTOFF} = 0.1\mu F$ ,  $V_{OPTO} = 2V$ ,  $V_{ILIM} = 4V$ ,  $V_{CS} = 0.6V$ ,  $C_{DRV} = 10pF$ ,  $T_A = -40^\circ C$  to  $+85^\circ C$ , unless otherwise noted.) (Note 5)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
<b>EN</b>					
Input Threshold	$V_{IL}$			1.2	V
	$V_{IH}$	2.6			
Pullup Current	$V_{EN} = 2.6V$	5			$\mu A$
<b>CURRENT LIMIT</b>					
$V_{ILIM}$ Range		0.075		1.25	V
CS Current Limit to DRV Delay	Includes leading-edge blanking time			150	ns
$V_{CS}$ Cycle-by-Cycle Threshold Voltage	Accuracy when $V_{ILIM} = 0.075V$		$\pm 10$		%
	$V_{ILIM} = 1.250V$	1.130		1.375	V
ILIM Leakage Current		-1		+1	$\mu A$
Hiccup Skip Off-Charging Current		0.9		2.1	$\mu A$
Hiccup Skip On-Charging Current		1.5		3.5	$\mu A$
Hiccup SKTOFF Voltage Threshold		2.3		2.7	V
<b>DUTY CYCLE</b>					
Duty-Cycle Range	$V_{UV} = 1.3V$	15		80	%
Maximum Duty Cycle	Internal programmed max duty at all frequencies	79		82	%
<b>SOFT-START</b>					
Source Current	$V_{SS} = 1V$	4.5		6.5	$\mu A$
Pulldown Resistance in Shutdown	$I_{SS} = 10mA$ , $V_{EN} = 3V$			30	$\Omega$
<b>FREQUENCY</b>					
Initial Accuracy	$R_{FREQ} = 32.4k\Omega$	280		320	kHz
<b>SYNC (EXTERNAL FREQUENCY SYNCHRONIZATION)</b>					
Frequency Range	Frequency syncs $\pm 30\%$ of frequency set by external R on FREQ pin	0.2		1.0	MHz
FREQ Input Threshold	(Note 4)	2		3	V

**Note 1:** This is the  $V_{CC}$  operating range after clearing the rising UVLO.

**Note 2:** Guaranteed by design.

**Note 3:** See the *SKTON* and *SKTOFF* section.

**Note 4:** The minimum FREQ pulse must be 200ns in duration with a minimum magnitude of 3V plus  $V_f$  of the external diode and have a maximum duty cycle of 55%.

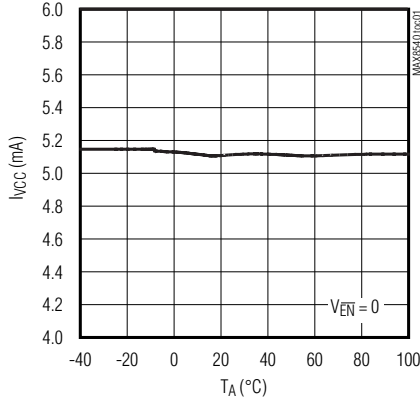
**Note 5:** Specifications to  $-40^\circ C$  are guaranteed by design and not production tested.

# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

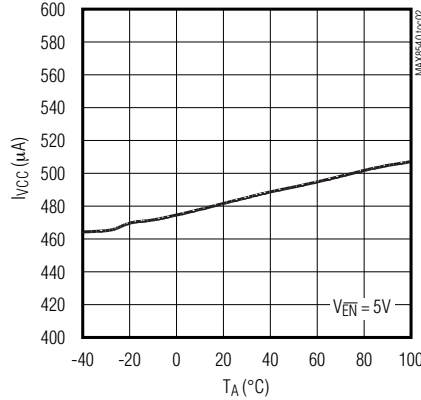
## Typical Operating Characteristics

( $V_{CC} = 12V$ ,  $T_A = +25^\circ C$ , unless otherwise specified.)

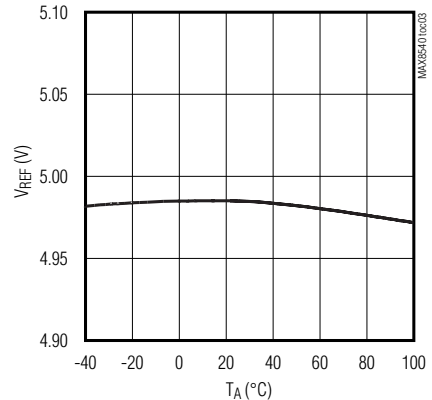
**V<sub>CC</sub> NO-LOAD SWITCHING CURRENT vs. TEMPERATURE**



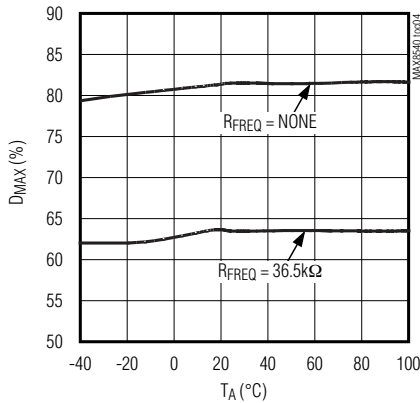
**SHUTDOWN V<sub>CC</sub> CURRENT vs. TEMPERATURE**



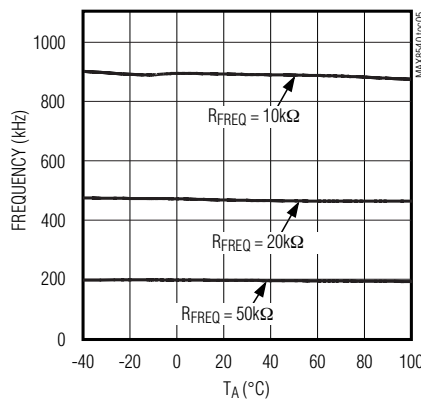
**REFERENCE VOLTAGE vs. TEMPERATURE**



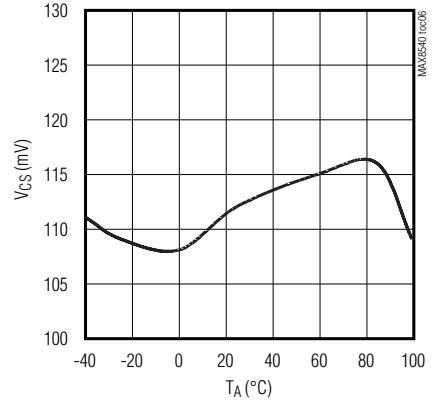
**MAXIMUM DUTY CYCLE vs. TEMPERATURE**



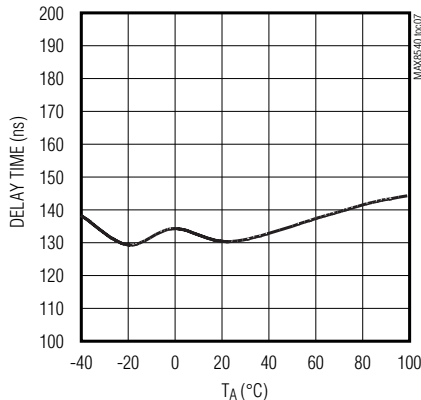
**FREQUENCY vs. TEMPERATURE**



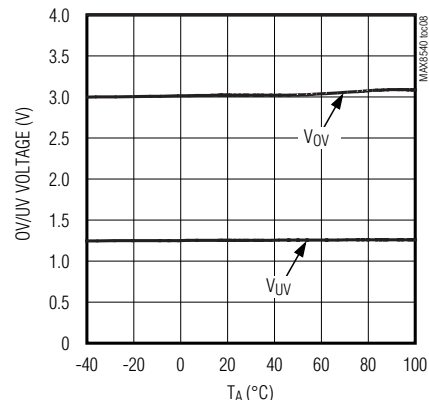
**CURRENT-SENSE THRESHOLD vs. TEMPERATURE**



**CURRENT-LIMIT DELAY TIME vs. TEMPERATURE**



**OV/UV THRESHOLD VOLTAGE vs. TEMPERATURE**

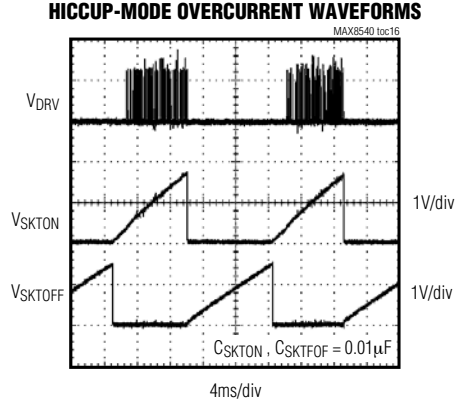
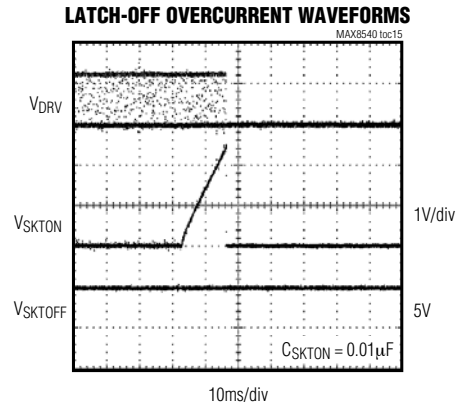
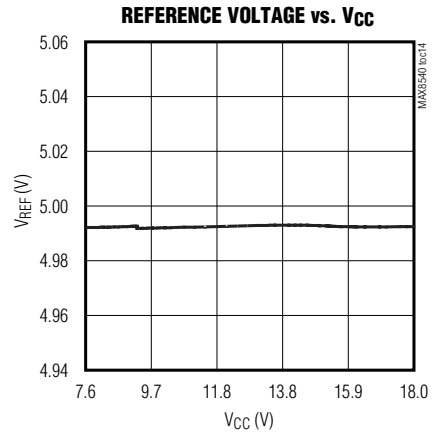
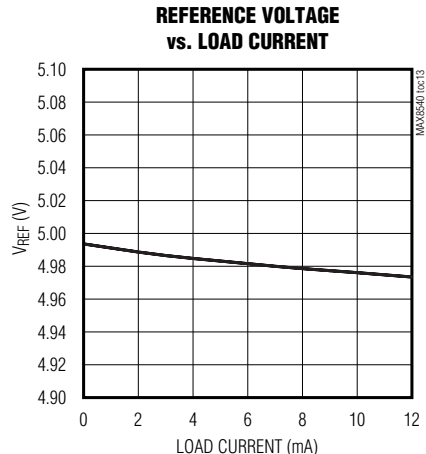
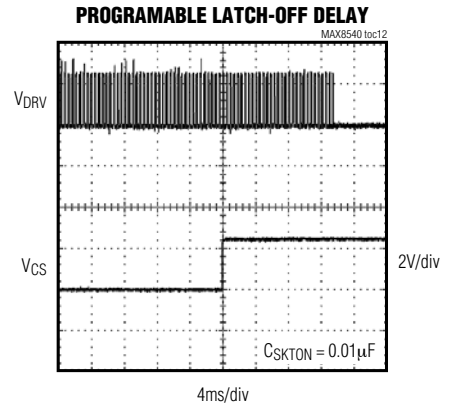
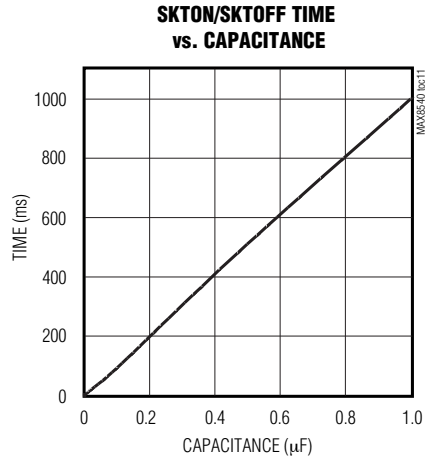
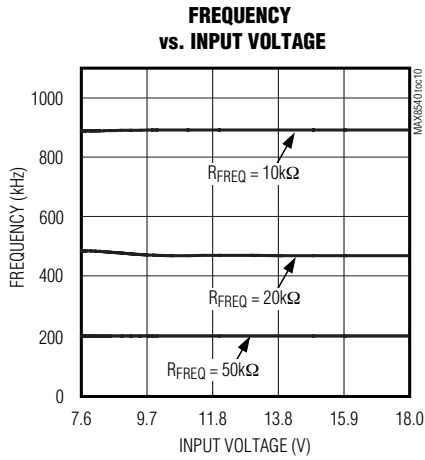


# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

MAX8540/MAX8541

## Typical Operating Characteristics (continued)

( $V_{CC} = 12V$ ,  $T_A = +25^\circ C$ , unless otherwise specified.)



# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

## Pin Description

PIN		NAME	FUNCTION
MAX8540	MAX8541		
1	1	REF	5V Reference Voltage Output. Bypass to ground with a 1 $\mu$ F capacitor. REF is pulled to GND during shutdown.
2	2	OV	System Input Overvoltage Monitoring. The OV threshold is 3.021V with 130mV hysteresis. Connect to the center of a resistor-divider from the system input to GND to set the overvoltage trip point (see the <i>Overvoltage Threshold</i> section).
3	3	UV	System Input Undervoltage Monitoring and Feed-Forward Input. The UV threshold is 1.25V with 120mV hysteresis. Connect to the center of a resistor-divider from the system input to GND to set the undervoltage trip point (see the <i>Undervoltage Threshold</i> section). This input can be used as a disable input by pulling it below 1.2V. UV remains active during shutdown.
4	4	FREQ/ SYNC	Programmable Frequency and Sync Input. Connect a resistor in parallel with RC (10k $\Omega$ , 0.01 $\mu$ F) from FREQ/SYNC to GND to set the switching frequency or apply an external clock signal through a diode to synchronize to an external frequency.
5	5	SS	Soft-Start Capacitor Connection. Connect a capacitor from SS to GND to set the soft-start time period.
6	6	MAXDTY	Programmable Maximum Duty-Cycle Input. Connect a resistor from MAXDTY to GND to set the maximum duty cycle for minimum system input voltages. The maximum duty cycle is inversely proportional to the system input voltage. The higher the input voltage, the less the maximum duty cycle. The maximum duty cycle is internally limited to 80% at any switching frequency. MAXDTY is high impedance during shutdown. Bypass MAXDTY with a 2200pF capacitor.
7	7	$\overline{\text{EN}}$	Active-Low Enable Input. Drive $\overline{\text{EN}}$ to GND to enable the IC. Drive high to place the IC in shutdown mode.
8	—	SCOMP	Programmable Slope Compensation Input. Connect a resistor from SCOMP to GND to set the slope compensation.
—	8	PRAMP	Programmable Voltage-Mode Control-Ramp Input. Connect a resistor from PRAMP to GND to set the magnitude of the voltage ramp.
9	9	OPTO	Isolated Feedback Input. Connect to an optocoupler for an isolated power converter or connect to the output of a voltage-error amplifier for a nonisolated power converter for a feedback-error signal.
10	10	ILIM	Current-Limit Threshold Input. Connect to the center of a resistor-divider from REF to GND to set the current-limit threshold voltage.
11	11	SKTOFF	Current-Limit Off-Time Input. Connect a capacitor from SKTOFF to GND to set the current-limit off-time. Pull SKTOFF to REF through a 10k $\Omega$ resistor to latch off the IC after an overcurrent event.
12	12	CS	Current-Sense Input. Provides current-sense feedback for cycle-by-cycle current limit and is also the current-mode input for the MAX8540. Connect a current-sense resistor from CS to GND.
13	13	SKTON	Current-Limit On-Time Input. Connect a capacitor to ground to set the current-limit on-time.
14	14	GND	Ground
15	15	DRV	Gate Drive for External N-Channel Power MOSFET. Connect to the gate of an external MOSFET for low-power applications. Connect to the input of an external gate driver for high-power applications.
16	16	V <sub>CC</sub>	Voltage Supply for the IC. Operating input voltage range is 7.6V to 18V. Bypass V <sub>CC</sub> with a ceramic capacitor to GND.



# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

## Detailed Description

### Overvoltage Threshold

The MAX8540/MAX8541 include an overvoltage protection (OVP) feature that turns off the external MOSFET when the input voltage exceeds the user-set threshold. Connect a resistor-divider from the system input to GND with OV connected to the center to set the OVP trip point. The threshold voltage for OV is 3.021V (typ):

$$V_{IN(MAX)} = \left( \frac{R1 + R2}{R2} \right) \times V_{OV}$$

where  $V_{OV}$  is the OV threshold,  $V_{IN(MAX)}$  is the overvoltage trip point, R1 is the resistor from the system input to OV, and R2 is the resistor from OV to GND.

### Undervoltage Threshold

The MAX8540/MAX8541 also include an undervoltage (UV) sensing input. The IC holds the external MOSFET low until UV reaches its threshold (1.25V typ). Once the threshold has been reached, the circuit enters soft-start and brings the output into regulation. Connect a resistor-divider from the system input to GND with UV at the center to set the undervoltage protection (UVP) trip point.

$$V_{IN(MIN)} = \left( \frac{R3 + R4}{R4} \right) \times V_{UV}$$

where  $V_{UV}$  is the UV threshold,  $V_{IN(MIN)}$  is the UV trip point, R3 is the resistor from the system input to UV, and R4 is the resistor from UV to GND.

An alternate method used in the application circuits for setting the OV and UV trip points is demonstrated in Figure 1. Use 36.5k $\Omega$  for the bottom resistor (RC). RA and RB are calculated as follows:

$$RB = RC \times \left( \frac{V_{OV} \times V_{IN(MIN)}}{V_{UV} \times V_{IN(MAX)}} - 1 \right)$$

$$RA = \frac{RC \times V_{IN(MIN)}}{V_{UV}} - RB - RC$$

where  $V_{IN(MIN)}$  is the UV trip point,  $V_{IN(MAX)}$  is the OV trip point,  $V_{UV}$  is the UV threshold (1.25V typ), and  $V_{OV}$  is the OV threshold (3.021V typ). RA should consist of two equal-value resistors in series to protect against single-point failure.

Table 1. Typical Specifications of UV/OV and the Actual On/Off Hysteresis of Input Voltage

UV VOLTAGE SPECIFICATIONS (V)		V <sub>IN</sub> OFF WINDOW (LTP) (V)	V <sub>IN</sub> ON WINDOW (UTP) (V)
MIN	1.083	29.76	—
TYP	1.128	31.00	
MAX	1.173	32.24	
MIN	1.200	—	32.97
TYP	1.250		34.34
MAX	1.300		36.00
OV VOLTAGE SPECIFICATIONS (V)		V <sub>IN</sub> OFF WINDOW (UTP) (V)	V <sub>IN</sub> ON WINDOW (LTP) (V)
MIN	2.901	79.70	—
TYP	3.021	83.00	
MAX	3.142	86.32	
MIN	2.778	—	76.32
TYP	2.894		79.50
MAX	3.010		82.68

Assume that 1.250V at UV/OV is scaled to 34.34V for a 48V bus.

Table 2. Switching Frequency Selection

RFREQ/SYNC (k $\Omega$ )	SWITCHING FREQUENCY (kHz)
48.7	200
19.1	500
15.8	600
11.0	800
8.87	1000

### Switching Frequency and Synchronization

The MAX8540/MAX8541 oscillator operates in two modes: stand-alone or synchronized (sync). A single input, FREQ/SYNC, doubles as the attachment point for the frequency-programming resistor and as the synchronization input. The mode recognition is automatic, based on the signal applied to FREQ/SYNC.

In stand-alone mode, an external resistor connected from FREQ/SYNC to GND sets the operating frequency. A 1.25V source is internally applied to FREQ/SYNC and the oscillator frequency is proportional to the current out of FREQ/SYNC through the programming resistor.

# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

The MAX8540/MAX8541 also synchronize with an external oscillator. Drive FREQ/SYNC with a square wave through a series diode with a positive pulse width of at least 200ns and a minimum pulse amplitude of 3V, plus the  $V_F$  of the external diode. Alternatively, a 1.5V level-shifted external clock can be applied without the series diode. The maximum duty cycle of the external signal allowed is 55%. The MAX8540/MAX8541 synchronize to frequencies between 200kHz and 1MHz; however, the signal must be within  $\pm 30\%$  of the frequency set by the external resistor at FREQ/SYNC.

### Maximum Duty Cycle

Set the maximum duty cycle at the minimum system input voltage ( $V_{IN(MIN)}$ ) connecting a resistor from MAXDTY to GND. The maximum duty cycle is inversely proportional to the voltage at UV. As the voltage on UV increases, the duty cycle decreases. The maximum duty cycle is internally limited to 80% at all switching frequencies. The MAXDTY resistor is determined as:

$$R_{MAXDTY} = \frac{D_{MAX} \times (97.6 \times 10^3)}{60}$$

where  $D_{MAX}$  is the desired maximum duty cycle.

The range of valid resistor values for  $R_{MAXDTY}$  is from 24.3k $\Omega$  to 130k $\Omega$ .

### N-Channel MOSFET Driver

The DRV output drives an N-channel MOSFET in low-power applications. In high-power applications, the gate driver internal to the MAX8540/MAX8541 may not be capable of driving the external MOSFET efficiently and an external gate driver may be required. In this situation, connect DRV to the input of the external gate driver.

### Slope Compensation (MAX8540)

The MAX8540 is a current-mode device and requires slope compensation for proper operation. To provide slope compensation, connect a resistor from SCOMP to GND ( $R_{SCOMP}$ ). The value of  $R_{SCOMP}$  is determined as follows.

For applications using a synchronous rectifier in the output, set the slope compensation equal to the negative slope of the output inductor.  $R_{SCOMP}$  is equal to:

$$SCF = N \frac{V_{OUT}}{L1} R_{CS}$$

$$R_{SCOMP} = \frac{dV_{RAMP}}{dt} \times \frac{R_{SUM}}{2SCF}$$

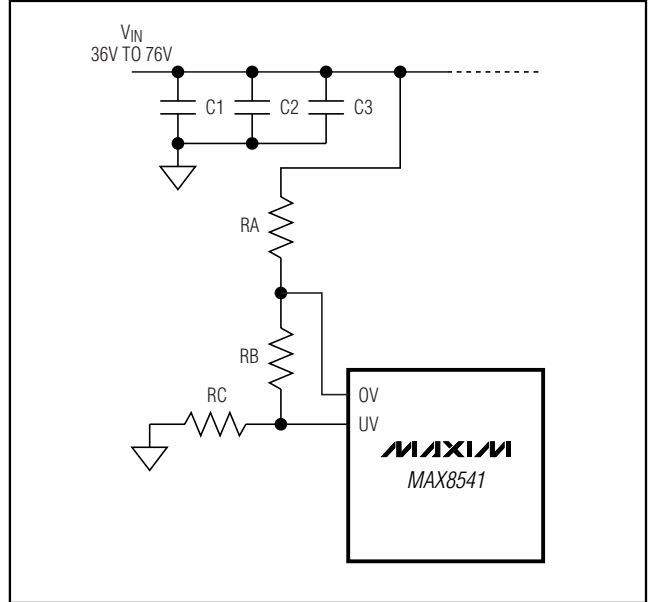


Figure 1. A Method to Set UV and OV Thresholds

where  $dV_{RAMP}/dt = 2.5V/(f_s)$ ,  $R_{SUM} = 25k\Omega$ ,  $N$  is the turns ratio of the primary to secondary,  $L1$  is the output inductance,  $V_{OUT}$  is the output voltage,  $f_s$  is the switching frequency, and  $R_{CS}$  is the current-sense resistance.

For applications where a diode is used in the output instead of the synchronous rectifier, the slope compensation resistor is then equal to:

$$SCF = N \frac{V_{OUT} + V_F}{L1} R_{CS}$$

$$R_{SCOMP} = \frac{dV_{RAMP}}{dt} \times \frac{R_{SUM}}{2SCF}$$

where  $dV_{RAMP}/dt = 2.5V/(f_s)$ ,  $R_{SUM} = 25k\Omega$ ,  $N$  is the turns ratio of the primary to secondary,  $L1$  is the output inductance,  $V_{OUT}$  is the output voltage,  $V_F$  is the diode voltage,  $f_s$  is the switching frequency, and  $R_{CS}$  is the current-sense resistance.

### Voltage-Ramp Amplitude (MAX8541)

The MAX8541 is a voltage-mode device and features adjustable voltage ramp. Connect a resistor from PRAMP to GND ( $R_{PRAMP}$ ) to set the voltage-ramp magnitude,  $V_M$ .

$$V_M = 1.25V \frac{25k\Omega}{R_{PRAMP}}$$

# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

where  $R_{PRAMP}$  is in  $k\Omega$ . The ramp-voltage magnitude is independent of frequency. The range of values for  $R_{PRAMP}$  is from  $12.4k\Omega$  to  $42k\Omega$ .

## Soft-Start

The soft-start feature allows converters built using the MAX8540/MAX8541 to apply power to the load in a controllable soft ramp, thus reducing startup surges and stresses. It also determines power-up sequencing when several converters are used.

Upon power turn-on, the soft-start pin acts as a current sink to discharge any capacitance connected to it. Once the voltage at  $V_{CC}$  has exceeded its lockout value, soft-start then charges the external capacitor ( $C_{SS}$ ), allowing the converter output voltage to ramp up. Full output voltage is reached in approximately  $440ms/\mu F$ .

## Current Limit

The MAX8540/MAX8541 utilize two current-limit schemes: cycle-by-cycle current limit and short-circuit current limit. Set the current-limit threshold using a resistor-divider from REF to GND with ILIM connected to the center. The current-limit threshold is determined as:

$$V_{ILIM} = \frac{R5}{R5 + R6} \times V_{REF}$$

where  $R5$  is the resistor from ILIM to GND and  $R6$  is the resistor from REF to ILIM. Use  $240k\Omega$  for  $R16$  and vary  $R23$  to change the threshold.

The CS signal provides feedback on the current ramp through the main external MOSFET. The voltage on CS is monitored by the IC. The cycle-by-cycle current limit abbreviates the on-time of the external MOSFET in the event that the voltage at CS is greater than the threshold voltage set by ILIM.

The current-limit feature protects against a hard short or overcurrent fault at the output by one of two selected protection modes: by latching off the output, or pulsing the output to reduce the average output current (hiccup mode).

To select latched mode, connect SKTOFF to REF. In this mode, if the hard short exists for the time period set by the capacitance at SKTON, the output is latched off. To unlatch the output, toggle  $\overline{EN}$  or cycle the input power to  $V_{CC}$ .

To select hiccup mode, connect capacitors to SKTON and SKTOFF to program the hiccup mode on- and off-times. When a cycle-by-cycle event is detected, the IC charges the capacitor at SKTON. The capacitor continues to charge as long as the CS voltage is greater than

the ILIM threshold voltage. Once the voltage on SKTON reaches its threshold voltage, the MAX8540/MAX8541 begin skipping switching cycles for a time determined by the capacitance connected to SKTOFF. Once this time period has elapsed, the IC begins to switch for the time period set by the capacitance connected to SKTON. This process continues until the output short is removed. See the *SKTON and SKTOFF* section for details on setting the hiccup-mode periods.

Connect SKTOFF to REF and SKTON to GND to disable the latched-mode and hiccup-mode protection, and operate continuously in cycle-by-cycle current-limit.

## PMW Comparator

The PWM comparator of the MAX8540 transforms the optocoupled error voltage ( $V_{OPTO}$ ) into a duty cycle by comparing the opto feedback-error voltage with a summed voltage. The summed voltage is the sum of the programmable slope compensation and the current-sense voltages. When the summed voltage exceeds the opto feedback error voltage, the gate-drive logic turns off the external MOSFET.

The PWM comparator in the MAX8541 compares  $V_{OPTO}$  with the programmable voltage ramp. When the voltage ramp exceeds  $V_{OPTO}$ , the gate-driver logic turns off the external MOSFET.

## SKTON and SKTOFF

The capacitance,  $C_{SKTON}$ , determines the time period allowed before the short-circuit current limit initiates. Once the CS voltage exceeds the ILIM threshold, the capacitor at SKTON begins to charge. The capacitor continues to charge until the SKTON threshold voltage is reached or the overcurrent event is removed. This feature allows for the higher currents required during startup with high-capacitance loads. Set  $C_{SKTON}$  to allow sufficient time for startup. The required capacitance at SKTON is determined as:

$$C_{SKTON} = t_{ON} / 10^3$$

where  $t_{ON}$  is in ms and  $C_{SKTON}$  is in  $\mu F$ . The allowable range for  $C_{SKTON}$  is  $100pF$  to  $0.01\mu F$ .

The capacitance at SKTOFF determines the time period that the external MOSFET is turned off during an overcurrent event. Once the SKTON time period is exceeded, the SKTOFF capacitor charges. Once  $V_{SKTOFF}$  reaches its threshold, the IC begins to switch again.  $C_{SKTOFF}$  is determined as:

$$C_{SKTOFF} = t_{OFF} / 10^3$$

where  $t_{OFF}$  is in ms and  $C_{SKTOFF}$  is in  $\mu F$ . The allowable range for  $C_{SKTOFF}$  is  $1000pF$  to  $1\mu F$ .

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Pull V<sub>SKTOFF</sub> to V<sub>REF</sub> through a 10kΩ pullup resistor to enable the latch-off feature. In this mode, once the SKTON time has elapsed, the IC is latched off. The circuit remains off until  $\overline{\text{EN}}$  is toggled, or the input power is toggled.

### Soft-Start Capacitor Selection

During startup, the capacitor at soft-start is charged using a 5μA current source. Once the voltage at soft-start reaches the threshold voltage (2V typ), the IC switches normally. Use a low-ESR ceramic capacitor placed as close as possible to the IC at soft-start. The value is determined as follows:

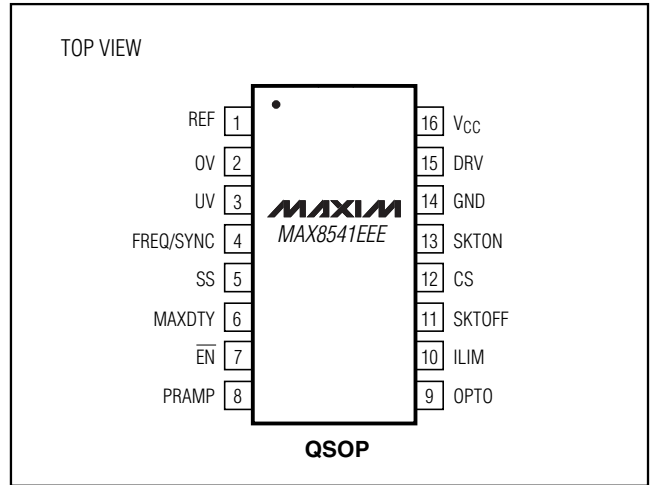
$$C_{SS} = \frac{t_{SS}}{530}$$

where t<sub>SS</sub> is the desired soft-start period in ms and C<sub>SS</sub> is in μF.

### Applications Information

Refer to the following application notes for the MAX8540/MAX8541 application circuits and applications information: *50W Current-Mode Forward Converter Design with the MAX8540* and *50W Voltage-Mode Forward Converter Design with the MAX8541*.

### Pin Configurations (continued)



### Chip Information

TRANSISTOR COUNT: 2704  
PROCESS: BiCMOS

# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

## Functional Diagrams

**MAX8540/MAX8541**

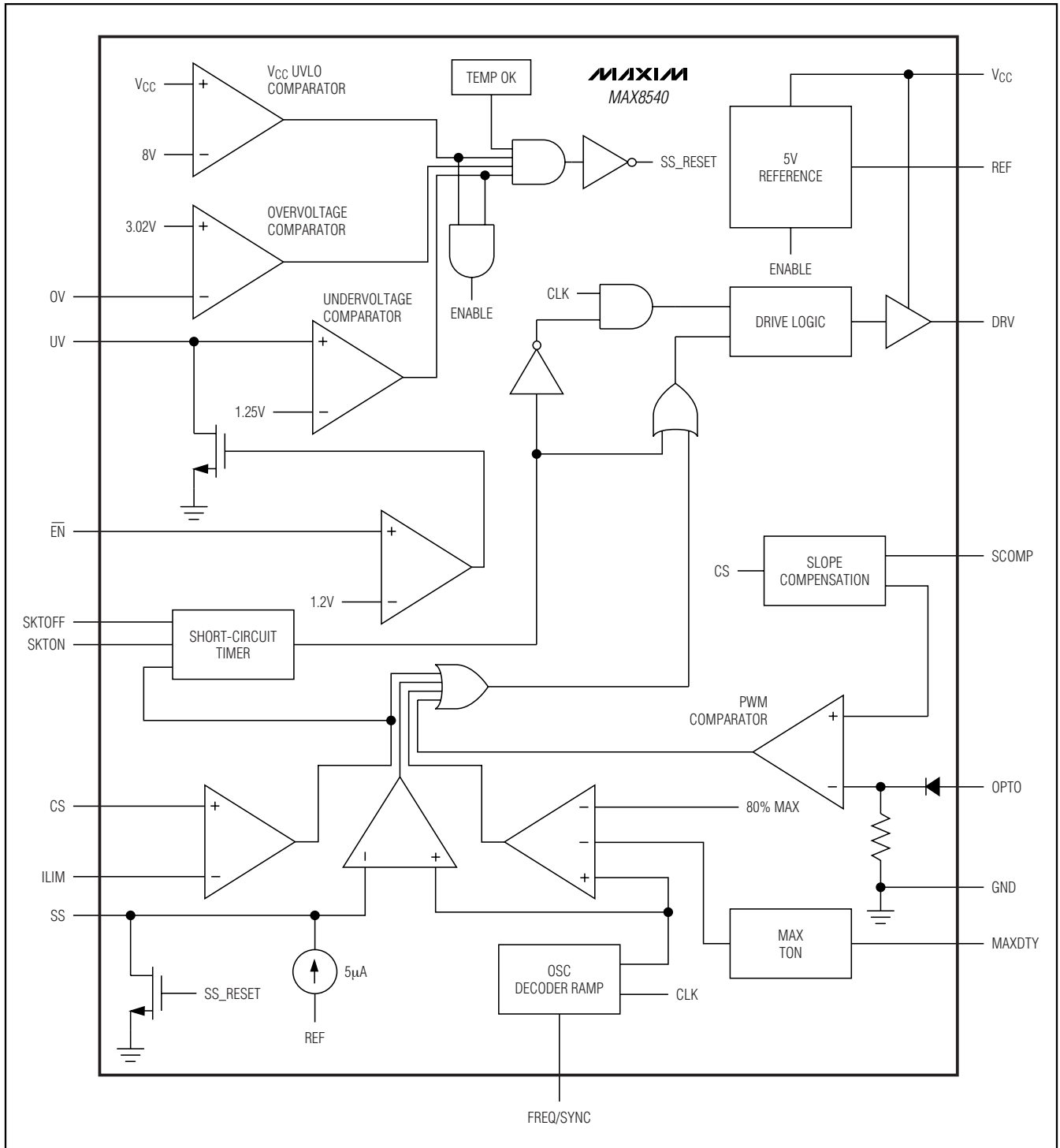


Figure 2. MAX8540 Functional Diagram

# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

## Functional Diagrams (continued)

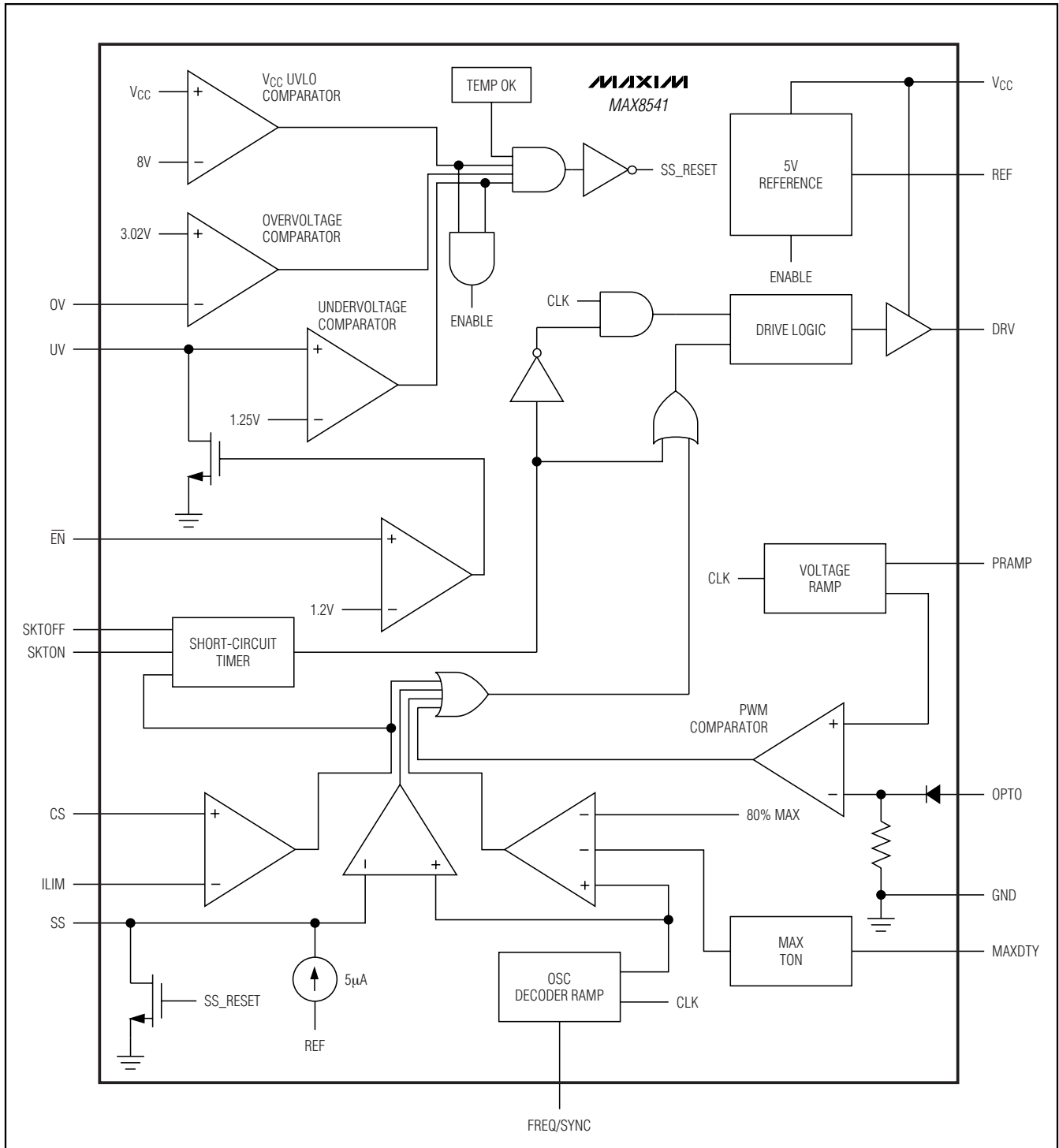
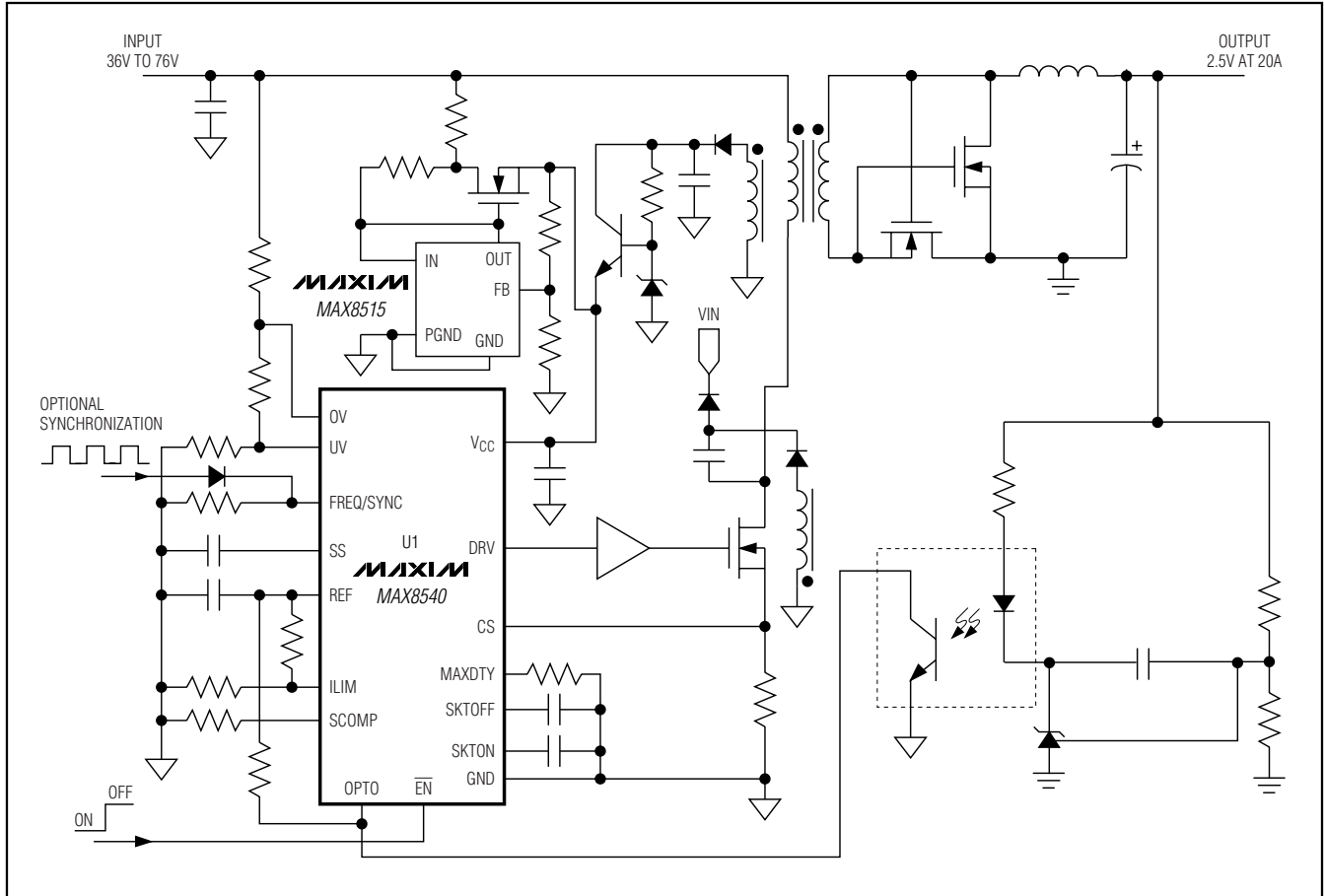


Figure 3. MAX8541 Functional Diagram

# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

## Typical Operating Circuit

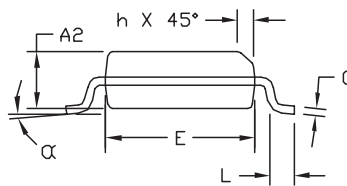
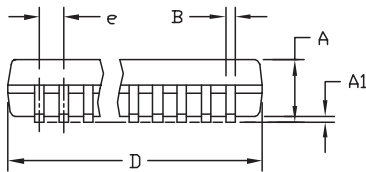
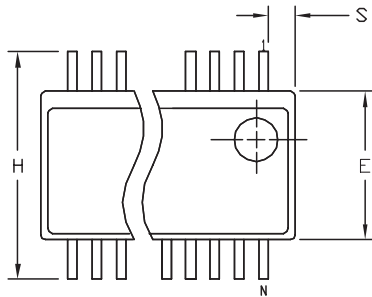
MAX8540/MAX8541



# Synchronizable, High-Frequency Current- and Voltage-Mode PWM Controllers for Isolated Supplies

## Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to [www.maxim-ic.com/packages](http://www.maxim-ic.com/packages).



DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	.053	.069	1.35	1.75
A1	.004	.010	.102	.254
A2	.049	.065	1.245	1.651
B	.008	.012	0.20	0.30
C	.0075	.0098	0.191	0.249
D	SEE VARIATIONS			
E	.150	.157	3.81	3.99
e	.025 BSC		0.635 BSC	
H	.230	.244	5.84	6.20
h	.010	.016	0.25	0.41
L	.016	.035	0.41	0.89
N	SEE VARIATIONS			
α	0°	8°	0°	8°

VARIAIONS:

DIM	INCHES		MILLIMETERS		N
	MIN.	MAX.	MIN.	MAX.	
D	.189	.196	4.80	4.98	16 AB
S	.0020	.0070	0.05	0.18	
D	.337	.344	8.56	8.74	20 AD
S	.0500	.0550	1.270	1.397	
D	.337	.344	8.56	8.74	24 AE
S	.0250	.0300	0.635	0.762	
D	.386	.393	9.80	9.98	28 AF
S	.0250	.0300	0.635	0.762	

NOTES:

- 1). D & E DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
- 2). MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .006" PER SIDE.
- 3). CONTROLLING DIMENSIONS: INCHES.
- 4). MEETS JEDEC MO137.

<small>PROPRIETARY INFORMATION</small>			
<small>TITLE:</small> PACKAGE OUTLINE, QSOP .150", .025" LEAD PITCH			
<small>APPROVAL</small>	<small>DOCUMENT CONTROL NO.</small> 21-0055	<small>REV.</small> F	<small>1/1</small>

QSOP.EPS

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