

## 500-kHz Half-Bridge DC/DC Controller with Integrated Secondary Synchronous Rectification Drivers

### DESCRIPTION

Si9122 is a dedicated half-bridge IC ideally suited to fixed telecom applications where efficiency is required at low output voltages (e.g. < 3.3 V). Designed to operate within the fixed telecom voltage range of 33 to 72 V, the IC is capable of controlling and driving both the low and high-side switching devices of a half bridge circuit and also controlling the switching devices on the secondary side of the bridge. Due to the very low on-resistance of the secondary MOSFETs, a significant increase in the efficiency can be achieved as compared with conventional Schottky diodes. Control of the secondary devices is by means of a pulse transformer and a pair of inverters. Such a system has efficiencies well in excess of 90 % even for low output voltages. On-chip control of the dead time delays between the primary and secondary synchronous signals keep efficiencies high and prevent accidental destruction of the power transformer. An external resistor sets the switching frequency from 200 kHz to 625 kHz.

Si9122 has advanced current monitoring and control circuitry which allow the user to set the maximum current in the primary circuit. Such a feature acts as protection against output shorting and also provides constant current into large capacitive loads during start-up or when paralleling power supplies. Current sensing is by means of a sense resistor on the low-side primary device.

### FEATURES

- 12 V to 72 V input voltage range
- Integrated half-bridge primary drivers (1 A drive capability)
- Secondary synchronous signals with programmable deadtime delay
- Voltage mode control
- Voltage feedforward compensation
- High voltage pre-regulator operates during start-up
- Current sensing on low-side primary device
- Frequency foldback eliminates constant current tail
- Advanced maximum current control during start-up and shorted load
- Low input voltage detection
- Programmable soft-start function
- Over temperature protections



RoHS  
COMPLIANT

### APPLICATIONS

- Network cards
- Power supply modules

### FUNCTIONAL BLOCK DIAGRAM

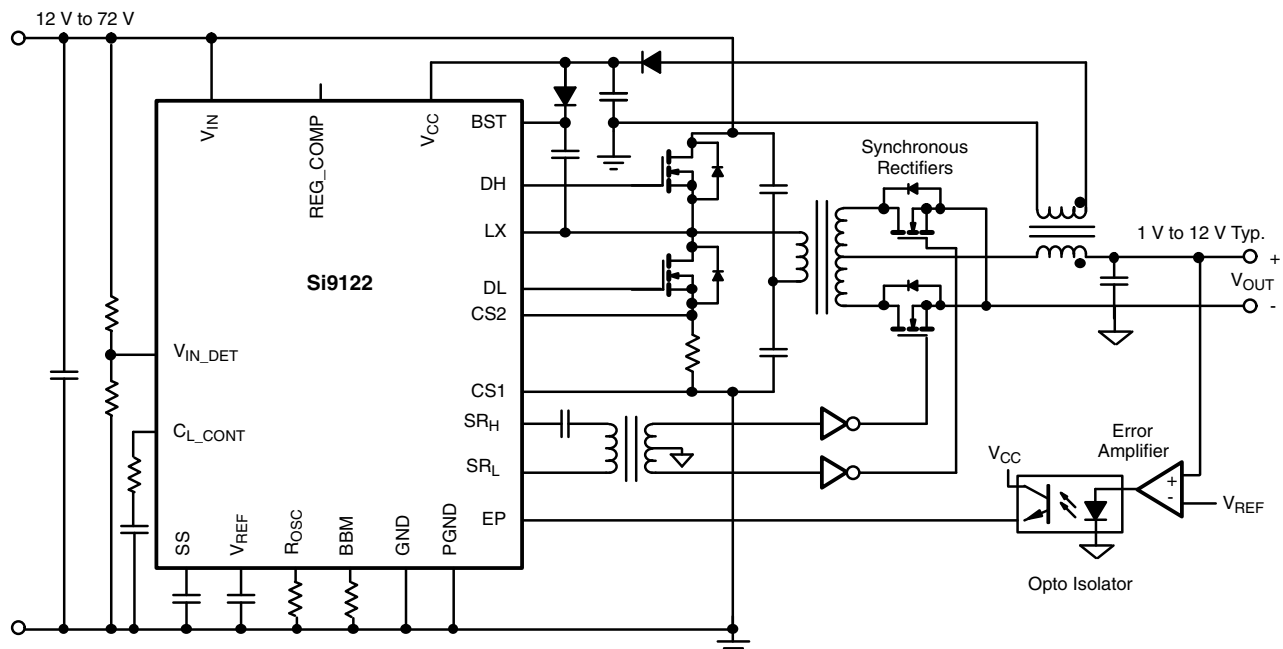


Figure 1.

## TECHNICAL DESCRIPTION

Si9122 is a voltage mode controller for the half-bridge topology. With 100 V depletion mode MOSFET capability, the Si9122 is capable of powering directly from the high voltage bus to  $V_{CC}$  through an external PNP pass transistor, or may be powered through an external regulator directly through the  $V_{CC}$  pin. With PWM control, Si9122 provides peak efficiency throughout the entire line and load range. In order to simplify the traditional secondary synchronous rectification, Si9122 provides intelligent gate drive signals to control the secondary MOSFETs. With independent gate drive signals from the controller, transformer design is no longer limited by the gate to a source rating of the MOSFETs. Si9122 provides constant  $V_{GS}$  voltage, independent of line voltage to minimize the gate charge loss as well as conduction loss. A break-before-make function is included to

prevent shoot through current or transformer shorting. Adjustable Break-Before-Make time is incorporated into the IC and is programmable by an external resistor value.

Si9122 is packaged in TSSOP-20 and MLP65-20 packages. Both TSSOP-20 and MLP65-20 packages are available in lead (Pb)-free option. In order to satisfy the stringent ambient temperature requirements, Si9122 is rated to handle the industrial temperature range of  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ . When a situation arises which results in a rapid increase in primary (or secondary current) such as output shorted or start-up with a large output capacitor, control of the PWM generator is handed over to the current loop. Monitoring of the load current is by means of a sense resistor on the primary low-side switch.

## DETAILED BLOCK DIAGRAM

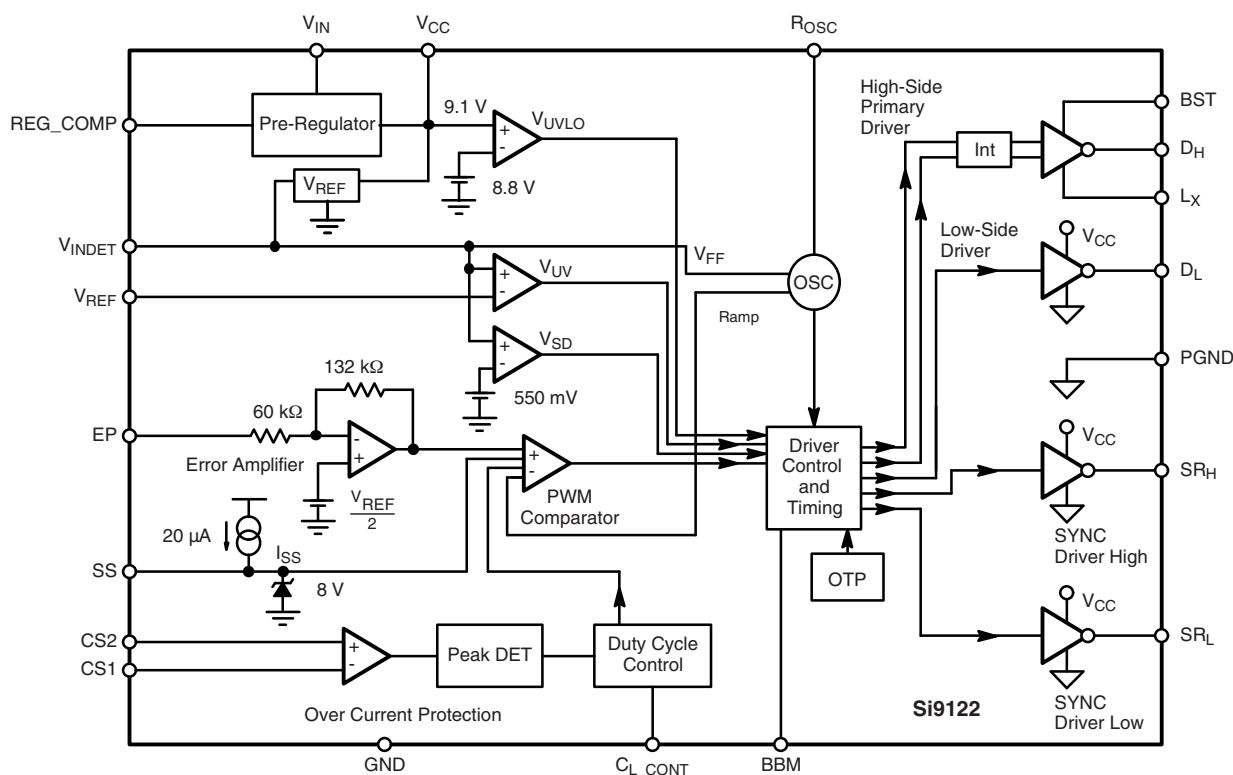


Figure 2.



<b>ABSOLUTE MAXIMUM RATINGS</b> All voltages referenced to GND = 0 V			
Parameter		Limit	Unit
$V_{IN}$ (Continuous)		75	V
$V_{IN}$ (100 ms)		100	
$V_{CC}$		14.5	
$V_{BST}$	Continuous	90	
	100 ms	115	
$V_{LX}$		75	
$V_{BST} - V_{LX}$		15	
$V_{REF}$ $R_{OSC}$		- 0.3 to $V_{CC} + 0.3$	
Logic Inputs		- 0.3 to $V_{CC} + 0.3$	
Analog Inputs		- 0.3 to $V_{CC} + 0.3$	
HV Pre-Regulator Input Current (Continuous)		5	mA
Storage Temperature		- 65 to 150	°C
Operating Junction Temperature		150	
Power Dissipation <sup>a</sup>	TSSOP-20	850	mW
	MLP65-20	2500	
Thermal Impedance ( $\Theta_{JA}$ )	TSSOP-20 <sup>b</sup>	75	°C/W
	MLP65-20 <sup>c</sup>	38	

Notes:

a. Device Mounted on JEDEC compliant 1S2P test board.

b. Derate - 14 mW/°C above 25 °C.

c. Derate - 26 mW/°C above 25 °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.

<b>RECOMMENDED OPERATING RANGE</b> All voltages referenced to GND = 0 V			
Parameter		Limit	Unit
$V_{IN}$		12 to 72	V
$C_{VIN1}    C_{VIN2}$		100 $\mu$ F/ESR $\leq$ 100 m $\Omega$ , 0.1 $\mu$ F	
$V_{CC}$ Operating		10 to 13.2	V
$C_{VCC}$		4.7	$\mu$ F
$f_{OSC}$		200 to 600	kHz
$R_{OSC}$		24 to 72	k $\Omega$
$R_{BBM}$		22 to 50	
$C_{BBM}^h$		> 680	pF
$C_{SS}$		4.7	nF
$C_{REF}$		0.1	$\mu$ F
$C_{BOOST}$		0.1	
$C_{LOAD}$		150	
Analog Inputs		0 V to $V_{CC} - 2$ V	V
Digital Inputs		0 V to $V_{CC}$	
Reference Voltage Output Current		0 to 2.5	mA

SPECIFICATIONS <sup>a</sup>							
Parameter	Symbol	Test Conditions Unless Otherwise Specified f <sub>NOM</sub> = 500 kHz, V <sub>IN</sub> = 72 V V <sub>INDET</sub> = 7.2 V; 10 V ≤ V <sub>CC</sub> ≤ 13.2 V		Limits - 40 to 85 °C			Unit
				Min. <sup>b</sup>	Typ. <sup>c</sup>	Max. <sup>b</sup>	
Reference (3.3 V)							
Output Voltage	V <sub>REF</sub>	V <sub>CC</sub> = 12 V, 25 °C Load = 0 mA		3.2	3.3	3.4	V
Short Circuit Current	I <sub>SREF</sub>	V <sub>REF</sub> = 0 V				- 50	mA
Load Regulation	dVr/dir	I <sub>REF</sub> = 0 to - 2.5 mA			- 30	- 75	mV
Power Supply Rejection	PSRR	at 100 Hz			60		dB
Oscillator							
Accuracy (1 % R <sub>OSC</sub> )		R <sub>OSC</sub> = 30 kΩ, f <sub>NOM</sub> = 500 kHz		- 20		20	%
Max Frequency <sup>i</sup>	F <sub>MAX</sub>	R <sub>OSC</sub> = 22.6 kΩ		500	625	750	kHz
Foldback Frequency <sup>d</sup>	F <sub>FOBK</sub>	f <sub>NOM</sub> = 500 kHz, V <sub>CS2</sub> - V <sub>CS1</sub> > 150 mV			100		
Error Amplifier							
Input Bias Current	I <sub>BIAS</sub>	V <sub>EP</sub> = 0 V		- 40		- 15	μA
Gain	A <sub>V</sub>				- 2.2		V/V
Bandwidth	BW				5		MHz
Power Supply Rejection	PSRR	at 100 Hz			60		dB
Slew Rate	SR				0.5		V/μs
Current Sense Amplifier							
Input Voltage CM Range	V <sub>CM</sub>	V <sub>CS1</sub> - GND, V <sub>CS2</sub> - GND			± 150		mV
Input Amplifier Gain	A <sub>VOL</sub>				17.5		dB
Input Amplifier Bandwidth	BW				5		MHz
Input Amplifier Offset Voltage	V <sub>OS</sub>				± 5		mV
CL_CONT Current	I <sub>CL_CONT</sub>	dV <sub>CS</sub> = 0			120		μA
		dV <sub>CS</sub> = 100 mV			0		
		dV <sub>CS</sub> = 170 mV			> 2		mA
Lower Current Limit Threshold	V <sub>TLCL</sub>	I <sub>PD</sub> = I <sub>PU</sub> - I <sub>CL_CONT</sub> = 0 See Figure 6			100		mV
Upper Current Limit Threshold	V <sub>THCL</sub>	I <sub>PD</sub> > 2 mA			150		
Hysteresis		I <sub>PU</sub> < 500 μA			- 50		
CL_CONT Clamp Level	C <sub>L_CONT(min)</sub>	I <sub>PU</sub> = 500 μA		0.6		1.5	V
PWM Operation							
Duty Cycle <sup>e</sup>	D <sub>MAX</sub>	f <sub>OSC</sub> = 500 kHz	V <sub>EP</sub> = 0 V	90	92	95	%
	D <sub>MIN</sub>		V <sub>EP</sub> = 1.75 V		< 15		
			V <sub>CS2</sub> - V <sub>CS1</sub> > 150 mV			3	
Pre-Regulator							
Input Voltage	+ V <sub>IN</sub>	I <sub>IN</sub> = 10 μA				72	V
Input Leakage Current	I <sub>LKG</sub>	V <sub>IN</sub> = 72 V, V <sub>CC</sub> > V <sub>REG</sub>				10	μA
Regulator Bias Current	I <sub>REG1</sub>	V <sub>IN</sub> = 72 V, V <sub>INDET</sub> < V <sub>SD</sub>			86	200	
	I <sub>REG2</sub>	V <sub>IN</sub> = 72 V, V <sub>INDET</sub> > V <sub>REF</sub>			8	14	mA
Regulator_Comp	I <sub>SOURCE</sub>	V <sub>CC</sub> = 12 V		- 29	- 19	- 9	μA
	I <sub>SINK</sub>			50	82	110	
Pre-Regulator Drive Capacity	I <sub>START</sub>	V <sub>CC</sub> < V <sub>REG</sub>		20			mA

**SPECIFICATIONS<sup>a</sup>**

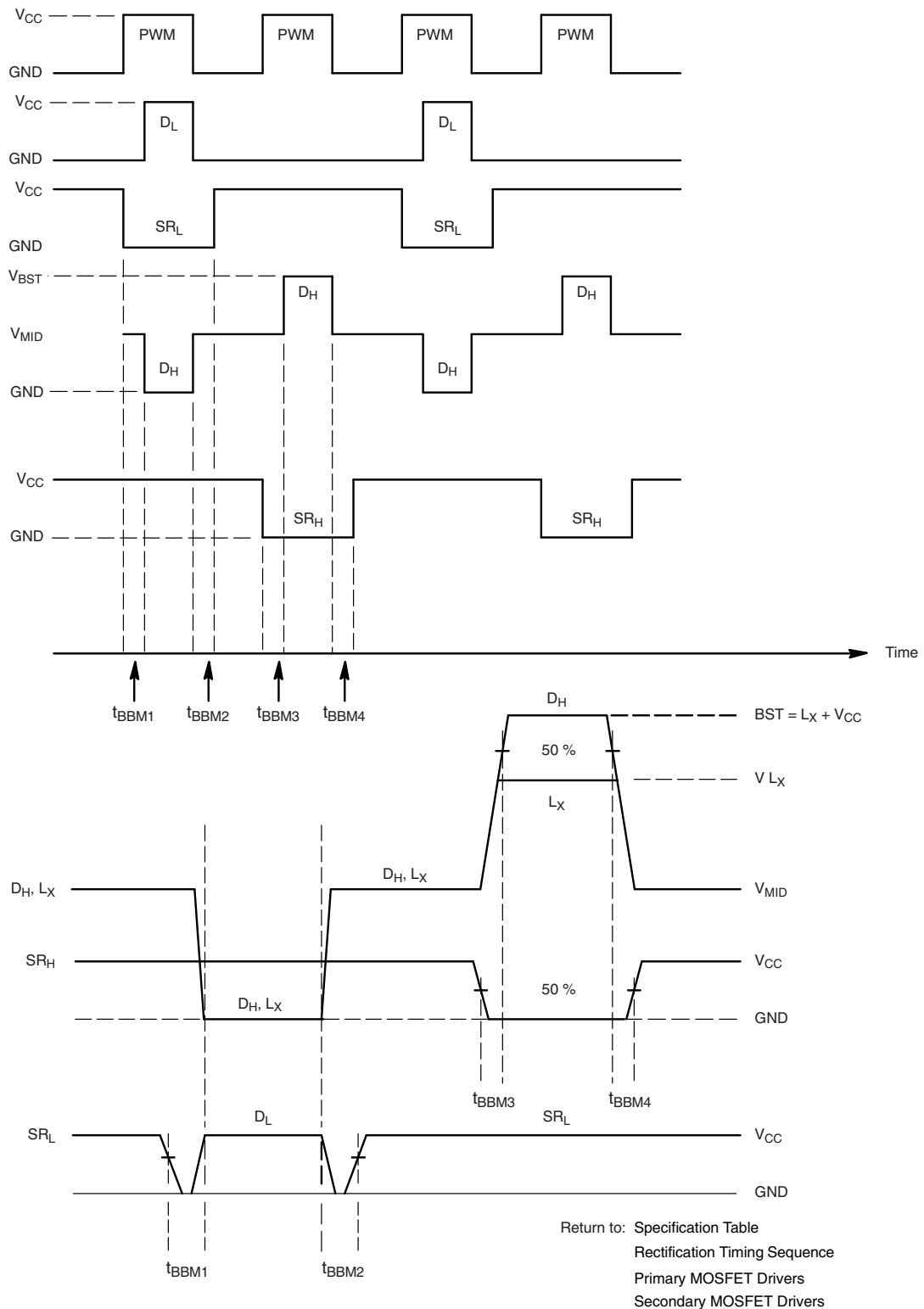
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				Min. <sup>b</sup>	Typ. <sup>c</sup>	Max. <sup>b</sup>	
Pre-Regulator							
V <sub>CC</sub> Pre-Regulator Turn Off Threshold Voltage	V <sub>REG1</sub>	V <sub>INDET</sub> > V <sub>REF</sub>	T <sub>A</sub> = 25 °C	7.4	9.1	10.4	V
	V <sub>REG2</sub>	V <sub>INDET</sub> = 0 V		8.5	9.1	9.7	
Undervoltage Lockout	V <sub>UVLO</sub>	V <sub>CC</sub> Rising	T <sub>A</sub> = 25 °C	7.15	8.8	9.8	
				8.1	8.8	9.3	
V <sub>UVLO</sub> Hysteresis <sup>g</sup>	V <sub>UVLOHYS</sub>				0.5		
Soft-Start							
Soft-Start Current Output	I <sub>SS</sub>	Start-Up Condition		12	20	28	μA
Soft-Start Completion Voltage	V <sub>SS_COMP</sub>	Normal Operation		7.35	8.05	8.85	V
Shutdown							
V <sub>INDET</sub> Shutdown FN	V <sub>SD</sub>	V <sub>INDET</sub> Rising		350	550	720	mV
V <sub>INDET</sub> Hysteresis		V <sub>INDET</sub>			200		
V <sub>INDET</sub> Input Threshold Voltages							
V <sub>INDET</sub> - V <sub>IN</sub> Under Voltage	V <sub>UV</sub>	V <sub>INDET</sub> Rising		3.13	3.3	3.46	V
V <sub>UV</sub> Hysteresis		V <sub>INDET</sub>		0.23	0.3	0.35	
Over Temperature Protection							
Activating Temperature		T <sub>J</sub> Increasing			160		°C
De-Activating Temperature		T <sub>J</sub> Decreasing			130		
Converter Supply Current (V <sub>CC</sub> )							
Shutdown	I <sub>CC1</sub>	Shutdown, V <sub>INDET</sub> = 0 V		50		350	μA
Switching Disabled	I <sub>CC2</sub>	V <sub>INDET</sub> < V <sub>REF</sub>		4	8	12	mA
Switching w/o Load	I <sub>CC3</sub>	V <sub>INDET</sub> > V <sub>REF</sub> , f <sub>NOM</sub> = 500 kHz		5	10	15	
Switching with C <sub>LOAD</sub>	I <sub>CC4</sub>	V <sub>CC</sub> = 12 V, C <sub>DH</sub> = C <sub>DL</sub> = 3 nF C <sub>SRH</sub> = C <sub>SRL</sub> = 0.3 nF			21		
Output MOSFET DH Driver (High-Side)							
Output High Voltage	V <sub>OH</sub>	Sourcing 10 mA		V <sub>BST</sub> - 0.3			V
Output Low Voltage	V <sub>OL</sub>	Sinking 10 mA				V <sub>LX</sub> + 0.3	
Boost Current	I <sub>BST</sub>	V <sub>LX</sub> = 72 V, V <sub>BST</sub> = V <sub>LX</sub> + V <sub>CC</sub>		1.3	1.9	2.7	mA
L <sub>X</sub> Current	I <sub>LX</sub>	V <sub>LX</sub> = 72 V, V <sub>BST</sub> = V <sub>LX</sub> + V <sub>CC</sub>		- 1.3	- 0.7	- 0.4	
Peak Output Source	I <sub>SOURCE</sub>	V <sub>CC</sub> = 10 V			- 1.0	- 0.75	A
Peak Output Sink	I <sub>SINK</sub>			0.75	1.0		
Rise Time	t <sub>r</sub>	C <sub>DL</sub> = 3 nF			35		ns
Fall Time	t <sub>f</sub>				35		
Output MOSFET DL Driver (Low-Side)							
Output High Voltage	V <sub>OH</sub>	Sourcing 10 mA		V <sub>CC</sub> - 0.3			V
Output Low Voltage	V <sub>OL</sub>	Sinking 10 mA				0.3	
Peak Output Source	I <sub>SOURCE</sub>	V <sub>CC</sub> = 10 V			- 1.0	- 0.75	A
Peak Output Sink	I <sub>SINK</sub>			0.75	1.0		
Rise Time	t <sub>r</sub>	C <sub>DH</sub> = 3 nF			35		ns
Fall Time	t <sub>f</sub>				35		

SPECIFICATIONS <sup>a</sup>						
Parameter	Symbol	Test Conditions Unless Otherwise Specified $f_{\text{NOM}} = 500 \text{ kHz}$ , $V_{\text{IN}} = 72 \text{ V}$ $V_{\text{INDET}} = 7.2 \text{ V}$ ; $10 \text{ V} \leq V_{\text{CC}} \leq 13.2 \text{ V}$	Limits - 40 to 85 °C			Unit
			Min. <sup>b</sup>	Typ. <sup>c</sup>	Max. <sup>b</sup>	
Synchronous Rectifier (SRH, SRL) Drivers						
Output High Voltage	$V_{\text{OH}}$	Sourcing 10 mA	$V_{\text{CC}} - 0.4$			V
Output Low Voltage	$V_{\text{OL}}$	Sinking 10 mA			0.4	
Break-Before-Make Time <sup>f</sup>	$t_{\text{BBM1}}$	$T_{\text{A}} = 25 \text{ }^{\circ}\text{C}$ , $R_{\text{BBM}} = 33 \text{ k}\Omega$ , See Figure 3		55		ns
	$t_{\text{BBM2}}$			40		
	$t_{\text{BBM3}}$	$T_{\text{A}} = 25 \text{ }^{\circ}\text{C}$ , $R_{\text{BBM}} = 33 \text{ k}\Omega$ , $L_{\text{X}} = 72 \text{ V}$		35		
	$t_{\text{BBM4}}$			55		
Peak Output Source	$I_{\text{SOURCE}}$	$V_{\text{CC}} = 10 \text{ V}$		- 100		mA
Peak Output Sink	$I_{\text{SINK}}$			100		
Rise Time	$t_{\text{r}}$	$C_{\text{SRH}} = C_{\text{SRL}} = 0.3 \text{ nF}$		35		ns
Fall Time	$t_{\text{f}}$			35		
Voltage Mode						
Error Amplifier	$t_{\text{d1DH}}$	Input to High-Side Switch Off		< 200		ns
	$t_{\text{d2DL}}$	Input to Low-Side Switch Off		< 200		
Current Mode						
Current Amplifier	$t_{\text{d3DH}}$	Input to High-Side Switch Off		< 200		ns
	$t_{\text{d4DL}}$	Input to Low-Side Switch Off		< 200		

## Notes:

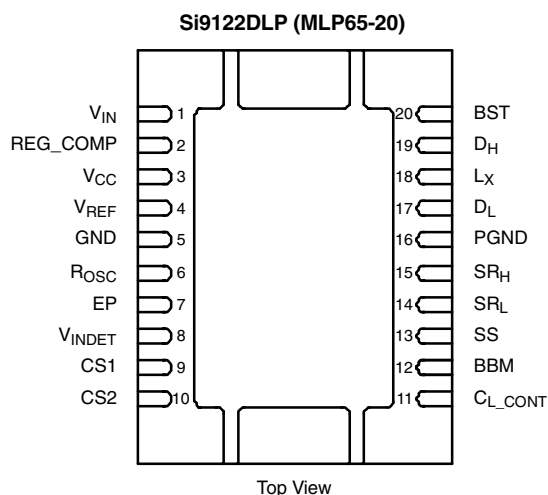
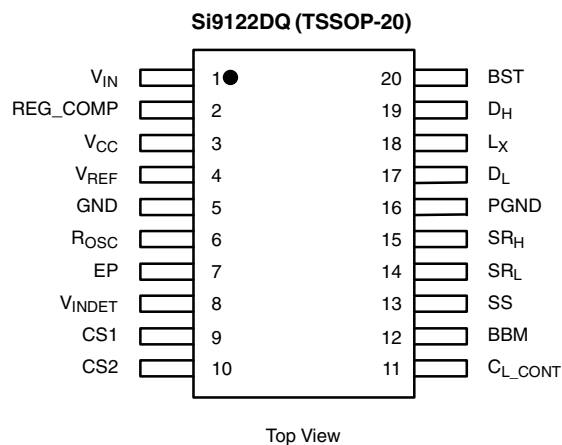
- Refer to PROCESS OPTION FLOWCHART for additional information.
- The algebraic convention whereby the most negative value is a minimum and the most positive a maximum (- 40 °C to 85 °C).
- Typical values are for DESIGN AID ONLY, not guaranteed nor subject to production testing.
- $F_{\text{MIN}}$  when  $V_{\text{CL\_CONT}}$  at clamp level. Typical foldback frequency change + 20 %, - 30 % over temperature.
- Measured on SRL or SRH outputs.
- See figure 3 for Break-Before-Make time definition.
- $V_{\text{UVLO}}$  tracks  $V_{\text{REG1}}$  by a diode drop.
- $C_{\text{BBM}}$  may be required to reduce noise into BBM pin for non-optimum layout.
- Guaranteed by design and characterization, not tested in production.

# TIMING DIAGRAM FOR MOS DRIVERS



**Figure 3.**

## PIN CONFIGURATION



## ORDERING INFORMATION

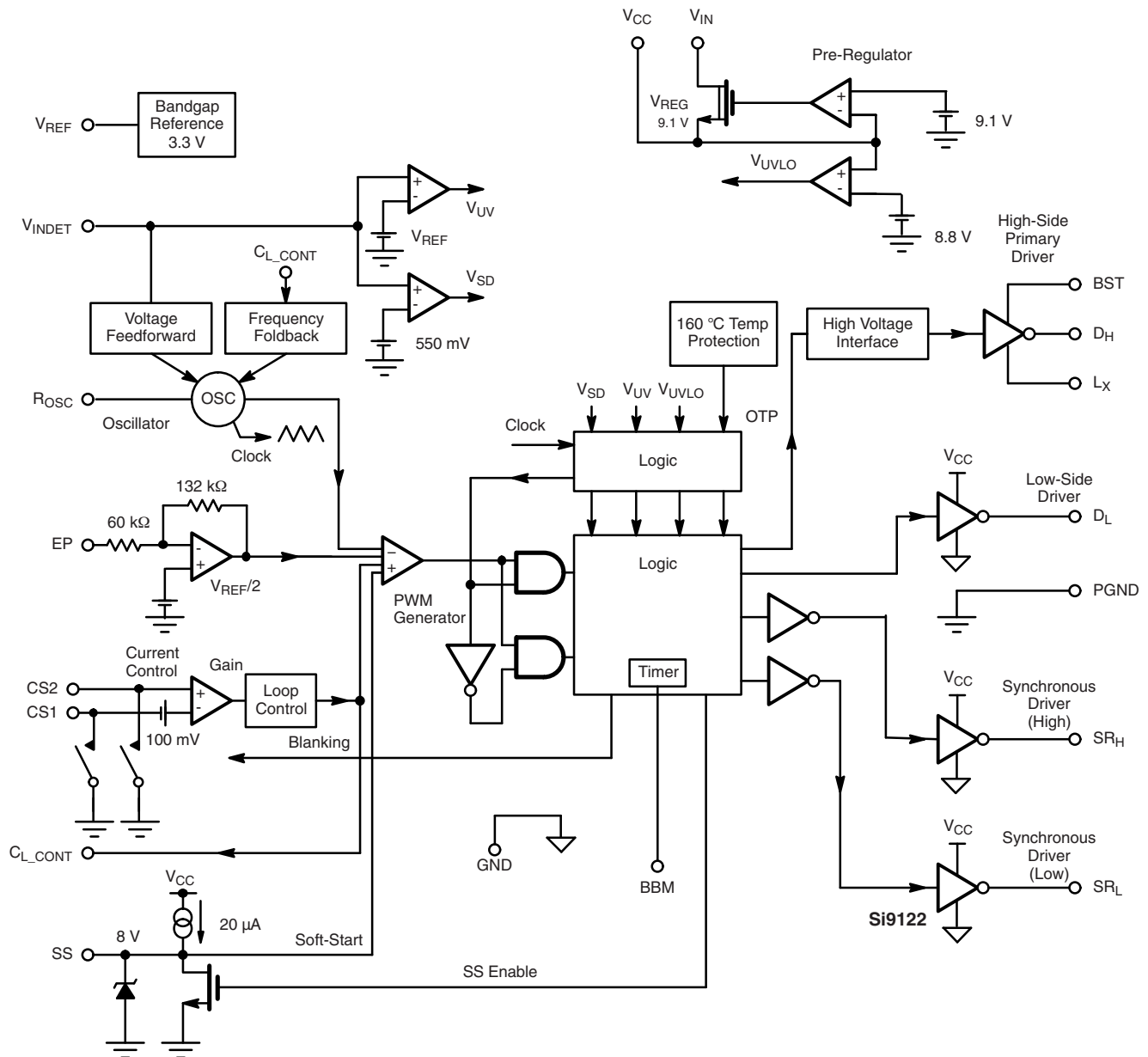
Lead (Pb)-free Part Number	Temperature Range	Package
Si9122DQ-T1-E3	- 40 °C to 85 °C	TSSOP-20
Si9122DLP-T1-E3		MLP65-20

Eval Kit	Temperature Range	Board Type
Si9122DB Issue 3	- 10 °C to 70 °C	Surface Mount and Thru-Hole

## PIN DESCRIPTION

Pin Number	Name	Function
1	V <sub>IN</sub>	Input supply voltage for the start-up circuit
2	REG_COMP	Control signal for an external pass transistor
3	V <sub>CC</sub>	Supply voltage for internal circuitry
4	V <sub>REF</sub>	3.3 V reference, decoupled with 1 μF capacitor
5	GND	Ground
6	R <sub>OSC</sub>	External resistor connection to oscillator
7	EP	Voltage control input
8	V <sub>INDET</sub>	V <sub>IN</sub> under voltage detect and shutdown function input. Shuts down or disables switching when V <sub>INDET</sub> falls below preset threshold voltages and provides the feed forward voltage.
9	CS1	Current limit amplifier negative input
10	CS2	Current limit amplifier positive input
11	C <sub>L_CONT</sub>	Current limit compensation
12	BBM	Programmable break-before-make time connection to an external resistor to set time delay
13	SS	Soft-start control - external capacitor connection
14	SR <sub>L</sub>	Signal transformer drive, sequenced with the primary side
15	SR <sub>H</sub>	Signal transformer drive, sequenced with the primary side
16	PGND	Power ground
17	D <sub>L</sub>	Low-side gate drive signal - primary
18	L <sub>X</sub>	High-side source and transformer connection node
19	D <sub>H</sub>	High-side gate drive signal - primary
20	BST	Bootstrap voltage to drive the high-side N-Channel MOSFET switch





**Figure 4. Detailed Functional Block**

## DETAILED OPERATION

### Start-Up

When  $V_{INEXT}$  rises above 0 V, the internal pre-regulator begins to charge up the  $V_{CC}$  capacitor. Current into the external  $V_{CC}$  capacitor is limited to typically 40 mA by the internal DMOS device. When  $V_{CC}$  exceeds the UVLO voltage of 8.8 V a soft-start cycle of the switch mode supply is initiated. The  $V_{CC}$  supply continues to be charged by the pre-regulator until  $V_{CC}$  equals  $V_{REG}$ . During this period, between  $V_{UVLO}$  and  $V_{REG}$ , excessive load current will result in  $V_{CC}$  falling below  $V_{UVLO}$  and stopping switch mode operation. This situation is avoided by the hysteresis between  $V_{REG}$  and  $V_{UVLO}$  and correct sizing of the  $V_{CC}$

capacitor, bootstrap capacitor and the soft-start capacitor. The value of the  $V_{CC}$  capacitor should therefore be chosen to be capable of maintaining switch mode operation until the  $V_{CC}$  can be supplied from the external circuit (e.g via a power transformer winding and zener regulator). Feedback from the output of the switch mode supply charges  $V_{CC}$  above  $V_{REG}$  and fully disconnects the pre-regulator, isolating  $V_{CC}$  from  $V_{IN}$ .  $V_{CC}$  is then maintained above  $V_{REG}$  for the duration of switch mode operation. In the event of an over voltage condition on  $V_{CC}$ , an internal voltage clamp turns on at 14.5 V to shunt excessive current to GND.

Care needs to be taken if there is a delay prior to the external circuit feeding back to the  $V_{CC}$  supply. To prevent excessive power dissipation within the IC it is advisable to use an external PNP device. A pin has been incorporated on the IC, (REG\_COMP) to provide compensation when employing the external device. In this case the  $V_{IN}$  pin is connected to the base of the PNP device and controls the current, while the REG\_COMP pin determines the frequency compensation of the circuit. The value of the REG\_COMP capacitor cannot be too big, otherwise it will slow down the response of the pre-regulator in the case that fault situations occur and pre-regulator needs to be turned on again. To understand the operation please refer to Figure 5.

The soft-start circuit is designed for the dc-dc converter to start-up in an orderly manner and reduce component stress on the IC. This feature is programmable by selecting an external  $C_{SS}$ . An internal 20  $\mu$ A current source charges  $C_{SS}$  from 0 V to the final clamped voltage of 8 V. In the event of UVLO or shutdown,  $V_{SS}$  will be held low ( $< 1$  V) disabling driver switching. To prevent oscillations, a longer soft-start time may be needed for high capacitive loads and high peak output current applications.

#### Reference

The reference voltage of Si9122 is set at 3.3 V. The reference voltage is de-coupled externally with 0.1  $\mu$ F capacitor. The  $V_{REF}$  voltage is 0 V in shutdown mode and has 50 mA source capability.

#### Voltage Mode PWM Operation

Under normal load conditions, the IC operates in voltage mode and generates a fixed frequency pulse width modulated signal to the drivers. Duty cycle is controlled over a wide range to maintain output voltage under line and load variation. Voltage feed forward is also included to take account of variations in supply voltage  $V_{IN}$ .

In the half-bridge topology requiring isolation between output and input, the reference voltage and error amplifier must be supplied externally, usually on the secondary side. The error information is thus passed to the power controller through an opto-coupling device. This information is inverted, hence 0 V represents the maximum duty cycle, whilst 2 V represents minimum duty cycle. The error information enters the IC via pin EP, and is passed to the PWM generator via an inverting amplifier. The relationship between Duty cycle and  $V_{EP}$  is shown in the Typical Characteristic Graph, Duty Cycle vs.  $V_{EP}$  25 °C, page 12. Voltage feedforward is implemented by taking the attenuated  $V_{IN}$  signal at  $V_{INDET}$  and directly modulating the duty cycle. The relationship between Duty cycle and  $V_{INDET}$  is shown in the Typical Characteristic Graph, Duty Cycle vs.  $V_{INDET}$ , page 16.

At start-up, i.e., once  $V_{CC}$  is greater than  $V_{UVLO}$ , switching is initiated under soft-start control which increases primary switch on-times linearly from  $D_{MIN}$  to  $D_{MAX}$  over the soft-start period. Start-up from a  $V_{INDET}$  power down is also initiated under soft-start control.

#### Half-Bridge and Synchronous Rectification Timing Sequence

The PWM signal generated within the Si9122 controls the low and high-side bridge drivers on alternative cycles. A period of inactivity always results after initiation of the soft-start cycle until the soft-start voltage reaches approximately 1.2 V and PWM controlled switching begins. The first bridge driver to switch is always the low-side,  $D_L$  as this allows charging of the high-side boost capacitor.

The timing and coordination of the drives to the primary and secondary stages is very important and shown in Figure 3. It is essential to avoid the situation where both of the secondary MOSFETs are on when either the high or the low-side switch are active. In this situation the transformer would effectively be presented with a short across the output. To avoid this, a dedicated break-before-make circuit is included which will generate non overlapping waveforms for the primary and the secondary drive signals. This is achieved by a programmable timer which delays the switching on of the primary driver relative to the switching off of the related secondary and subsequently delays the switching on of the secondary relative to the switching off of the related primary.

Typical variation in the  $t_{BBM3}$  and  $t_{BBM4}$  delay with  $L_X$  voltage is shown in graphs  $t_{BBM3}$ ,  $t_{BBM4}$  and for  $R_{BBM} = 33$  k $\Omega$ . This is due to a reduction in propagation delay through the high-side driver path as the  $L_X$  voltage increases and must be considered in setting the delay for the system level design. Variation of BBM time with  $R_{BBM}$  is shown in graph  $t_{BBM1}$  to  $t_{BBM4}$  vs.  $R_{BBM}$ .

#### Primary High- and Low-Side MOSFET Drivers

The drive voltage for the low-side MOSFET switch is provided directly from  $V_{CC}$ . The high-side MOSFET however requires the gate voltage to be enhanced above  $V_{IN}$ . This is achieved by bootstrapping the  $V_{CC}$  voltage onto the  $L_X$  voltage (the high-side MOSFET source). In order to provide the bootstrapping an external diode and capacitor are required as shown on the application schematic. The capacitor will charge up after the low-side driver has turned on. The switch gate drive signals  $D_H$  and  $D_L$  are shown in Figure 3.

#### Secondary MOSFET Drivers

The secondary side MOSFETs are driven from the Si9122 via a center tapped pulse transformer and inverter drivers. The waveforms from the IC SRH and SRL are shown in Figure 3. Of importance is the relative voltage between SRH and SRL, i.e. that which is presented across the primary of the pulse transformer. When both potentials of SRL and SRH are equal then by the action of the inverting driver both secondary MOSFETs are left on.

#### Oscillator

The oscillator is designed to operate at a nominal frequency of 500 kHz. The 500 kHz operating frequency allows the converter to minimize the inductor and capacitor size, improving the power density of the converter. The oscillator and therefore the switching frequency is programmable by attaching a resistor to the  $R_{OSC}$  pin. Under overload

conditions the oscillator frequency is reduced by the current overload protection to enable a constant current to be maintained into a low impedance circuit.

### Current Limit

Current mode control providing constant current operation is achieved by monitoring the differential voltage  $V_{CS}$  between the CS1 and CS2 pins, which are connected to a current sense resistor on the primary low-side MOSFET. In the absence of an overcurrent condition,  $V_{CS}$  is less than lower current limit threshold  $V_{TLCL}$  (typical 100 mV);  $C_{L\_CONT}$  is pulled up linearly via the 120  $\mu A$  current source ( $I_{PU}$ ) and both DL and DH switch at half the oscillator set frequency. When a moderate overcurrent condition occurs ( $V_{TLCL} < V_{CS} < V_{THCL}$ ), the  $C_{L\_CONT}$  capacitor will be discharged at a rate that is proportional to  $V_{CS} - 100$  mV by the  $I_{PD}$  current source. Both driver outputs are in frequency fold-back mode and the switching frequency becomes roughly 20 % of normal switching frequency. When a severe overcurrent condition occurs ( $V_{THCL} < V_{CS}$ ), the NMOS discharges  $C_{L\_CONT}$  capacitor immediately at 2 mA rate and the  $C_{L\_CONT}$  voltage will be clamped to 1.2 V disabling both DL and DH outputs.

Before  $V_{CS}$  reaches severe overcurrent condition, a lowering of the  $C_{L\_CONT}$  voltage results in PWM control of the output drive being taken over by the current limit control loop through  $C_{L\_CONT}$ . Current control initially reduces the switching duty cycle toward the minimum the chip can reach ( $D_{MIN}$ ). If this duty cycle reduction still cannot lower the load current, then the switching frequency will start to fold back to minimum 1/5 of the nominal frequency. This prevents the on-time of the primary drivers from being reduced to below 100 ns and avoids current tails. If  $V_{CS} > V_{THCL}$ , the switching will then stop.

With constant current mode control and frequency foldback, protection of the MOSFET switches is increased. The converter reverts to voltage mode operation immediately when the primary current falls below the limit level, and C<sub>LCONT</sub> capacitor is charged up and clamped to 6.5 V. The soft-start function does not apply during current limit period, as this would constitute hiccup mode operation.

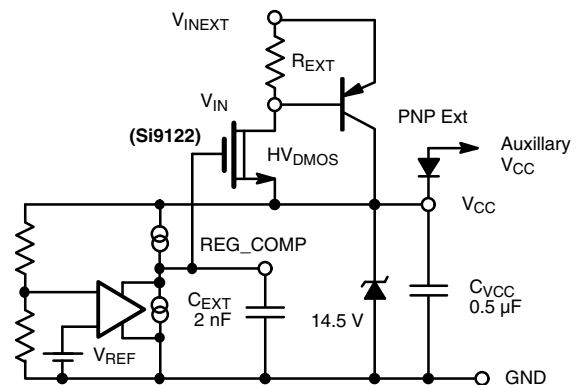
### V<sub>IN</sub> Voltage Monitor - V<sub>INDET</sub>

The chip provides a means of sensing the voltage of  $V_{IN}$ , and withholding operation of the output drivers until a minimum voltage of  $V_{REF}$  (3.3 V, 300 mV hysteresis), is achieved. This is achieved by choosing an appropriate resistive tap between the ground and  $V_{IN}$ , and comparing this voltage with the reference voltage. When the applied voltage is greater than  $V_{REF}$ , the output drivers are activated as normal.  $V_{INDET}$  also provides the input to the voltage feed forward function.

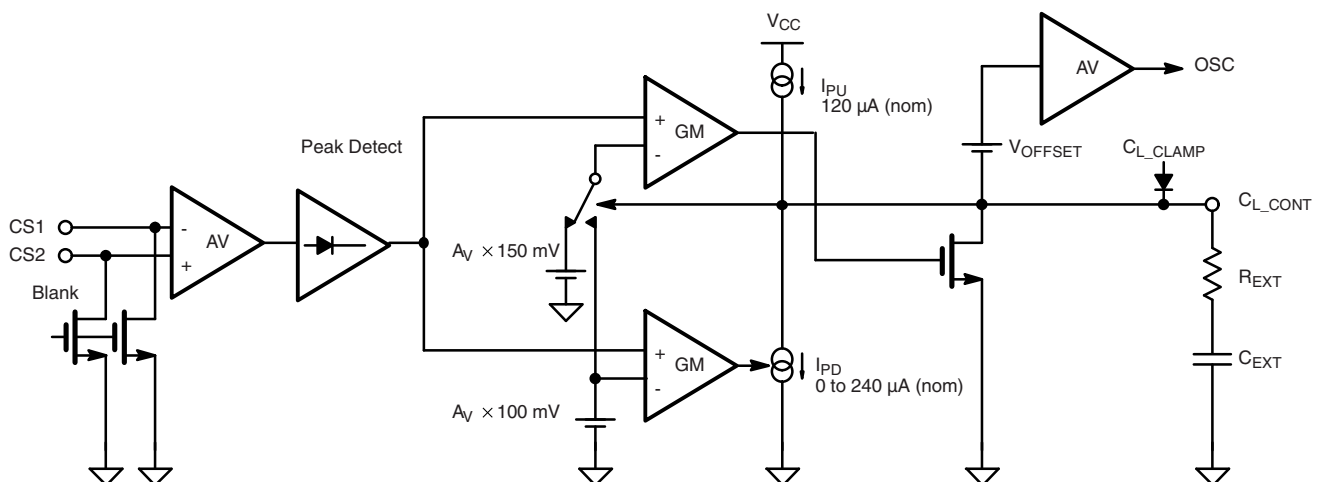
However, if the divided voltage applied to the  $V_{\text{INDET}}$  pin is greater than  $V_{\text{CC}} - 0.3 \text{ V}$ , the high-side driver,  $D_H$ , will stop switching until the voltage drops below  $V_{\text{CC}} - 0.3 \text{ V}$ . Thus, the resistive tap on the  $V_{\text{IN}}$  divider must be set to accommodate the normal  $V_{\text{CC}}$  operating voltage to avoid this condition. Alternatively, a zener clamp diode from  $V_{\text{INDET}}$  to GND may also be used.

## Shutdown Mode

If  $V_{\text{INDET}}$  is forced below the lower threshold, a minimum of 350 mV ( $V_{\text{SD}}$ ), the device will enter SHUTDOWN mode. This powers down all unnecessary functions of the controller, ensures that the primary switches are off and results in a low level current demand from the  $V_{\text{IN}}$  or  $V_{\text{CC}}$  supplies.

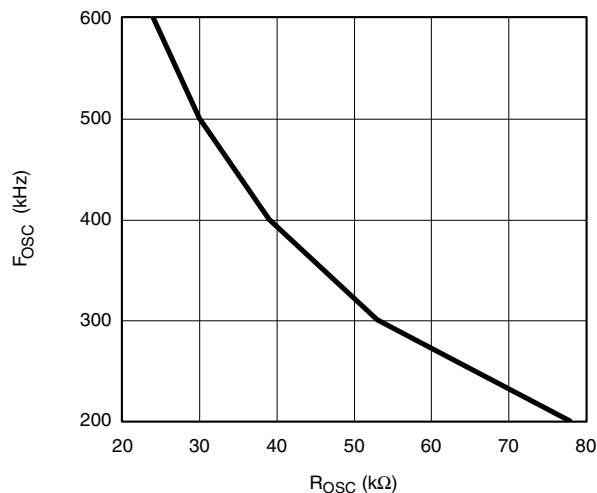
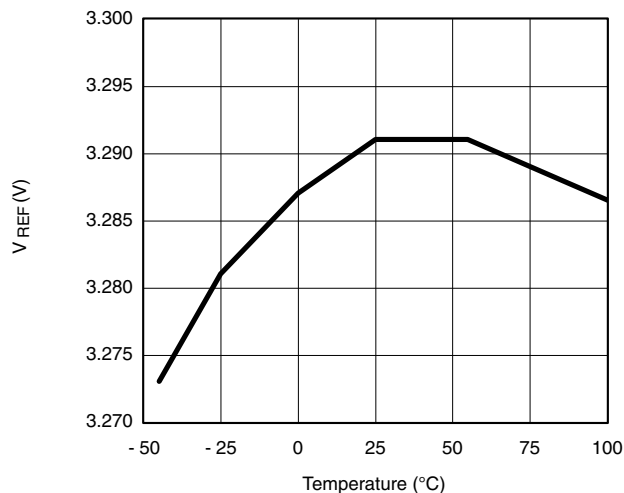
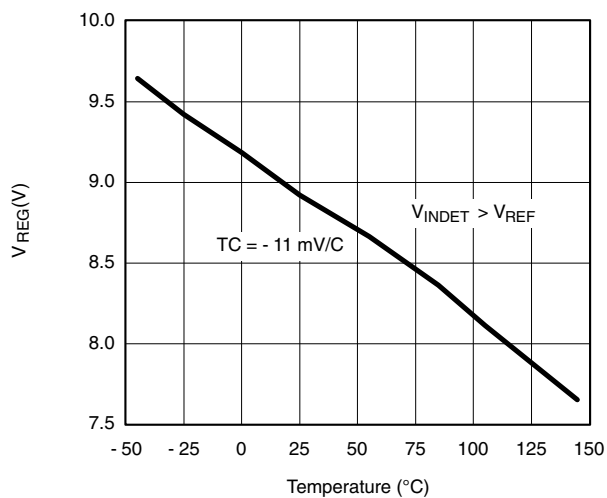
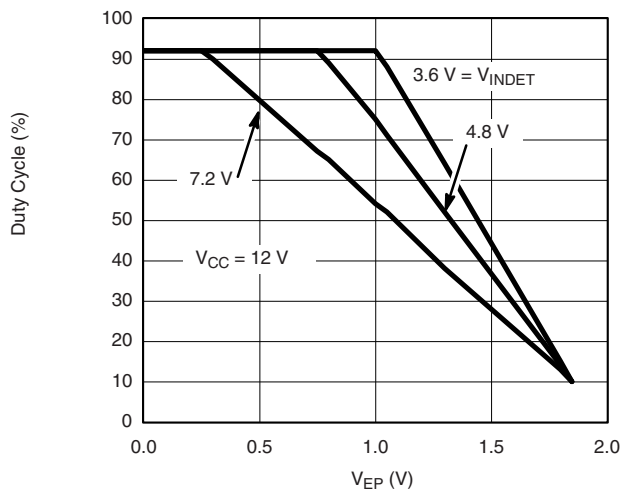
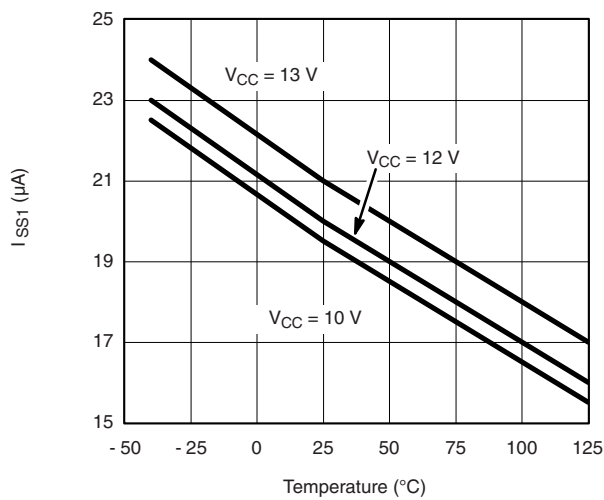
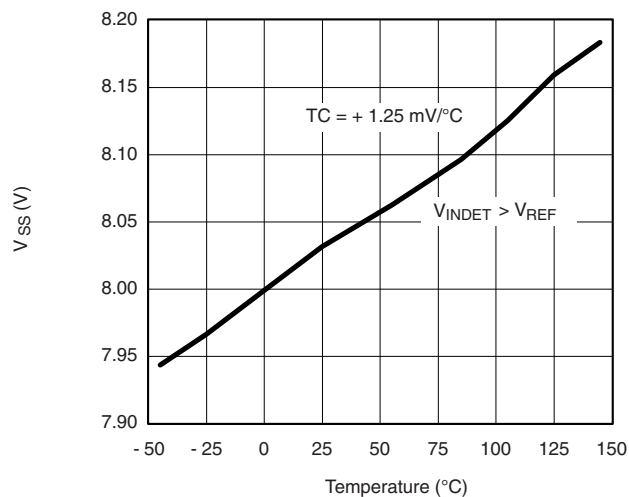


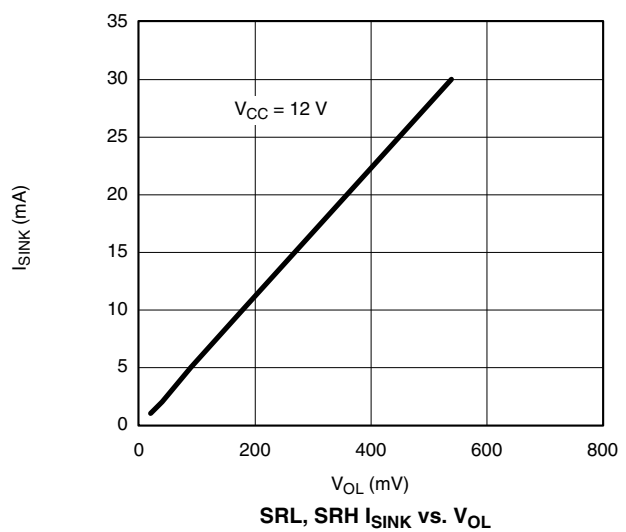
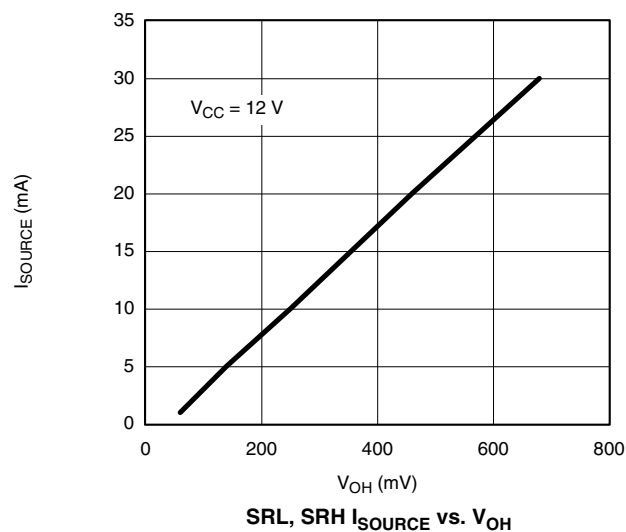
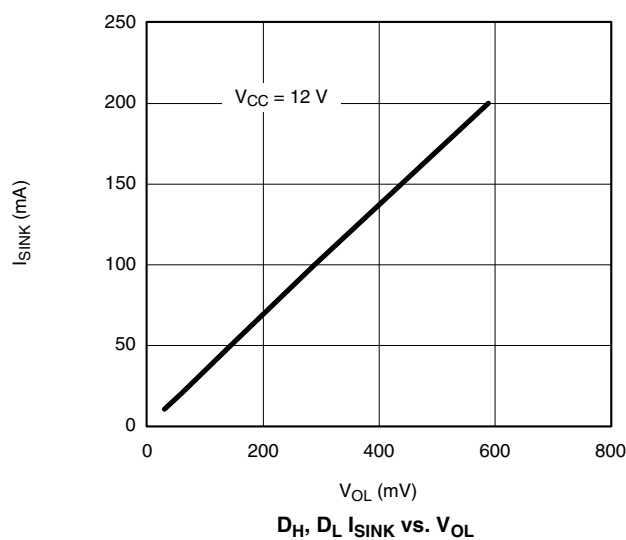
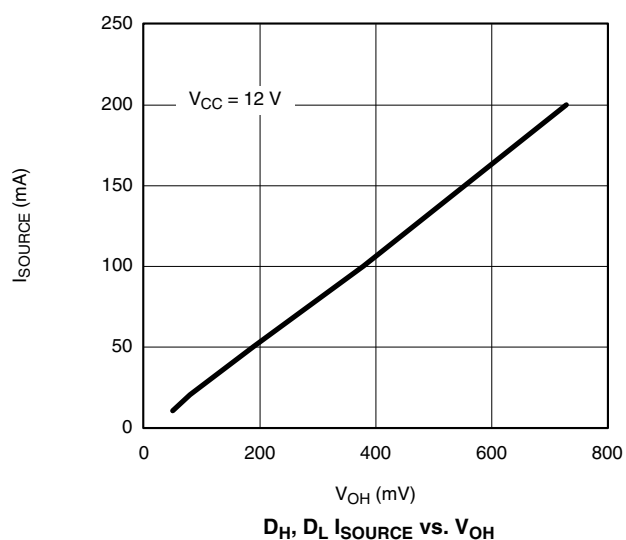
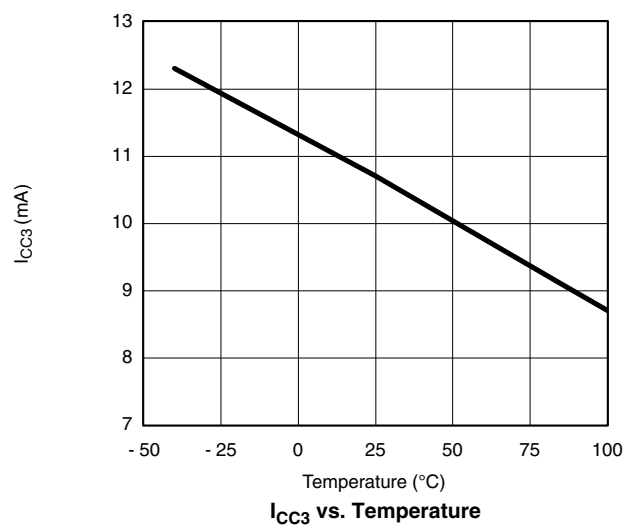
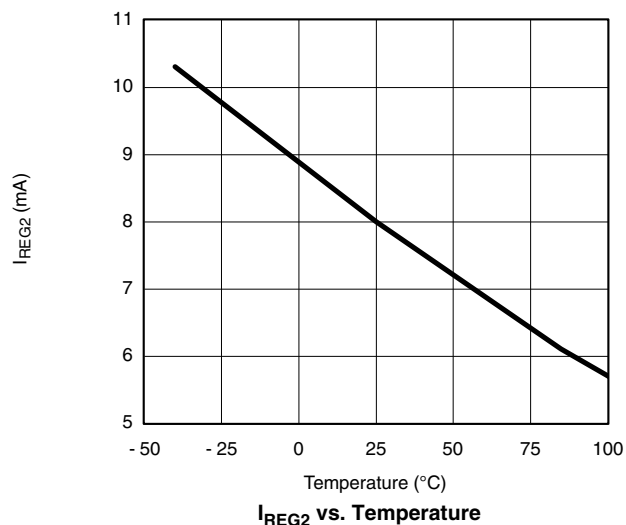
**Figure 5. High-Voltage Pre-Regulator Circuit**



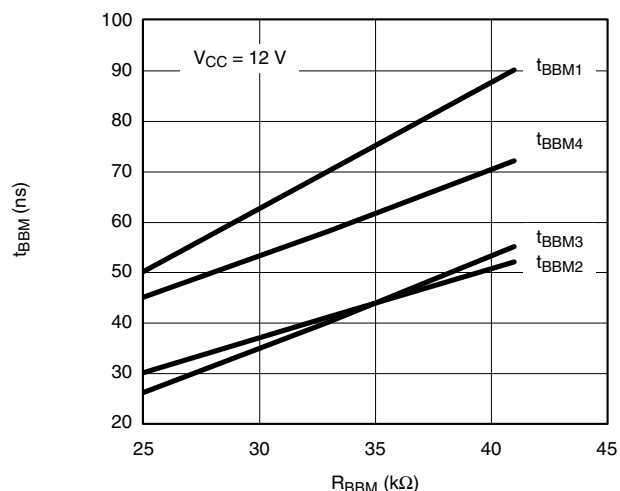
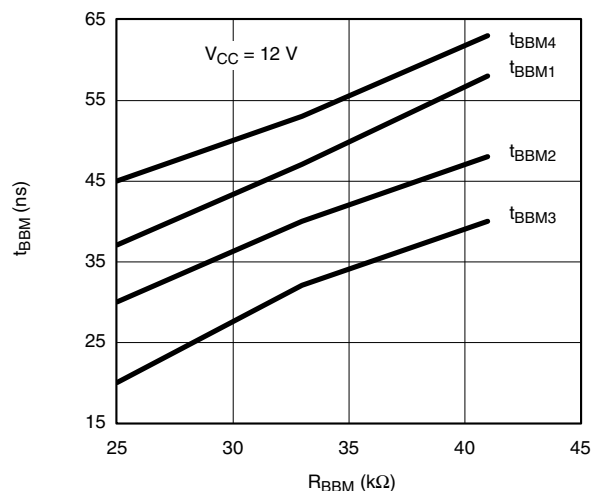
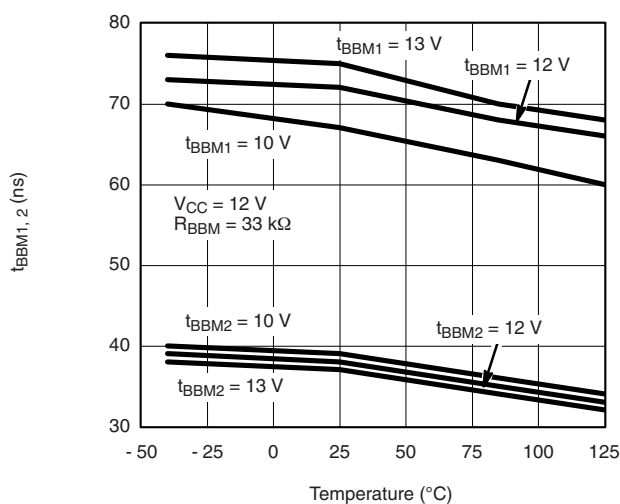
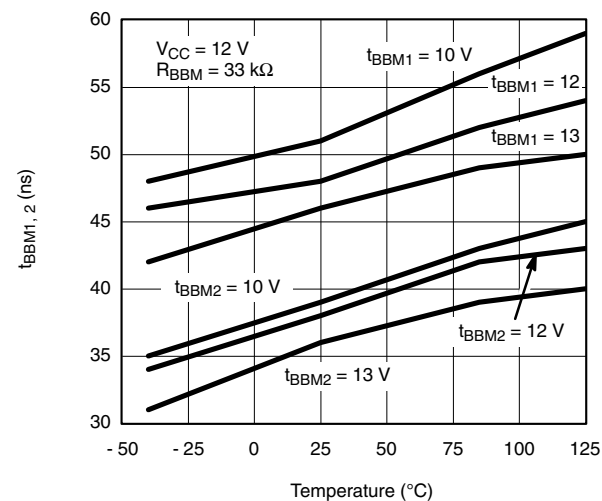
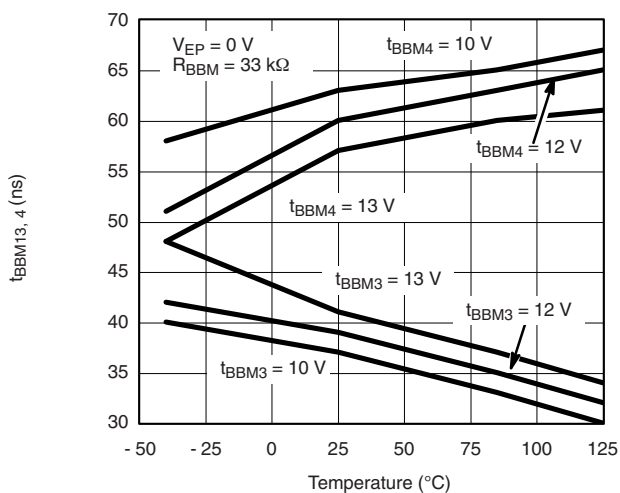
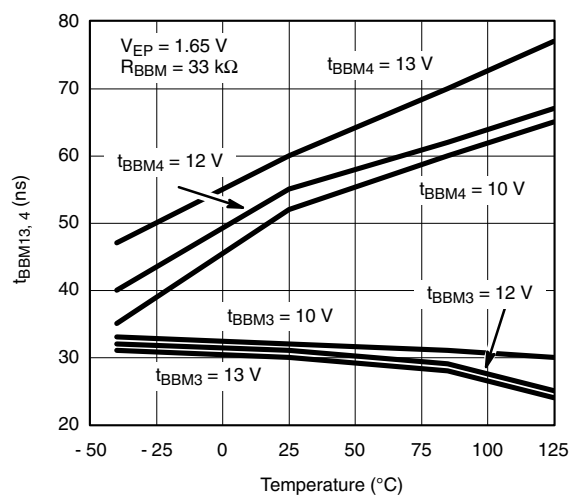
**Figure 6 . Current Limit Circuit**

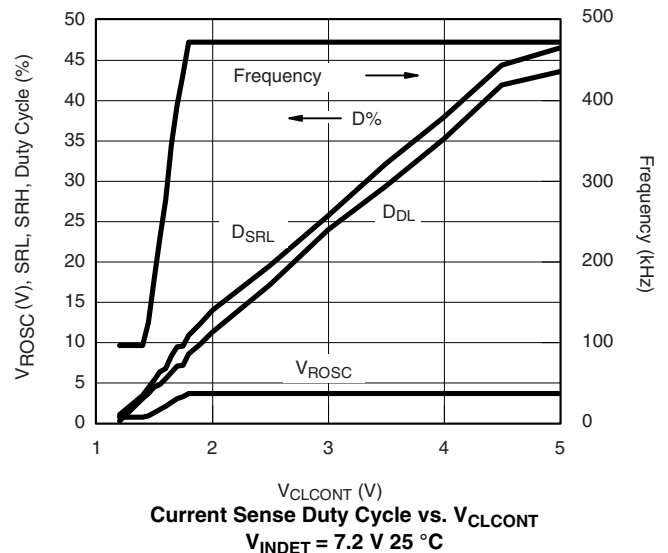
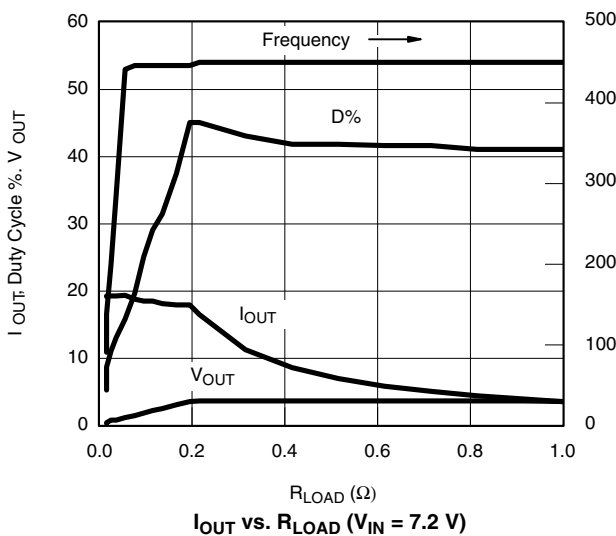
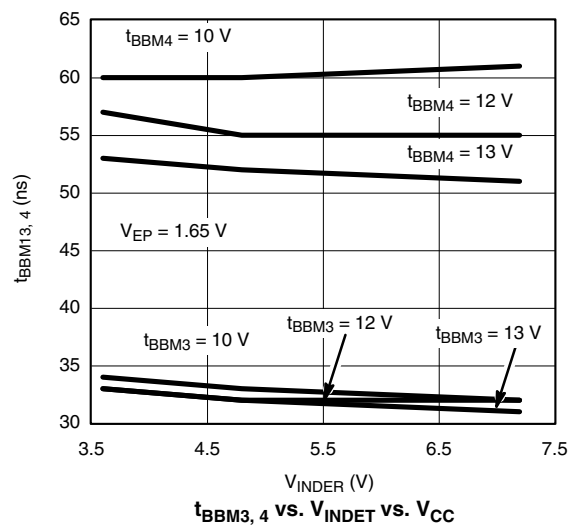
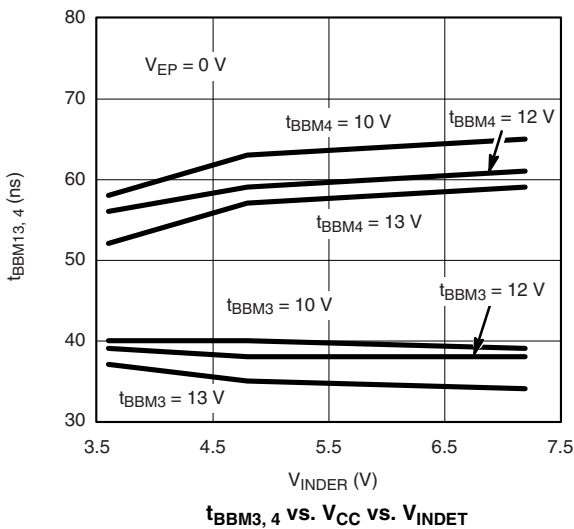
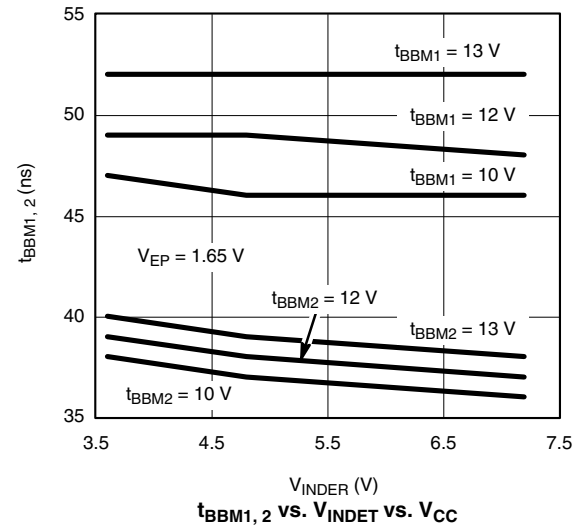
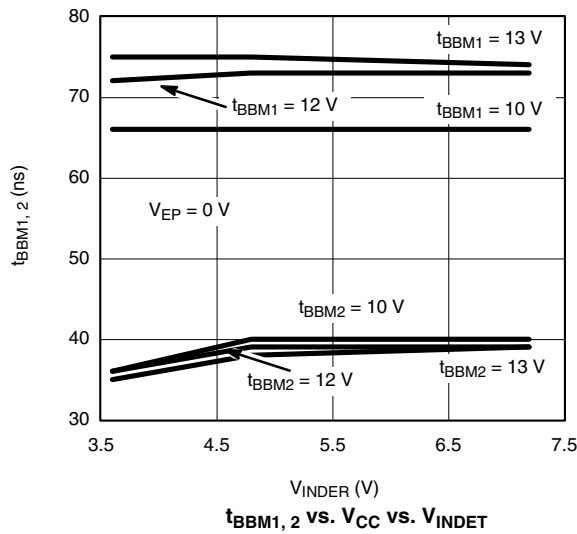
## TYPICAL CHARACTERISTICS

F<sub>OSC</sub> vs. R<sub>OSC</sub> at V<sub>CC</sub> = 12 VV<sub>REF</sub> vs. Temperature, V<sub>CC</sub> = 12 VV<sub>REG</sub> vs. Temperature, V<sub>IN</sub> = 48 VSRL, SRH Duty Cycle vs. V<sub>EP</sub>I<sub>SS</sub> vs. TemperatureV<sub>SS</sub> vs. Temperature, V<sub>CC</sub> = 12 V

**TYPICAL CHARACTERISTICS**


## TYPICAL CHARACTERISTICS

 $t_{BBM}$  vs.  $R_{BBM}$ ,  $V_{EP} = 0$  V $t_{BBM}$  vs.  $R_{BBM}$ ,  $V_{EP} = 1.65$  V $t_{BBM1,2}$  vs. Temperature,  $V_{EP} = 0$  V $t_{BBM1,2}$  vs. Temperature,  $V_{EP} = 1.65$  V $t_{BBM3,4}$  vs. Temperature,  $V_{EP} = 0$  V $t_{BBM3,4}$  vs. Temperature,  $V_{EP} = 1.65$  V

**TYPICAL CHARACTERISTICS**


## TYPICAL WAVEFORMS

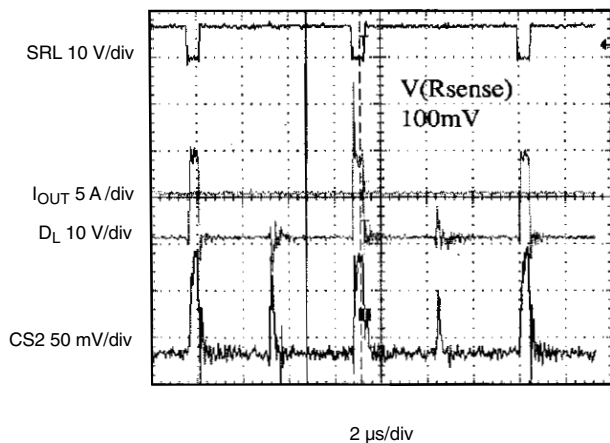
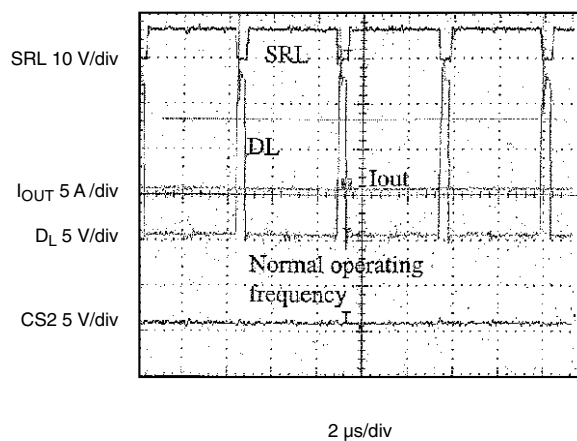
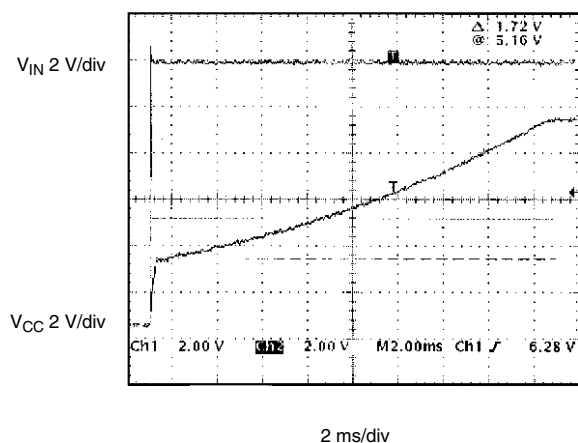
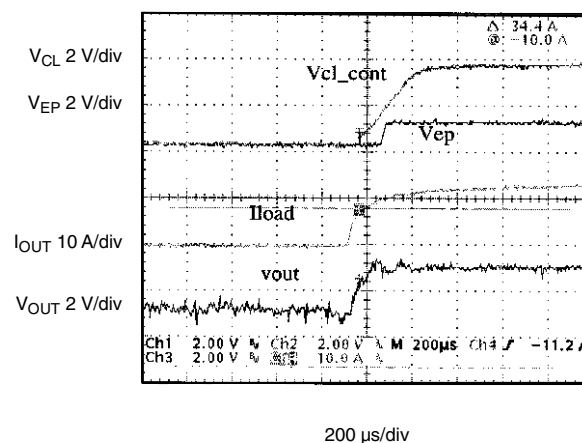
Figure 7. Foldback Mode,  $R_L = 0.02 \Omega$ Figure 8. Normal Mode,  $R_L = 0.1 \Omega$ Figure 9.  $V_{CC}$  Ramp-Up

Figure 10. Overload Recovery - Minimum Overshoot

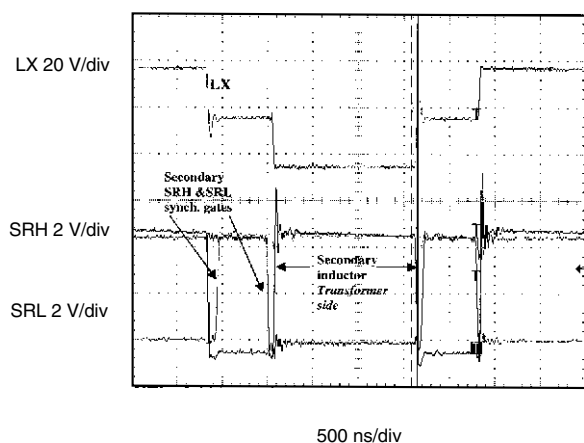


Figure 11. Effective BBM - Measured On Secondary

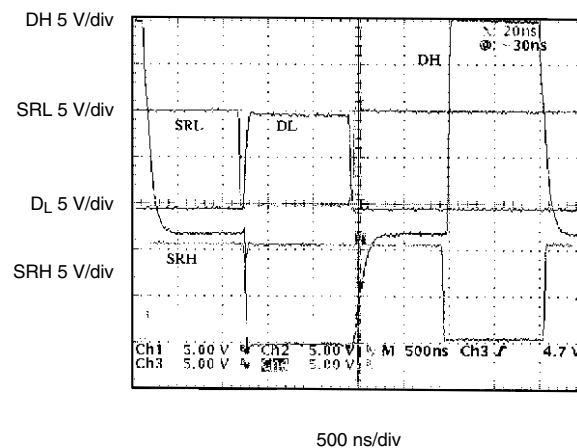
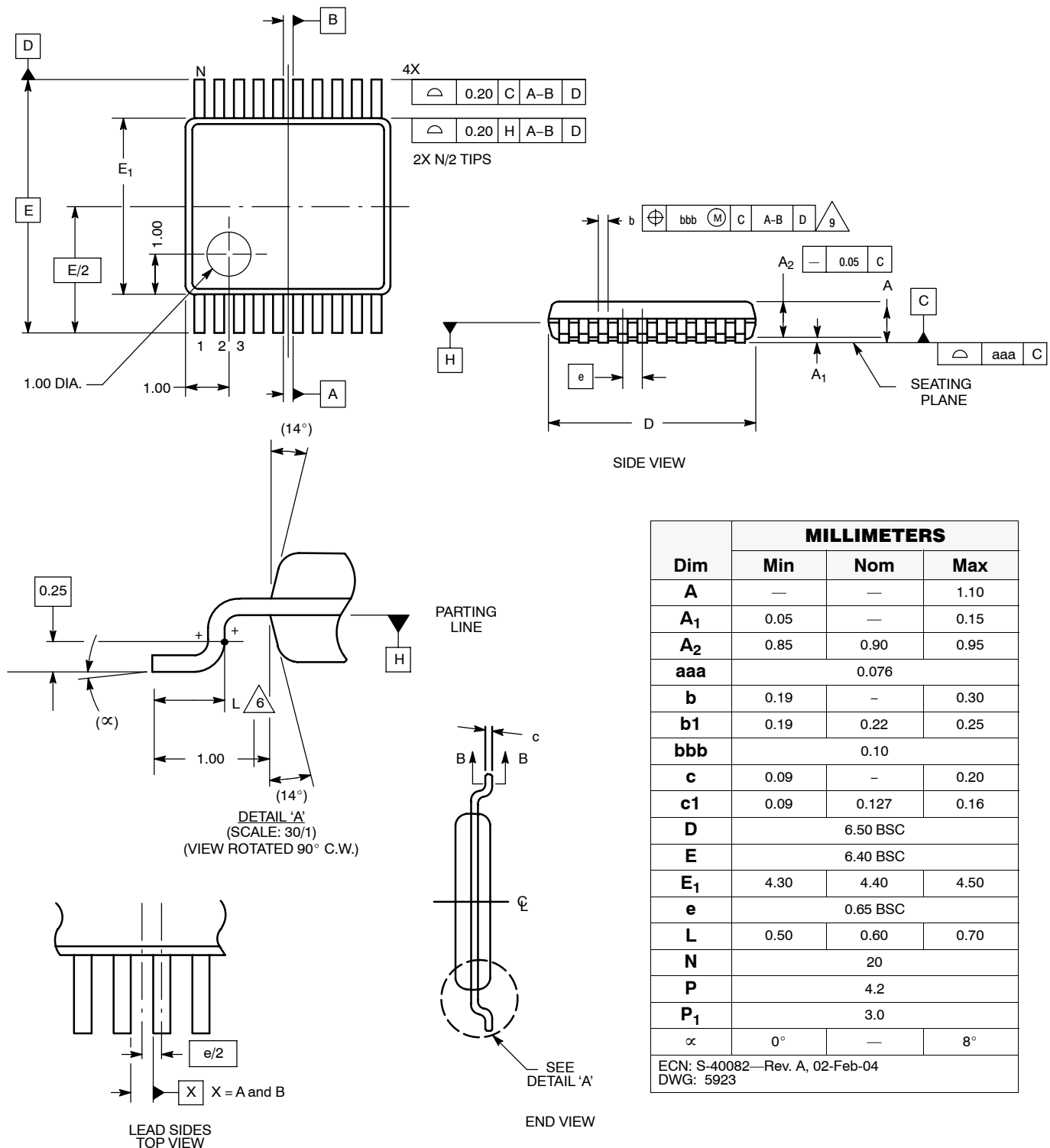


Figure 12. Drive Waveforms

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**TSSOP: 20-LEAD (POWER IC ONLY)**





### PowerPAK MLP65-18/20 (POWER IC ONLY)


**N = 18/20 PITCH: 0.5 mm, BODY SIZE: 6.00 x 5.00**

Dim	MILLIMETERS*			INCHES			Notes
	Min	Nom	Max	Min	Nom	Max	
A	0.80	0.90	1.00	0.031	0.035	0.039	1, 2
A1	0.00	0.02	0.05	0.000	0.001	0.002	1, 2
A2	0.00	0.65	1.00	0.000	0.003	0.004	1, 2
A3	0.20 REF			0.008 REF			
aaa	–	0.15	–	–	0.006	–	
b	0.18	0.25	0.30	0.007	0.010	0.012	8
bbb	–	0.10	–	–	0.004	–	
C'	–	0.225	–	–	0.009	–	4, 10
ccc	–	0.10	–	–	0.004	–	
D	6.00 BSC			0.236 BSC			1, 2
D2	4.00	4.15	4.25	0.157	1.63	0.167	1, 2
E	5.00 BSC			0.197 BSC			1, 2
E2	3.00	3.15	3.25	0.118	0.124	0.128	1, 2
e	–	0.50	–	–	0.020	–	
L	0.45	0.55	0.65	0.018	0.022	0.026	1, 2
N	18, 20			18, 20			1, 2
ND(18)	9			9			1, 2
NE(18)	0			0			1, 2
ND(20)	10			10			1, 2
NE(20)	0			0			1, 2

\* Use millimeters as the primary measurement.

ECN: S-41946—Rev. A, 18-Oct-04  
DWG: 5939

#### NOTES:

1. Dimensioning and tolerancing conform to ASME Y14.5M-1994.
2. All dimensions are in millimeters. All angles are in degrees.
3. N is the total number of terminals.
4. The terminal #1 identifier and terminal numbering convention shall conform to JEDEC publication 95 SSP-022. Details of terminal #1 identifier are optional, but must be located within the zone indicated. A dot can be marked on the top side by pin 1 to indicate orientation.
5.  ND and NE refer to the number of terminals on the D and E side respectively.
6. Depopulation is possible in a symmetrical fashion.
7. NJR refers to NON JEDEC REGISTERED.
8. Dimension "b" applies to metalized terminal and is measured between 0.15 mm and 0.30 mm from the terminal tip. If the terminal has optional radius on the other end of the terminal, the dimension "b" should not be measured in that radius area.
9. Coplanarity applies to the exposed heat slug as well as the terminal.
10. The 45° chamfer dimension C' is located by pin 1 on the bottom side of the package.



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