



**Qualification Information<sup>†</sup>**

<b>Qualification Level</b>		Industrial <sup>††</sup>	
		Comments: This family of ICs has passed JEDEC's Industrial qualification. IR's Consumer qualification level is granted by extension of the higher Industrial level.	
<b>Moisture Sensitivity Level</b>		SOIC28W	MSL3 <sup>†††</sup> , 260°C (per IPC/JEDEC J-STD-020)
		PLCC44	MSL3 <sup>†††</sup> , 245°C (per IPC/JEDEC J-STD-020)
<b>ESD</b>	Human Body Model	Class 2 (per JEDEC standard JESD22-A114)	
	Machine Model	Class B (per EIA/JEDEC standard EIA/JESD22-A115)	
<b>IC Latch-Up Test</b>		Class I, Level A (per JESD78)	
<b>RoHS Compliant</b>		Yes	

† Qualification standards can be found at International Rectifier's web site <http://www.irf.com/>

†† Higher qualification ratings may be available should the user have such requirements. Please contact your International Rectifier sales representative for further information.

††† Higher MSL ratings may be available for the specific package types listed here. Please contact your International Rectifier sales representative for further information.

## Absolute Maximum Ratings

Absolute Maximum Ratings indicate sustained limits beyond which damage to the device may occur. All voltage parameters are absolute voltages referenced to  $V_{SO}$ . The thermal resistance and power dissipation ratings are measured under board mounted and still air conditions.

Symbol	Definition	Min.	Max.	Units	
$V_{B1,2,3}$	High Side Floating Supply Voltage	-0.3	620	V	
$V_{S1,2,3}$	High Side Floating Offset Voltage	$V_{B1,2,3} - 20$	$V_{B1,2,3} + 0.3$		
$V_{HO1,2,3}$	High Side Floating Output Voltage	$V_{S1,2,3} - 0.3$	$V_{B1,2,3} + 0.3$		
$V_{CC}$	Low Side and Logic Fixed Supply Voltage	-0.3	20		
$V_{SS}$	Logic Ground	$V_{CC} - 20$	$V_{CC} + 0.3$		
$V_{LO1,2,3}$	Low Side Output Voltage	-0.3	$V_{CC} + 0.3$		
$V_{IN}$	Logic Input Voltage ( $\overline{HIN1,2,3}$ , $\overline{LIN1,2,3}$ & ITRIP)	$V_{SS} - 0.3$	( $V_{SS} + 15$ ) or ( $V_{CC} + 0.3$ ) Whichever is lower		
$V_{FLT}$	FAULT Output Voltage	$V_{SS} - 0.3$	$V_{CC} + 0.3$		
$V_{CAO}$	Operational Amplifier Output Voltage	$V_{SS} - 0.3$	$V_{CC} + 0.3$		
$V_{CA-}$	Operational Amplifier Inverting Input Voltage	$V_{SS} - 0.3$	$V_{CC} + 0.3$		
$dV_S/dt$	Allowable Offset Supply Voltage Transient	—	50	V/ns	
$P_D$	Package Power Dissipation @ $T_A \leq +25^\circ\text{C}$	(28 lead SOIC)	—	1.6	W
		(44 lead PLCC)	—	2.0	
$R_{thJA}$	Thermal Resistance, Junction to Ambient	(28 lead SOIC)	—	78	$^\circ\text{C/W}$
		(44 lead PLCC)	—	63	
$T_J$	Junction Temperature	—	150	$^\circ\text{C}$	
$T_S$	Storage Temperature	-55	150		
$T_L$	Lead Temperature (soldering, 10 seconds)	—	300		

## Recommended Operating Conditions

The Input/Output logic timing diagram is shown in figure 1. For proper operation the device should be used within the recommended conditions. All voltage parameters are absolute voltage referenced to  $V_{SO}$ . The  $V_S$  offset rating is tested with all supplies biased at 15 V differential.

Symbol	Definition	Min.	Max.	Units	
$V_{B1,2,3}$	High Side Floating Supply Voltage	$V_{S1,2,3} + 10$	$V_{S1,2,3} + 20$	V	
$V_{S1,2,3}$	Static High side floating offset voltage	$V_{SO} - 8$ (Note1)	600		
$V_{S11,2,3}$	Transient High side floating offset voltage	-50 (Note2)	600		
$V_{HO1,2,3}$	High Side Floating Output Voltage	$V_{S1,2,3}$	$V_{B1,2,3}$		
$V_{CC}$	Low Side and Logic Fixed Supply Voltage	10	20		
$V_{SS}$	Logic Ground	-5	5		
$V_{LO1,2,3}$	Low Side Output Voltage	0	$V_{CC}$		
$V_{IN}$	Logic Input Voltage (HIN1,2,3, LIN1,2,3 & ITRIP)	$V_{SS}$	$V_{SS} + 5$		
$V_{FLT}$	FAULT Output Voltage	$V_{SS}$	$V_{CC}$		
$V_{CAO}$	Operational Amplifier Output Voltage	$V_{SS}$	$V_{SS} + 5$		
$V_{CA-}$	Operational Amplifier Inverting Input Voltage	$V_{SS}$	$V_{SS} + 5$		
$T_A$	Ambient temperature	-40	125		°C

**Note 1:** Logic operational for  $V_S$  of ( $V_{SO} - 8$  V) to ( $V_{SO} + 600$  V). Logic state held for  $V_S$  of ( $V_{SO} - 8$  V) to ( $V_{SO} - V_{BS}$ ).

**Note 2:** Operational for transient negative  $V_S$  of  $V_{SS} - 50$  V with a 50 ns pulse width. Guaranteed by design. Refer to the Application Information section of this datasheet for more details.

**Note 3:** CAO input pin is internally clamped with a 5.2 V zener diode.

## Dynamic Electrical Characteristics

$V_{BIAS}$  ( $V_{CC}$ ,  $V_{BS1,2,3}$ ) = 15 V,  $V_{SO1,2,3}$  =  $V_{SS}$ ,  $C_L$  = 1000 pF,  $T_A$  = 25 °C unless otherwise specified.

Symbol	Definition	Min	Typ	Max	Units	Test Conditions	
$t_{on}$	Turn-on propagation delay	400	500	700	ns	$V_{S1,2,3} = 0$ V to 600 V	
$t_{off}$	Turn-off propagation delay	400	500	700			
$t_r$	Turn-on rise time	—	80	125		$V_{S1,2,3} = 0$ V	
$t_f$	Turn-off fall time	—	35	55			
$t_{trip}$	ITRIP to Output Shutdown Propagation Delay	400	660	920			
$t_{bl}$	ITRIP Blanking Time	—	400	—			
$t_{fit}$	ITRIP to FAULT Indication Delay	350	550	870			
$t_{fit, in}$	Input Filter Time (All Six Inputs)	—	325	—			
$t_{fitclr}$	LIN1,2,3 to FAULT Clear Time (2330/2)	5300	8500	13700			
DT	Deadtime: (IRS2330(D)) (IRS2332(D))	1300	2000	3100			$V_{IN} = 0$ V & 5 V without external deadtime
		500	700	1100			
MDT	Deadtime matching: : (IRS2330(D)) (IRS2332(D))	—	—	400			
		—	—	140			
MT	Delay matching time ( $t_{ON}$ , $t_{OFF}$ )	—	—	50	$V_{IN} = 0$ V & 5 V without external deadtime larger than DT		
PM	Pulse width distortion	—	—	75	PM input 10 $\mu$ s		

**NOTE:** For high side PWM, HIN pulse width must be  $\geq 1.5$  usec

## Dynamic Electrical Characteristics

$V_{BIAS}$  ( $V_{CC}$ ,  $V_{BS1,2,3}$ ) = 15 V,  $V_{SO1,2,3}$  =  $V_{SS}$ ,  $C_L$  = 1000 pF,  $T_A$  = 25 °C unless otherwise specified.

Symbol	Definition	Min	Typ	Max	Units	Test Conditions
SR+	Operational Amplifier Slew Rate (+)	5	10	—	V/ $\mu$ s	1 V input step
SR-	Operational Amplifier Slew Rate (-)	2.4	3.2	—		

## Static Electrical Characteristics

$V_{BIAS}$  ( $V_{CC}$ ,  $V_{BS1,2,3}$ ) = 15 V,  $V_{SO1,2,3}$  =  $V_{SS}$  and  $T_A$  = 25 °C unless otherwise specified. The  $V_{IN}$ ,  $V_{TH}$  and  $I_{IN}$  parameters are referenced to  $V_{SS}$  and are applicable to all six logic input leads:  $\overline{HIN1,2,3}$  &  $\overline{LIN1,2,3}$ . The  $V_O$  and  $I_O$  parameters are referenced to  $V_{SO1,2,3}$  and are applicable to the respective output leads:  $HO1,2,3$  or  $LO1,2,3$ .

Symbol	Definition	Min	Typ	Max	Units	Test Conditions
$V_{IH}$	Logic "0" input Voltage (OUT = LO)	—	—	2.2	V	
$V_{IL}$	Logic "1" input Voltage (OUT = HI)	0.8	—	—		
$V_{IT,TH+}$	ITRIP Input Positive Going Threshold	400	490	580	mV	$V_{IN} = 0\text{ V}$ , $I_O = 20\text{ mA}$
$V_{OH}$	High Level Output Voltage, $V_{BIAS} - V_O$	—	—	1000		$V_{IN} = 5\text{ V}$ , $I_O = 20\text{ mA}$
$V_{OL}$	Low Level Output Voltage, $V_O$	—	—	400	$\mu\text{A}$	$V_B = V_S = 600\text{ V}$
$I_{LK}$	Offset Supply Leakage Current	—	—	50		$V_{IN} = 0\text{ V}$ or $4\text{ V}$
$I_{QBS}$	Quiescent $V_{BS}$ Supply Current	—	30	50	mA	$V_{IN} = 0\text{ V}$
$I_{QCC}$	Quiescent $V_{CC}$ Supply Current	—	4	6.2		$V_{IN} = 0\text{ V}$
$I_{IN+}$	Logic "1" Input Bias Current (OUT = HI)	-400	-300	-100	$\mu\text{A}$	$V_{IN} = 0\text{ V}$
$I_{IN-}$	Logic "0" Input Bias Current (OUT = LO)	-300	-220	-100		$V_{IN} = 4\text{ V}$
$I_{ITRIP+}$	"High" ITRIP Bias Current	—	5	10	nA	ITRIP = 4 V
$I_{ITRIP-}$	"LOW" ITRIP Bias Current	—	—	30		ITRIP = 0 V
$V_{BSUV+}$	$V_{BS}$ Supply Undervoltage Positive Going Threshold	7.5	8.35	9.2	V	
$V_{BSUV-}$	$V_{BS}$ Supply Undervoltage Negative Going Threshold	7.1	7.95	8.8		
$V_{CCUV+}$	$V_{CC}$ Supply Undervoltage Positive going Threshold	8.3	9	9.7		
$V_{CCUV-}$	$V_{CC}$ Supply Undervoltage Negative Going Threshold	8	8.7	9.4		
$V_{CCUVH}$	Hysteresis	—	0.3	—		
$V_{BSUVH}$	Hysteresis	—	0.4	—		
$R_{on,FLT}$	FAULT Low On-Resistance	—	55	75		
$I_{O+}$	Output High Short Circuit Pulsed Current	—	-250	-180	mA	$V_O = 0\text{ V}$ , $V_{IN} = 0\text{ V}$ PW $\leq 10\text{ us}$
$I_{O-}$	Output Low Short Circuit Pulsed Current	420	500	—		$V_O = 15\text{ V}$ , $V_{IN} = 5\text{ V}$ PW $\leq 10\text{ us}$
$R_{BS}$	Integrated Bootstrap Diode resistance	—	200	—	$\Omega$	
$V_{OS}$	Operational Amplifier Input Offset Voltage	—	—	20	mV	$V_{SO} = 0.2\text{ V}$
$I_{CA-}$	CA- Input Bias Current	—	—	100	nA	$V_{CA-} = 1\text{ V}$
CMRR	Operational Amplifier Common Mode Rejection Ratio	—	80	—	dB	$V_{SO} = 0.1\text{ V}$ & $5\text{ V}$
PSRR	Operational Amplifier Power Supply Rejection Ratio	—	75	—		$V_{SO} = 0.2\text{ V}$ $V_{CC} = 9.7\text{ V}$ & $20\text{ V}$
$V_{OH,AMP}$	Operational Amplifier High Level Output Voltage	4.8	5.2	5.6	V	$V_{CA-} = 0\text{ V}$ , $V_{SO} = 1\text{ V}$
$V_{OL,AMP}$	Operational Amplifier Low Level Output Voltage	—	—	40	mV	$V_{CA-} = 1\text{ V}$ , $V_{SO} = 0\text{ V}$

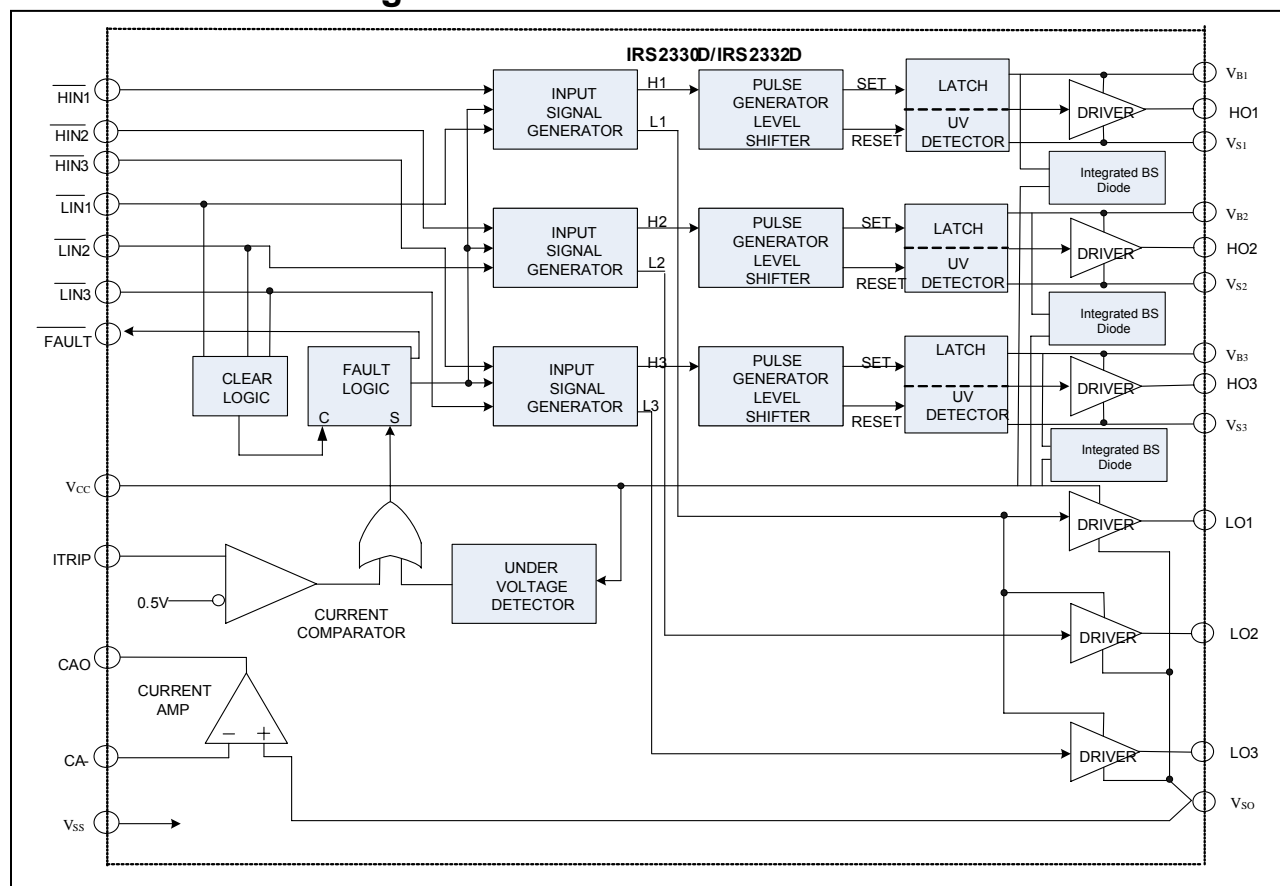
**Note:** The integrated bootstrap diode does not work well with the trapezoidal control.

### Static Electrical Characteristics- Continued

$V_{BIAS}$  ( $V_{CC}$ ,  $V_{BS1,2,3}$ ) = 15 V,  $V_{SO1,2,3}$  =  $V_{SS}$  and  $T_A$  = 25 °C unless otherwise specified. The  $V_{IN}$ ,  $V_{TH}$  and  $I_{IN}$  parameters are referenced to  $V_{SS}$  and are applicable to all six logic input leads: HIN1,2,3 & LIN1,2,3. The  $V_O$  and  $I_O$  parameters are referenced to  $V_{SO1,2,3}$  and are applicable to the respective output leads: HO1,2,3 or LO1,2,3.

Symbol	Definition	Min	Typ	Max	Units	Test Conditions
$I_{SRC,AMP}$	Operational Amplifier Output Source Current	—	-7	-4	mA	$V_{CA-} = 0\text{ V}$ , $V_{SO} = 1\text{ V}$ $V_{CAO} = 4\text{ V}$
$I_{SNK,AMP}$	Operational Amplifier Output Sink Current	1	2.1	—		$V_{CA-} = 1\text{ V}$ , $V_{SO} = 0\text{ V}$ $V_{CAO} = 2\text{ V}$
$I_{O+,AMP}$	Operational Amplifier Output High Short Circuit Current	-30	-10	—		$V_{CA-} = 0\text{ V}$ , $V_{SO} = 5\text{ V}$ $V_{CAO} = 0\text{ V}$
$I_{O-,AMP}$	Operational Amplifier Output Low Short Circuit Current	—	4	—		$V_{CA-} = 5\text{ V}$ , $V_{SO} = 0\text{ V}$ $V_{CAO} = 5\text{ V}$

### Functional Block Diagram

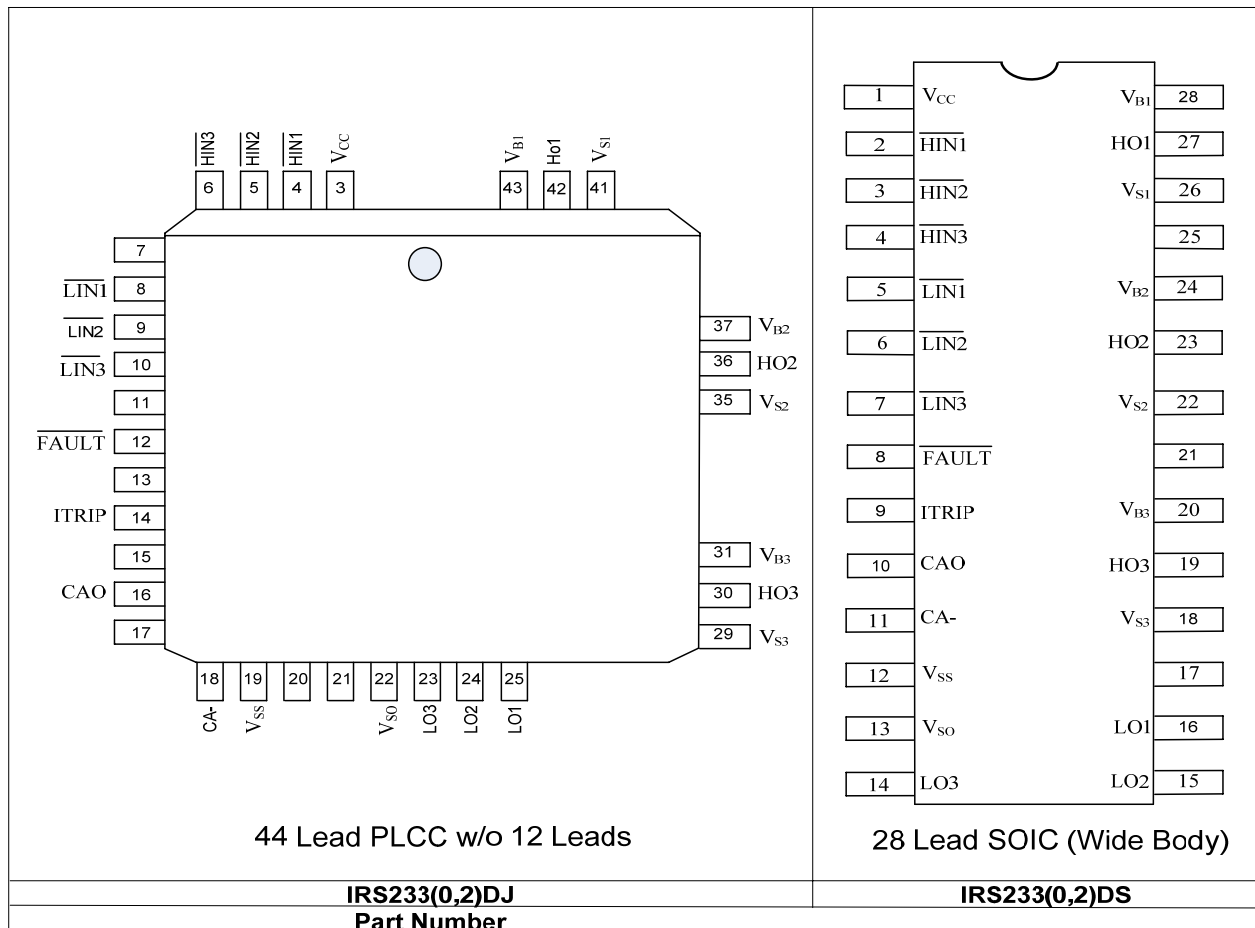


**Note:** IRS2330 & IRS2332 are without integrated bootstrap diode.

### Lead Definitions

Symbol	Description
HIN1,2,3	Logic input for high side gate driver outputs (HO1,2,3), out of phase
LIN1,2,3	Logic input for low side gate driver output (LO1,2,3), out of phase
FAULT	Indicates over-current or undervoltage lockout (low side) has occurred, negative logic
V <sub>CC</sub>	Low side and logic fixed supply
ITRIP	Input for over-current shutdown
CAO	Output of current amplifier
CA-	Negative input of current amplifier
V <sub>SS</sub>	Logic Ground
V <sub>B1,2,3</sub>	High side floating supply
HO1,2,3	High side gate drive output
V <sub>S1,2,3</sub>	High side floating supply return
LO1,2,3	Low side gate drive output
V <sub>SO</sub>	Low side return and positive input of current amplifier

### Lead Assignments





## Application Information and Additional Details

Information regarding the following topics are included as subsections within this section of the datasheet.

- IGBT/MOSFET Gate Drive
- Switching and Timing Relationships
- Deadtime
- Matched Propagation Delays
- Input Logic Compatibility
- Undervoltage Lockout Protection
- Shoot-Through Protection
- Fault Reporting
- Over-Current Protection
- Over-Temperature Shutdown Protection
- Truth Table: Undervoltage lockout, ITRIP
- Advanced Input Filter
- Short-Pulse / Noise Rejection
- Integrated Bootstrap Functionality
- Bootstrap Power Supply Design
- Separate Logic and Power Grounds
- Negative  $V_S$  Transient SOA
- DC- bus Current Sensing
- PCB Layout Tips
- Additional Documentation

### IGBT/MOSFET Gate Drive

The IRS233(2,0)(D) HVICs are designed to drive up to six MOSFET or IGBT power devices. Figures 1 and 2 illustrate several parameters associated with the gate drive functionality of the HVIC. The output current of the HVIC, used to drive the gate of the power switch, is defined as  $I_{O+}$ . The voltage that drives the gate of the external power switch is defined as  $V_{HO}$  for the high-side power switch and  $V_{LO}$  for the low-side power switch; this parameter is sometimes generically called  $V_{OUT}$  and in this case does not differentiate between the high-side or low-side output voltage.

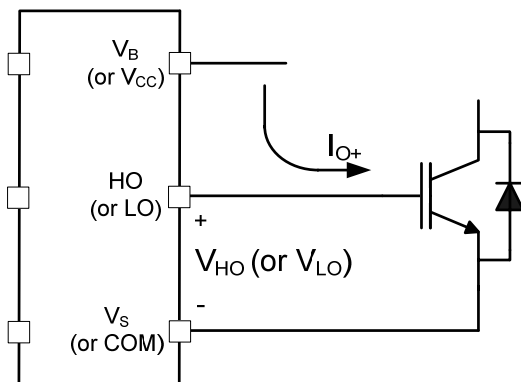


Figure 1: HVIC sourcing current

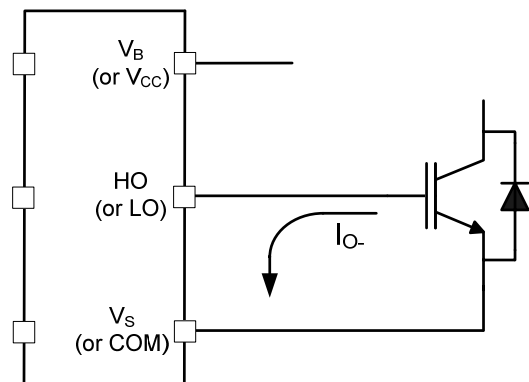
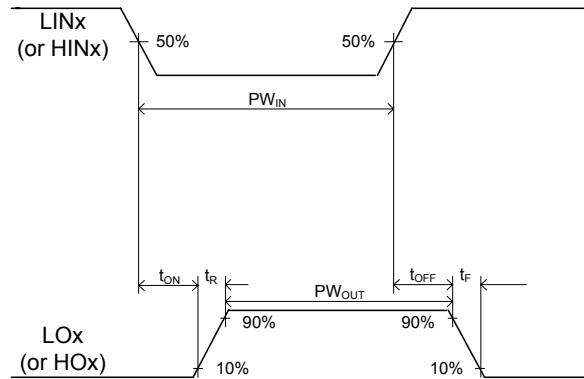


Figure 2: HVIC sinking current

**Switching and Timing Relationships**

The relationship between the input and output signals of the IRS233(0,2)(D) are illustrated below in Figures 3. From these figures, we can see the definitions of several timing parameters (i.e.,  $PW_{IN}$ ,  $PW_{OUT}$ ,  $t_{ON}$ ,  $t_{OFF}$ ,  $t_r$ , and  $t_f$ ) associated with this device.

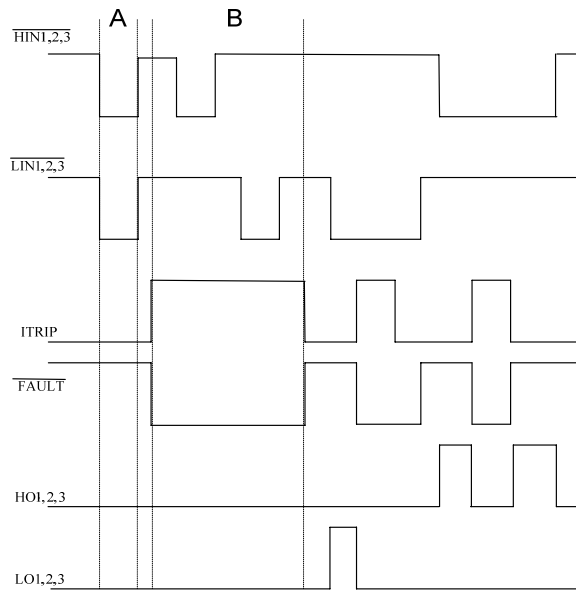


**Figure 3: Switching time waveforms**

The following two figures illustrate the timing relationships of some of the functionality of the IRS233(0,2)(D); this functionality is described in further detail later in this document.

During interval A of Figure 4, the HVIC has received the command to turn-on both the high- and low-side switches at the same time; as a result, the shoot-through protection of the HVIC has prevented this condition and both the high- and low-side output are held in the off state.

Interval B of Figures 4 shows that the signal on the ITRIP input pin has gone from a low to a high state; as a result, all of the gate drive outputs have been disabled (i.e., see that HOx has returned to the low state; LOx is also held low) and a fault is reported by the FAULT output transitioning to the low state. Once the ITRIP input has returned to the low state, the fault condition is latched until the all LINx become high.

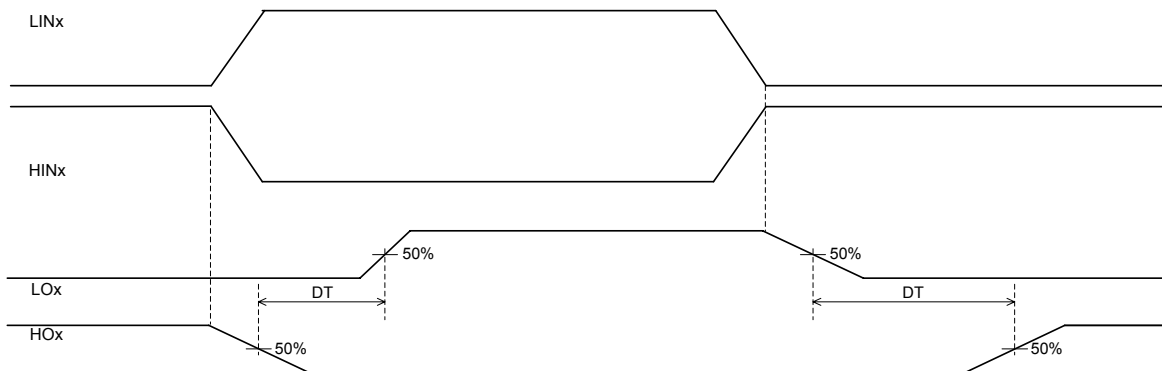


**Figure 4: Input/output timing diagram**

**Deadtime**

This family of HVICs features integrated deadtime protection circuitry. The deadtime for these ICs is fixed; other ICs within IR's HVIC portfolio feature programmable deadtime for greater design flexibility. The deadtime feature inserts a time period (a minimum deadtime) in which both the high- and low-side power switches are held off; this is done to ensure that the power switch being turned off has fully turned off before the second power switch is turned on. This minimum deadtime is automatically inserted whenever the external deadtime is shorter than DT; external deadtimes larger than DT are not modified by the gate driver. Figure 5 illustrates the deadtime period and the relationship between the output gate signals.

The deadtime circuitry of the IRS233(0,2)(D) is matched with respect to the high- and low-side outputs of a given channel; additionally, the deadtimes of each of the three channels are matched.



**Figure 5: Illustration of deadtime**

### Matched Propagation Delays

The IRS233(0,2)(D) family of HVICs is designed with propagation delay matching circuitry. With this feature, the IC's response at the output to a signal at the input requires approximately the same time duration (i.e.,  $t_{ON}$ ,  $t_{OFF}$ ) for both the low-side channels and the high-side channels. Additionally, the propagation delay for each low-side channel is matched when compared to the other low-side channels and the propagation delays of the high-side channels are matched with each other. The propagation turn-on delay ( $t_{ON}$ ) of the IRS233(0,2)(D) is matched to the propagation turn-on delay ( $t_{OFF}$ ).

### Input Logic Compatibility

The inputs of this IC are compatible with standard CMOS and TTL outputs. The IRS233(0,2)(D) family has been designed to be compatible with 3.3 V and 5 V logic-level signals. The IRS233(0,2)(D) features an integrated 5.2 V Zener clamp on the HIN, LIN, and ITRIP pins. Figure 6 illustrates an input signal to the IRS233(0,2)(D), its input threshold values, and the logic state of the IC as a result of the input signal.

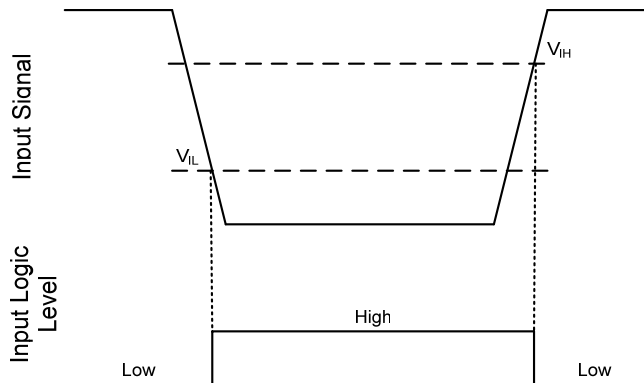


Figure 6: HIN & LIN input thresholds

### Undervoltage Lockout Protection

This family of ICs provides undervoltage lockout protection on both the  $V_{CC}$  (logic and low-side circuitry) power supply and the  $V_{BS}$  (high-side circuitry) power supply. Figure 7 is used to illustrate this concept;  $V_{CC}$  (or  $V_{BS}$ ) is plotted over time and as the waveform crosses the UVLO threshold ( $V_{CCUV+/-}$  or  $V_{BSUV+/-}$ ) the undervoltage protection is enabled or disabled.

Upon power-up, should the  $V_{CC}$  voltage fail to reach the  $V_{CCUV+}$  threshold, the IC will not turn-on. Additionally, if the  $V_{CC}$  voltage decreases below the  $V_{CCUV-}$  threshold during operation, the undervoltage lockout circuitry will recognize a fault condition and shutdown the high- and low-side gate drive outputs, and the FAULT pin will transition to the low state to inform the controller of the fault condition.

Upon power-up, should the  $V_{BS}$  voltage fail to reach the  $V_{BSUV}$  threshold, the IC will not turn-on. Additionally, if the  $V_{BS}$  voltage decreases below the  $V_{BSUV}$  threshold during operation, the undervoltage lockout circuitry will recognize a fault condition, and shutdown the high-side gate drive outputs of the IC.

The UVLO protection ensures that the IC drives the external power devices only when the gate supply voltage is sufficient to fully enhance the power devices. Without this feature, the gates of the external power switch could be driven with a low voltage, resulting in the power switch conducting current while the channel impedance is high; this could result in very high conduction losses within the power device and could lead to power device failure.

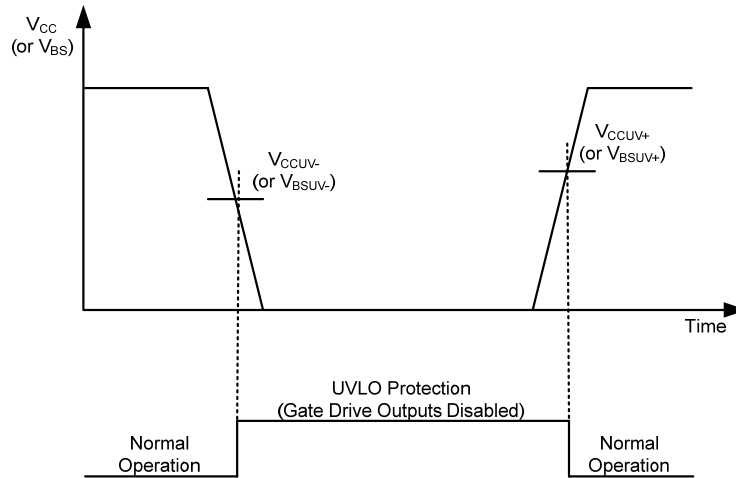


Figure 7: UVLO protection

**Shoot-Through Protection**

The IRS233(0,2)(D) family of high-voltage ICs is equipped with shoot-through protection circuitry (also known as cross-conduction prevention circuitry). Figure 8 shows how this protection circuitry prevents both the high- and low-side switches from conducting at the same time. Table 1 illustrates the input/output relationship of the devices in the form of a truth table. Note that the IRS233(0,2)(D) has inverting inputs (the output is out-of-phase with its respective input).

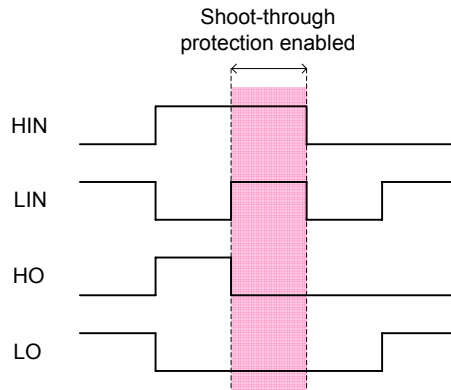


Figure 8: Illustration of shoot-through protection circuitry

IRS233(0,2)(D)			
HIN	LIN	HO	LO
0	0	0	0
0	1	1	0
1	0	0	1
1	1	0	0

Table 1: Input/output truth table

### Fault Reporting

The IRS233(0,2)(D) family provides an integrated fault reporting output. There are two situations that would cause the HVIC to report a fault via the FAULT pin. The first is an undervoltage condition of  $V_{CC}$  and the second is if the ITRIP pin recognizes a fault. Once the fault condition occurs, the FAULT pin is internally pulled to  $V_{SS}$  and the fault condition is latched. The fault output stays in the low state until the fault condition has been removed by all LINx set to high state. Once the fault is removed, the voltage on the FAULT pin will return to  $V_{CC}$ .

### Over-Current Protection

The IRS233(0,2)(D) HVICs are equipped with an ITRIP input pin. This functionality can be used to detect over-current events in the DC- bus. Once the HVIC detects an over-current event through the ITRIP pin, the outputs are shutdown, a fault is reported through the FAULT pin.

The level of current at which the over-current protection is initiated is determined by the resistor network (i.e.,  $R_0$ ,  $R_1$ , and  $R_2$ ) connected to ITRIP as shown in Figure 9, and the ITRIP threshold ( $V_{IT,TH+}$ ). The circuit designer will need to determine the maximum allowable level of current in the DC- bus and select  $R_0$ ,  $R_1$ , and  $R_2$  such that the voltage at node  $V_X$  reaches the over-current threshold ( $V_{IT,TH+}$ ) at that current level.

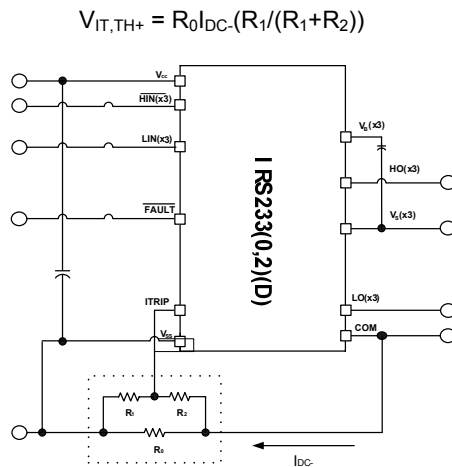


Figure 9: Programming the over-current protection

For example, a typical value for resistor  $R_0$  could be 50 mΩ. The voltage of the ITRIP pin should not be allowed to exceed 5 V; if necessary, an external voltage clamp may be used.

### Over-Temperature Shutdown Protection

The ITRIP input of the IRS233(0,2)(D) can also be used to detect over-temperature events in the system and initiate a shutdown of the HVIC (and power switches) at that time. In order to use this functionality, the circuit designer will need to design the resistor network as shown in Figure 10 and select the maximum allowable temperature.

This network consists of a thermistor and two standard resistors  $R_3$  and  $R_4$ . As the temperature changes, the resistance of the thermistor will change; this will result in a change of voltage at node  $V_X$ . The resistor values should be selected such the voltage  $V_X$  should reach the threshold voltage ( $V_{IT,TH+}$ ) of the ITRIP functionality by the time that the maximum allowable temperature is reached. The voltage of the ITRIP pin should not be allowed to exceed 5 V.

When using both the over-current protection and over-temperature protection with the ITRIP input, OR-ing diodes (e.g., DL4148) can be used. This network is shown in Figure 11; the OR-ing diodes have been labeled  $D_1$  and  $D_2$ .

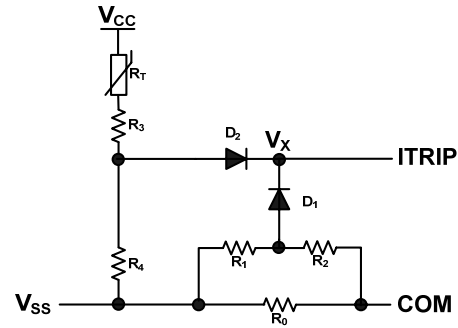
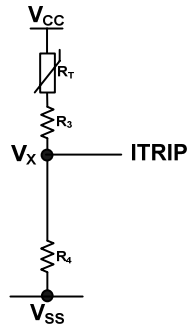


Figure 10: Programming over-temperature protection    Figure 11: Using over-current protection and over-temperature protection

**Truth Table: Undervoltage lockout and ITRIP**

Table 2 provides the truth table for the IRS233(0,2)(D). The first line shows that the UVLO for  $V_{CC}$  has been tripped; the FAULT output has gone low and the gate drive outputs have been disabled.  $V_{CCUV}$  is not latched in this case and when  $V_{CC}$  is greater than  $V_{CCUV}$ , the FAULT output returns to the high impedance state.

The second case shows that the UVLO for  $V_{BS}$  has been tripped and that the high-side gate drive outputs have been disabled. After  $V_{BS}$  exceeds the  $V_{BSUV}$  threshold, HO will stay low until the HVIC input receives a new falling transition of HIN. The third case shows the normal operation of the HVIC. The fourth case illustrates that the ITRIP trip threshold has been reached and that the gate drive outputs have been disabled and a fault has been reported through the fault pin. The fault output stays in the low state until the fault condition has been removed by all LINx set to high state. Once the fault is removed, the voltage on the FAULT pin will return to  $V_{CC}$ .

	VCC	VBS	ITRIP	FAULT	LO	HO
UVLO $V_{CC}$	$<V_{CCUV}$	---	---	0	0	0
UVLO $V_{BS}$	15 V	$<V_{BSUV}$	0 V	High impedance	LIN	0
Normal operation	15 V	15 V	0 V	High impedance	LIN	HIN
ITRIP fault	15 V	15 V	$>V_{ITRIP}$	0	0	0

Table 2: IRS233(0,2)(D) UVLO, ITRIP & FAULT truth table

**Advanced Input Filter**

The advanced input filter allows an improvement in the input/output pulse symmetry of the HVIC and helps to reject noise spikes and short pulses. This input filter has been applied to the HIN and LIN. The working principle of the new filter is shown in Figures 12 and 13.

Figure 12 shows a typical input filter and the asymmetry of the input and output. The upper pair of waveforms (Example 1) show an input signal with a duration much longer than  $t_{FIL,IN}$ ; the resulting output is approximately the difference between the input signal and  $t_{FIL,IN}$ . The lower pair of waveforms (Example 2) show an input signal with a duration slightly longer than  $t_{FIL,IN}$ ; the resulting output is approximately the difference between the input signal and  $t_{FIL,IN}$ .

Figure 13 shows the advanced input filter and the symmetry between the input and output. The upper pair of waveforms (Example 1) show an input signal with a duration much longer than  $t_{FIL,IN}$ ; the resulting output is approximately the same duration as the input signal. The lower pair of waveforms (Example 2) show an input signal with a duration slightly longer than  $t_{FIL,IN}$ ; the resulting output is approximately the same duration as the input signal.

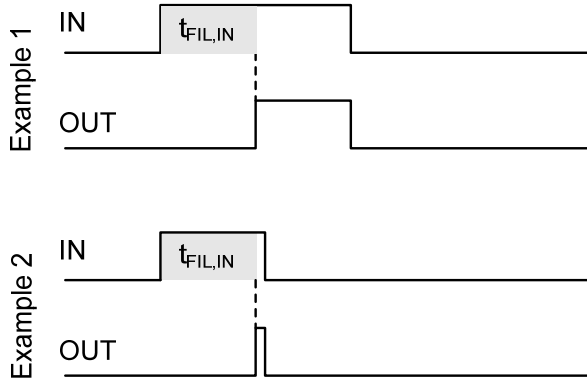


Figure 12: Typical input filter

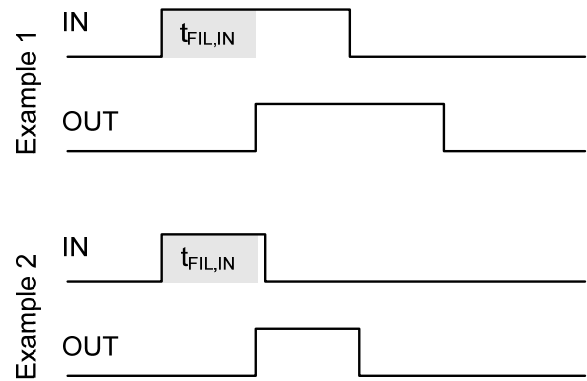


Figure 13: Advanced input filter

**Short-Pulse / Noise Rejection**

This device's input filter provides protection against short-pulses (e.g., noise) on the input lines. If the duration of the input signal is less than  $t_{FIL,IN}$ , the output will not change states. Example 1 of Figure 14 shows the input and output in the low state with positive noise spikes of durations less than  $t_{FIL,IN}$ ; the output does not change states. Example 2 of Figure 19 shows the input and output in the high state with negative noise spikes of durations less than  $t_{FIL,IN}$ ; the output does not change states.

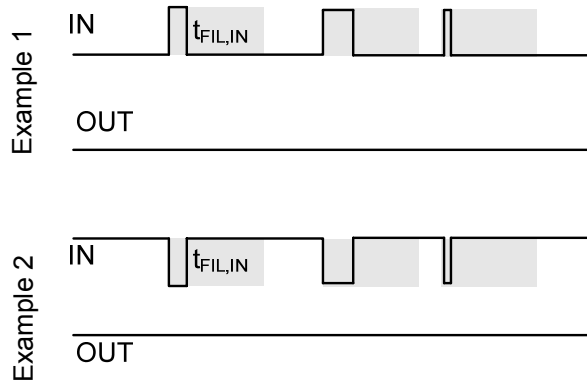


Figure 14: Noise rejecting input filters

Figures 15 and 16 present lab data that illustrates the characteristics of the input filters while receiving ON and OFF pulses.

The input filter characteristic is shown in Figure 15; the left side illustrates the narrow pulse ON (short positive pulse) characteristic while the left shows the narrow pulse OFF (short negative pulse) characteristic. The x-axis of Figure 20 shows the duration of  $PW_{IN}$ , while the y-axis shows the resulting  $PW_{OUT}$  duration. It can be seen that for a  $PW_{IN}$  duration less than  $t_{FIL,IN}$ , that the resulting  $PW_{OUT}$  duration is zero (e.g., the filter rejects the input signal/noise). We also see that once the  $PW_{IN}$  duration exceed  $t_{FIL,IN}$ , that the  $PW_{OUT}$  durations mimic the  $PW_{IN}$  durations very well over this interval with the symmetry improving as the duration increases. To ensure proper operation of the HVIC, it is suggested that the input pulse width for the high-side inputs be  $\geq 500$  ns.

The difference between the  $PW_{OUT}$  and  $PW_{IN}$  signals of both the narrow ON and narrow OFF cases is shown in Figure 16; the careful reader will note the scale of the y-axis. The x-axis of Figure 21 shows the duration of  $PW_{IN}$ , while the y-axis shows the resulting  $PW_{OUT}-PW_{IN}$  duration. This data illustrates the performance and near symmetry of this input filter.





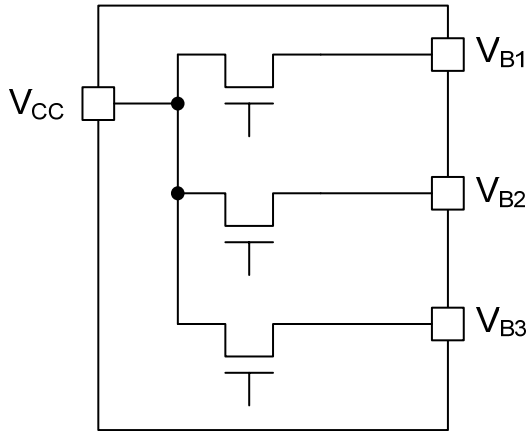


Figure 17: Internal bootstrap MOSFET connection

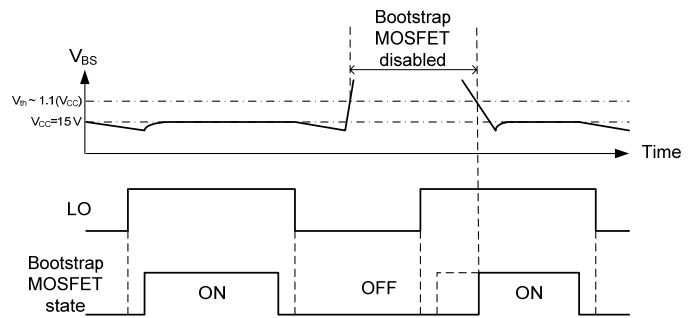


Figure 18: Bootstrap MOSFET state diagram

A bootstrap MOSFET is suitable for most of the PWM modulation schemes and can be used either in parallel with the external bootstrap network (i.e., diode and resistor) or as a replacement of it. The use of the integrated bootstrap as a replacement of the external bootstrap network may have some limitations. An example of this limitation may arise when this functionality is used in non-complementary PWM schemes (typically 6-step modulations) and at very high PWM duty cycle. In these cases, superior performances can be achieved by using an external bootstrap diode in parallel with the internal bootstrap network.

### Bootstrap Power Supply Design

For information related to the design of the bootstrap power supply while using the integrated bootstrap functionality of the IRS233(0,2)D family, please refer to Application Note 1123 (AN-1123) entitled "Bootstrap Network Analysis: Focusing on the Integrated Bootstrap Functionality." This application note is available at [www.irf.com](http://www.irf.com).

For information related to the design of a standard bootstrap power supply (i.e., using an external discrete diode) please refer to Design Tip 04-4 (DT04-4) entitled "Using Monolithic High Voltage Gate Drivers." This design tip is available at [www.irf.com](http://www.irf.com).

### Separate Logic and Power Grounds

The IRS233(0,2)(D) has separate logic and power ground pin ( $V_{SS}$  and  $V_{SO}$  respectively) to eliminate some of the noise problems that can occur in power conversion applications. Current sensing shunts are commonly used in many applications for power inverter protection (i.e., over-current protection), and in the case of motor drive applications, for motor current measurements. In these situations, it is often beneficial to separate the logic and power grounds.

Figure 19 shows a HVIC with separate  $V_{SS}$  and  $V_{SO}$  pins and how these two grounds are used in the system. The  $V_{SS}$  is used as the reference point for the logic and over-current circuitry;  $V_X$  in the figure is the voltage between the ITRIP pin and the  $V_{SS}$  pin. Alternatively, the  $V_{SO}$  pin is the reference point for the low-side gate drive circuitry. The output voltage used to drive the low-side gate is  $V_{LO-VSO}$ ; the gate-emitter voltage ( $V_{GE}$ ) of the low-side switch is the output voltage of the driver minus the drop across  $R_{G,LO}$ .

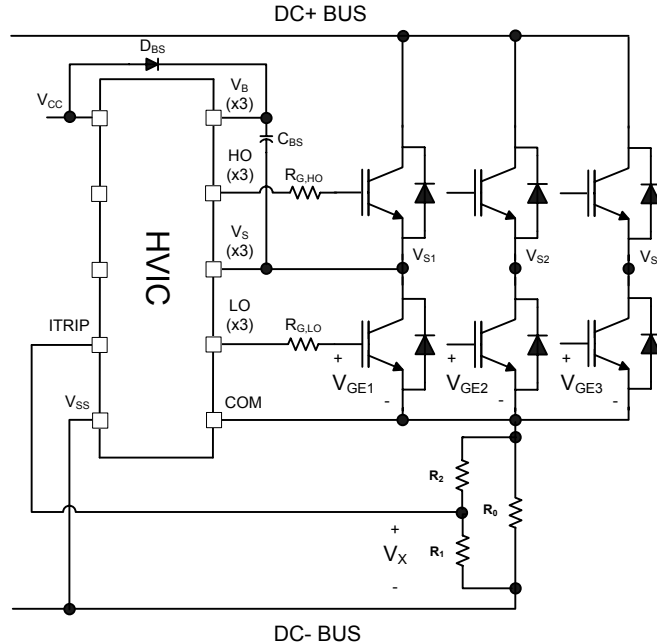


Figure 19: Separate  $V_{SS}$  and VSO pins

### Negative $V_s$ Transient SOA

A common problem in today's high-power switching converters is the transient response of the switch node's voltage as the power switches transition on and off quickly while carrying a large current. A typical 3-phase inverter circuit is shown in Figure 20; here we define the power switches and diodes of the inverter.

If the high-side switch (e.g., the IGBT Q1 in Figures 21 and 22) switches off, while the U phase current is flowing to an inductive load, a current commutation occurs from high-side switch (Q1) to the diode (D2) in parallel with the low-side switch of the same inverter leg. At the same instance, the voltage node  $V_{S1}$ , swings from the positive DC bus voltage to the negative DC bus voltage.

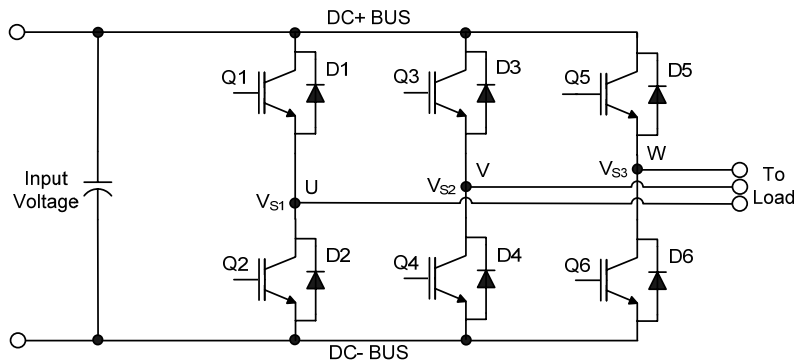


Figure 20: Three phase inverter

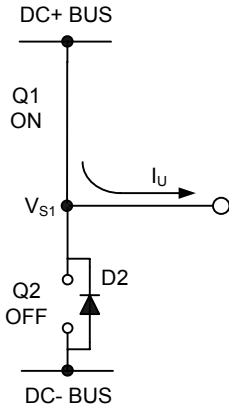


Figure 21: Q1 conducting

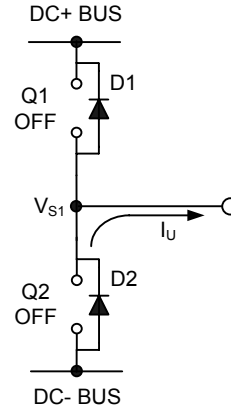


Figure 22: D2 conducting

Also when the V phase current flows from the inductive load back to the inverter (see Figures 23 and 24), and Q4 IGBT switches on, the current commutation occurs from D3 to Q4. At the same instance, the voltage node,  $V_{S2}$ , swings from the positive DC bus voltage to the negative DC bus voltage.

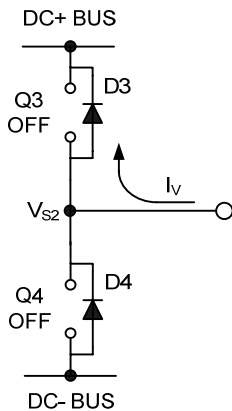


Figure 23: D3 conducting

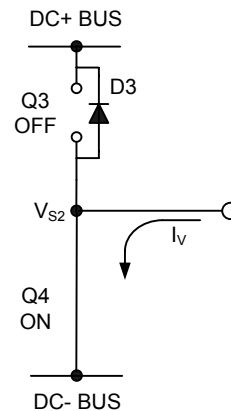


Figure 24: Q4 conducting

However, in a real inverter circuit, the  $V_S$  voltage swing does not stop at the level of the negative DC bus, rather it swings below the level of the negative DC bus. This undershoot voltage is called "negative  $V_S$  transient".

The circuit shown in Figure 25 depicts one leg of the three phase inverter; Figures 26 and 27 show a simplified illustration of the commutation of the current between Q1 and D2. The parasitic inductances in the power circuit from the die bonding to the PCB tracks are lumped together in  $L_C$  and  $L_E$  for each IGBT. When the high-side switch is on,  $V_{S1}$  is below the DC+ voltage by the voltage drops associated with the power switch and the parasitic elements of the circuit. When the high-side power switch turns off, the load current momentarily flows in the low-side freewheeling diode due to the inductive load connected to  $V_{S1}$  (the load is not shown in these figures). This current flows from the DC- bus (which is connected to the VSO pin of the HVIC) to the load and a negative voltage between  $V_{S1}$  and the DC- Bus is induced (i.e., the VSO pin of the HVIC is at a higher potential than the  $V_S$  pin).

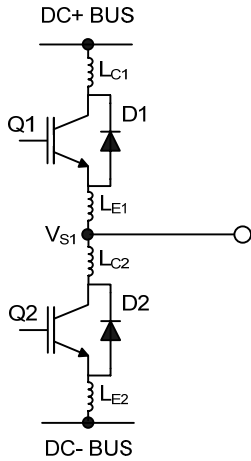


Figure 25: Parasitic Elements

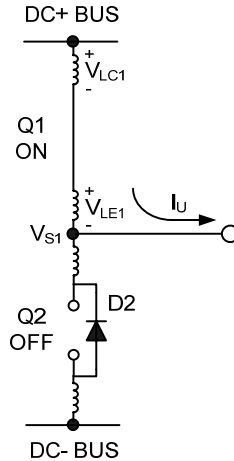


Figure 26:  $V_s$  positive

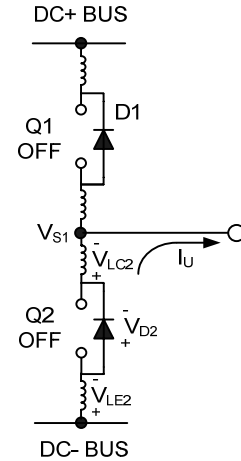


Figure 27:  $V_s$  negative

In a typical motor drive system,  $dV/dt$  is typically designed to be in the range of 3-5 V/ns. The negative  $V_s$  transient voltage can exceed this range during some events such as short circuit and over-current shutdown, when  $di/dt$  is greater than in normal operation.

International Rectifier's HVICs have been designed for the robustness required in many of today's demanding applications. An indication of the IRS233(0,2)(D)'s robustness can be seen in Figure 28, where there is represented the IRS233(0,2)(D) Safe Operating Area at  $V_{BS}=15V$  based on repetitive negative  $V_s$  spikes. A negative  $V_s$  transient voltage falling in the grey area (outside SOA) may lead to IC permanent damage; viceversa unwanted functional anomalies or permanent damage to the IC do not appear if negative  $V_s$  transients fall inside SOA.

At  $V_{BS}=15V$  in case of  $-V_s$  transients greater than  $-16.5 V$  for a period of time greater than 50 ns; the HVIC will hold by design the high-side outputs in the off state for 4.5  $\mu s$ .

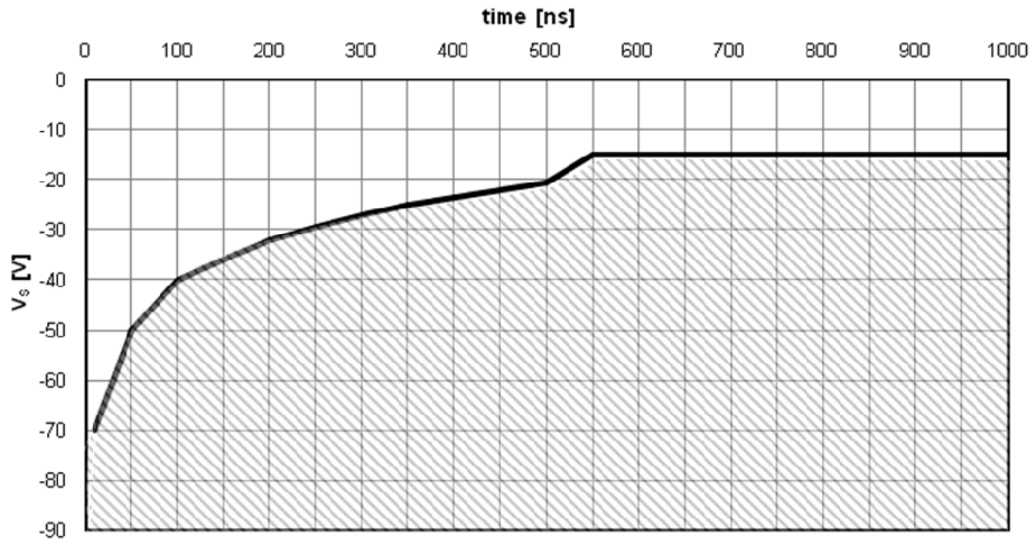
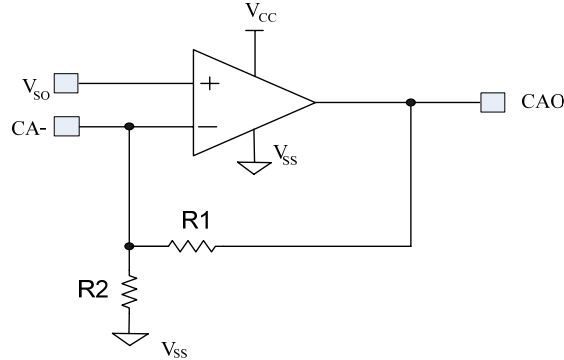


Figure 28: Negative  $V_s$  transient SOA for IRS233(0,2)(D)

Even though the IRS233(0,2)(D) has been shown able to handle these large negative  $V_s$  transient conditions, it is highly recommended that the circuit designer always limit the negative  $V_s$  transients as much as possible by careful PCB layout and component use.

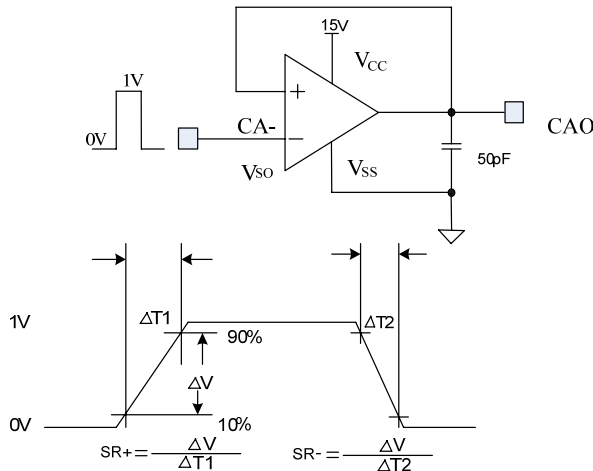
**DC- bus Current Sensing**

A ground referenced current signal amplifier has been included so that the current in the return leg of the DC bus may be monitored. A typical circuit configuration is provided in Fig.29. The signal coming from the shunt resistor is amplified by the ratio  $(R1+R2)/R2$ . Additional details can be found on Design Tip DT 92-6. This design tip is available at [www.irf.com](http://www.irf.com).

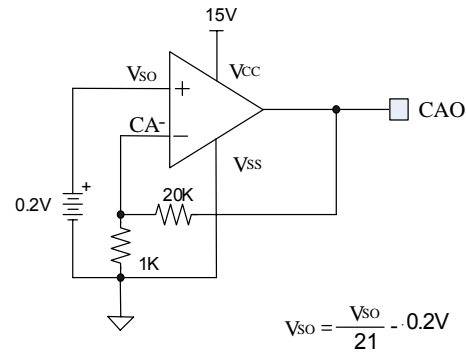


**Figure 29: Current amplifier typical configuration**

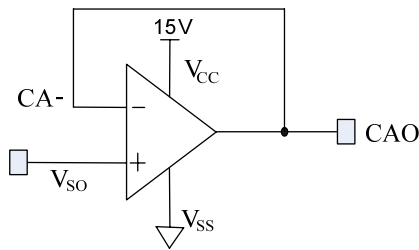
In the following Figures 30, 31, 32, 33 the configurations used to measure the operational amplifier characteristics are shown.



**Figure 30: Operational Amplifier Slew rate measurement**



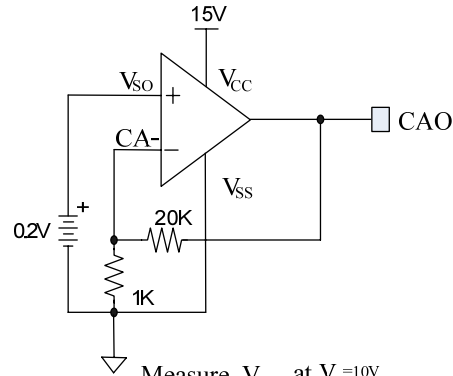
**Figure 31: Operational Amplifier Input Offset Voltage measurement**



Measure  $V_{CAO1}$  at  $V_{SO} = 0.1V$   
 $V_{CAO2}$  at  $V_{SO} = 1.1V$

$$CMRR = -20 \cdot \log \left| \frac{(V_{CAO1} - 0.1V) - (V_{CAO2} - 1.1V)}{1V} \right| \text{ (dB)}$$

Figure 32: Operational Amplifier Common mode rejection measurement



Measure  $V_{CAO1}$  at  $V_{CC} = 10V$   
 $V_{CAO2}$  at  $V_{CC} = 20V$

$$PSRR = -20 \cdot \log \left| \frac{V_{CAO1} - V_{CAO2}}{(10V) (21)} \right| \text{ (dB)}$$

Figure 33: Operational Amplifier Power supply rejection measurement

### PCB Layout Tips

**Distance between high and low voltage components:** It's strongly recommended to place the components tied to the floating voltage pins ( $V_B$  and  $V_S$ ) near the respective high voltage portions of the device. The IRS233(0,2)(D) in the PLCC44 package has had some unused pins removed in order to maximize the distance between the high voltage and low voltage pins. Please see the Case Outline PLCC44 information in this datasheet for the details.

**Ground Plane:** In order to minimize noise coupling, the ground plane should not be placed under or near the high voltage floating side.

**Gate Drive Loops:** Current loops behave like antennas and are able to receive and transmit EM noise (see Figure 34). In order to reduce the EM coupling and improve the power switch turn on/off performance, the gate drive loops must be reduced as much as possible. Moreover, current can be injected inside the gate drive loop via the IGBT collector-to-gate parasitic capacitance. The parasitic auto-inductance of the gate loop contributes to developing a voltage across the gate-emitter, thus increasing the possibility of a self turn-on effect.

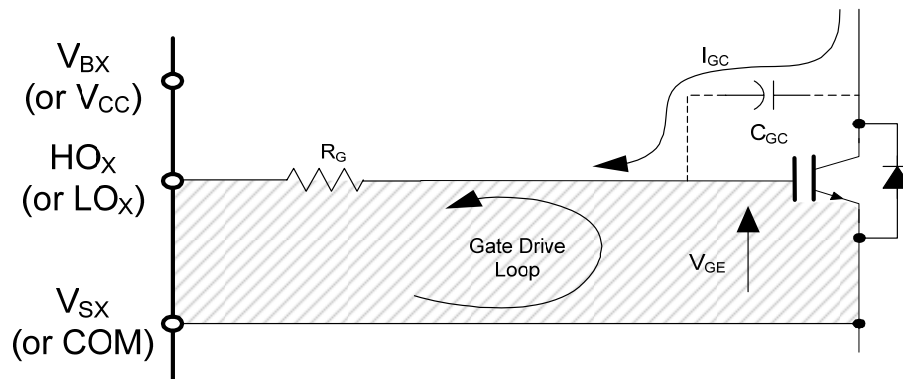
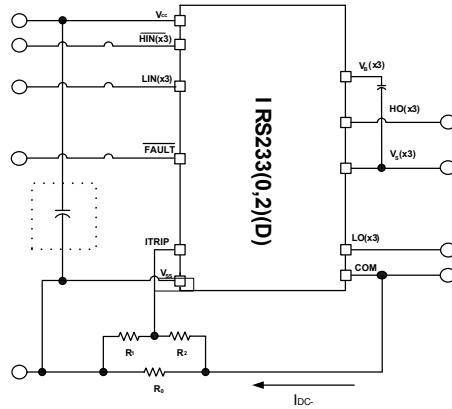


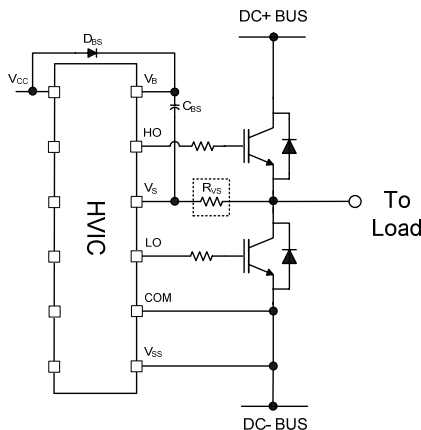
Figure 34: Antenna Loops

**Supply Capacitor:** It is recommended to place a bypass capacitor ( $C_{IN}$ ) between the  $V_{CC}$  and  $V_{SS}$  pins. This connection is shown in Figure 35. A ceramic  $1\ \mu\text{F}$  ceramic capacitor is suitable for most applications. This component should be placed as close as possible to the pins in order to reduce parasitic elements.

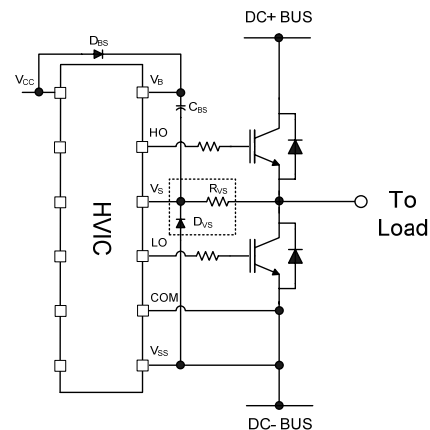


**Figure 35: Supply capacitor**

**Routing and Placement:** Power stage PCB parasitic elements can contribute to large negative voltage transients at the switch node; it is recommended to limit the phase voltage negative transients. In order to avoid such conditions, it is recommended to 1) minimize the high-side emitter to low-side collector distance, and 2) minimize the low-side emitter to negative bus rail stray inductance. However, where negative  $V_S$  spikes remain excessive, further steps may be taken to reduce the spike. This includes placing a resistor ( $5\ \Omega$  or less) between the  $V_S$  pin and the switch node (see Figure 36), and in some cases using a clamping diode between  $V_{SS}$  and  $V_S$  (see Figure 37). See DT04-4 at [www.irf.com](http://www.irf.com) for more detailed information.



**Figure 36:  $V_S$  resistor**



**Figure 37:  $V_S$  clamping diode**

### Additional Documentation

Several technical documents related to the use of HVICs are available at [www.irf.com](http://www.irf.com); use the Site Search function and the document number to quickly locate them. Below is a short list of some of these documents.

- DT97-3: Managing Transients in Control IC Driven Power Stages
- AN-1123: Bootstrap Network Analysis: Focusing on the Integrated Bootstrap Functionality
- DT04-4: Using Monolithic High Voltage Gate Drivers
- AN-978: HV Floating MOS-Gate Driver ICs



### Parameter Temperature Trends

Figures 38-76 provide information on the experimental performance of the IRS233(0,2)(D)(S&J) HVIC. The line plotted in each figure is generated from actual lab data. A small number of individual samples were tested at three temperatures (-40 °C, 25 °C, and 125 °C) in order to generate the experimental (Exp.) curve. The line labeled Exp. consist of three data points (one data point at each of the tested temperatures) that have been connected together to illustrate the understood temperature trend. The individual data points on the curve were determined by calculating the averaged experimental value of the parameter (for a given temperature).

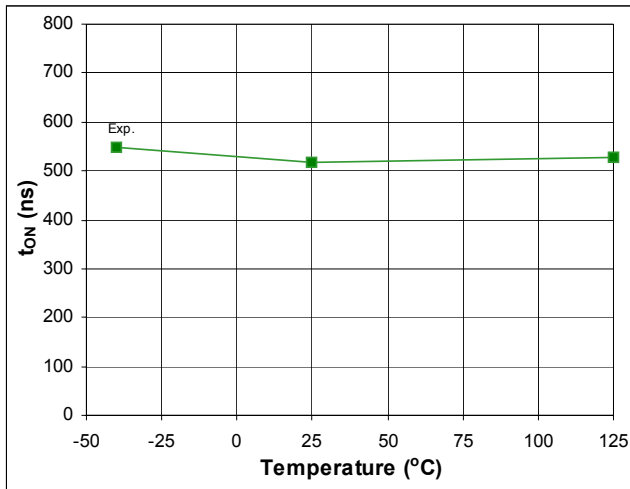


Fig. 38. Turn-on Propagation Delay vs. Temperature

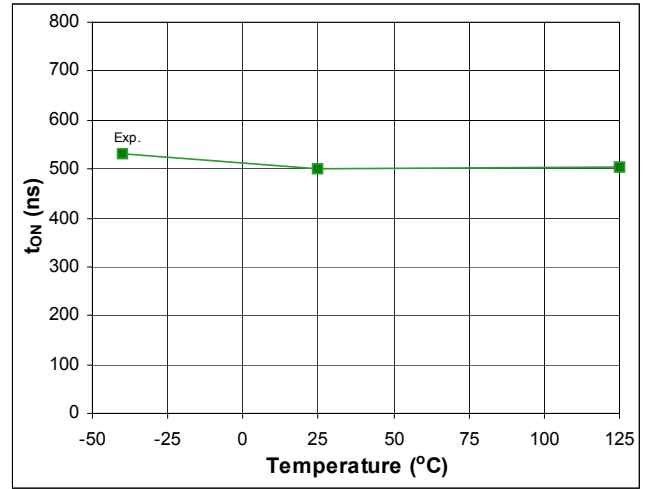


Fig. 39. Turn-on Propagation Delay vs. Temperature

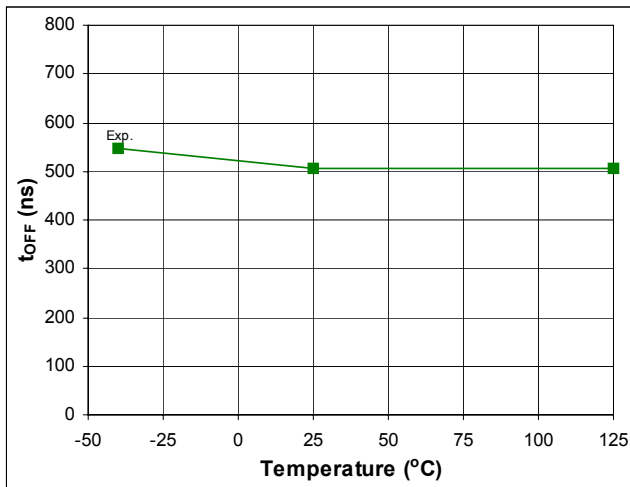


Fig. 40. Turn-off Propagation Delay vs. Temperature

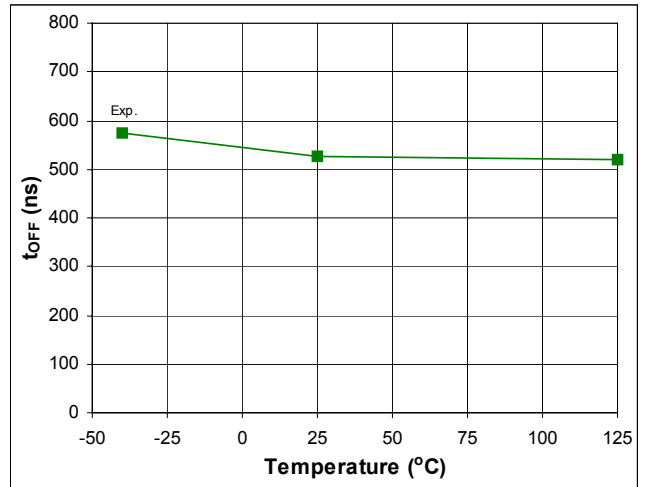


Fig. 41. Turn-off Propagation Delay vs. Temperature

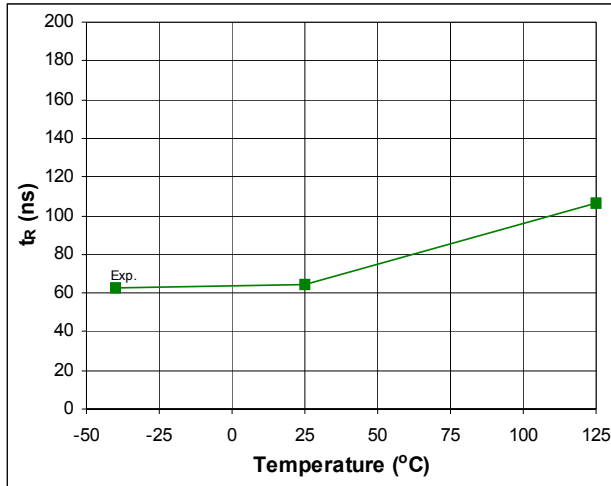


Fig. 42. Turn-on Rise Time vs. Temperature

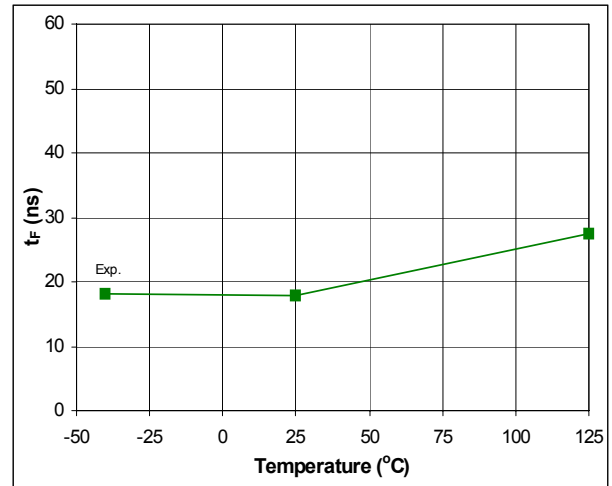


Fig.43. Turn-off Fall Time vs. Temperature

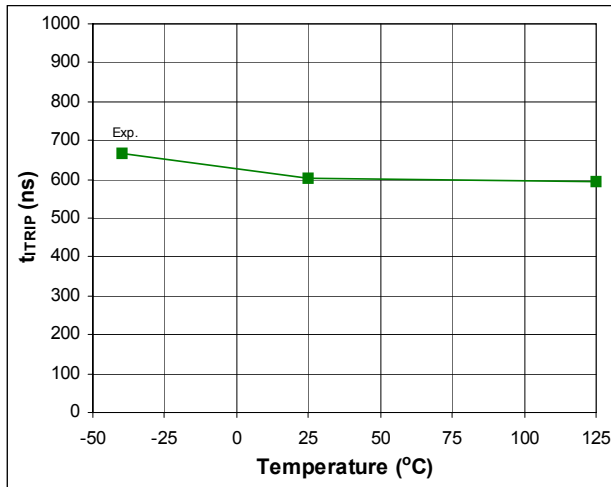


Fig. 44. ITRIP to Output Shutdown Propagation Delay vs. Temperature

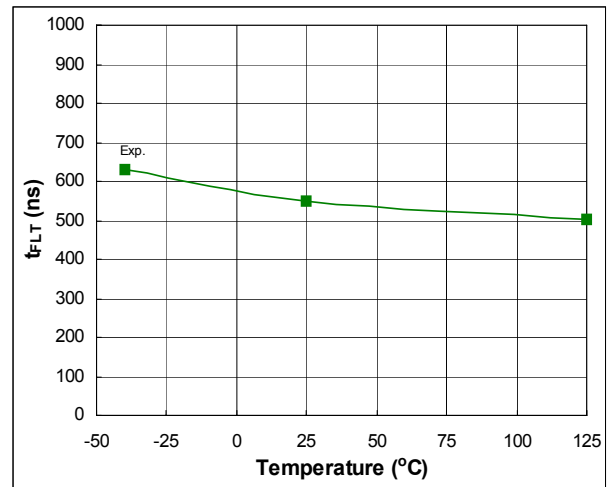


Fig. 45. ITRIP to FAULT Indication Delay vs. Temperature

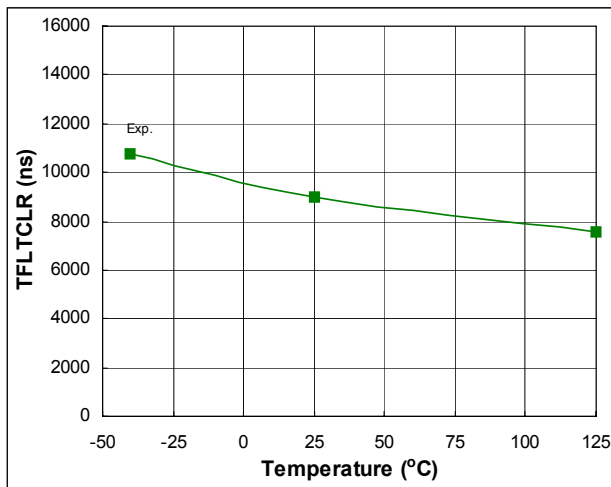


Fig.46. FAULT Clear Time vs. Temperature

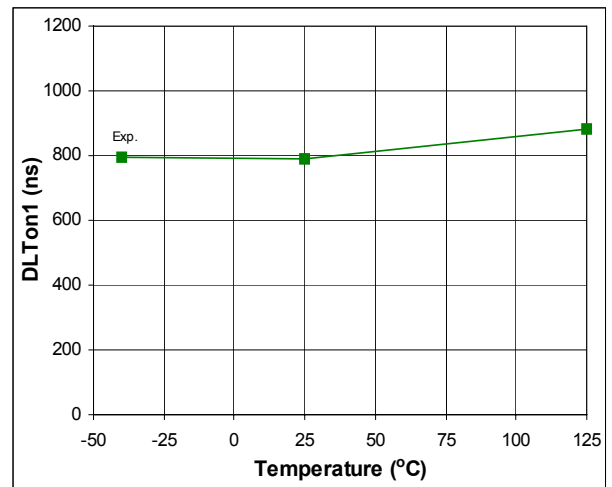


Fig. 47. Dead Time vs. Temperature

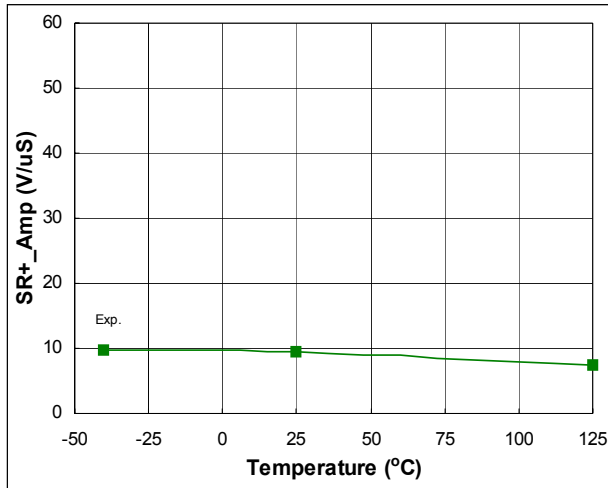


Fig. 48. Operational Amplifier Slew Rate (+) vs. Temperature

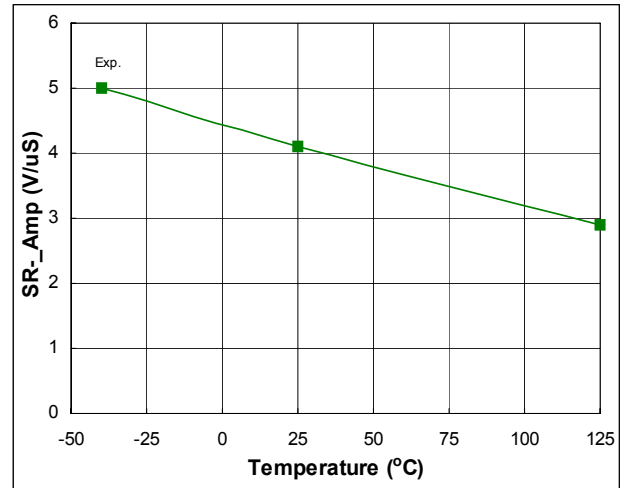


Fig. 49. Operational Amplifier Slew Rate (-) vs. Temperature

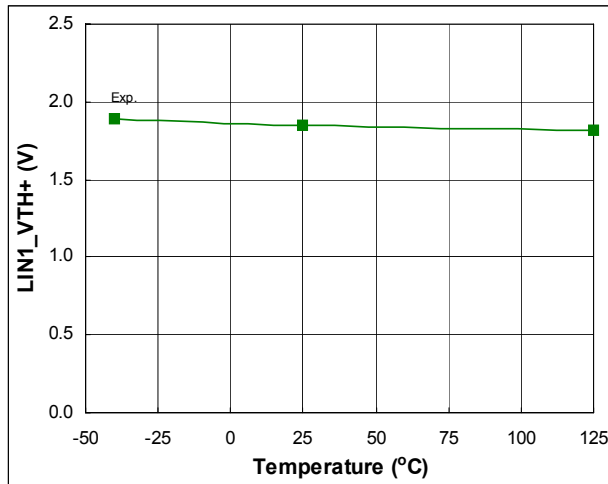


Fig. 50. Input Positive Going Threshold vs. Temperature

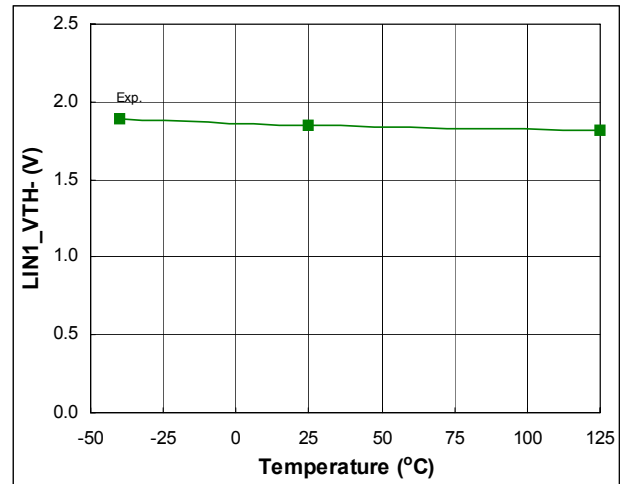


Fig. 51. Input Negative Going Threshold vs. Temperature

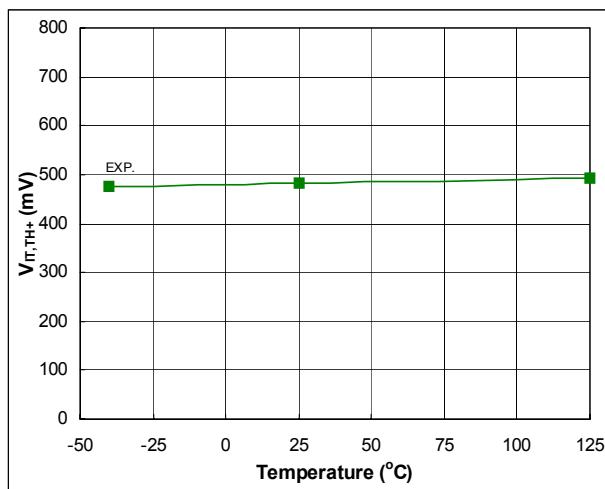


Fig. 52. ITRIP Input Positive Going Threshold vs. Temperature

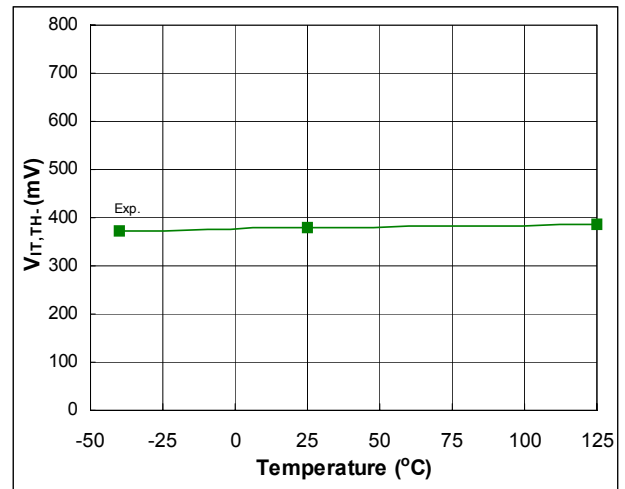


Fig. 53. ITRIP Input Negative Going Threshold vs. Temperature

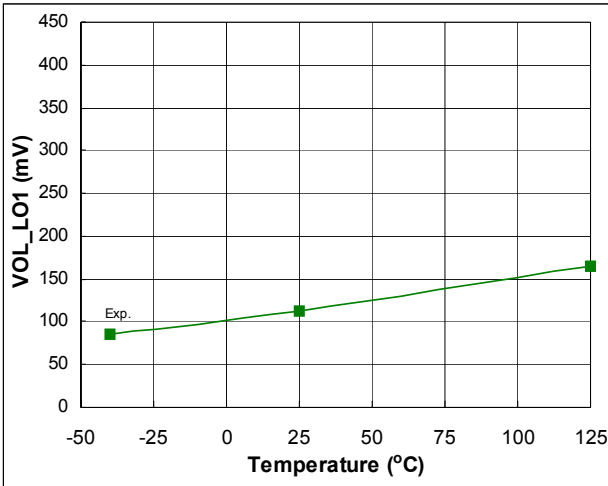


Fig. 54. Low Level Output Voltage vs. Temperature

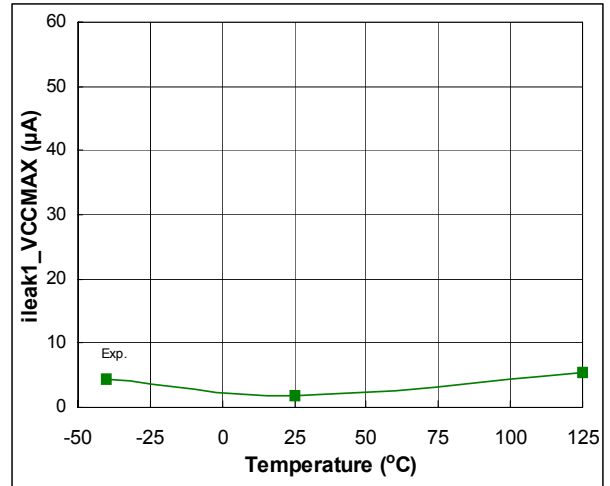


Fig. 55. Offset Supply Leakage Current vs. Temperature

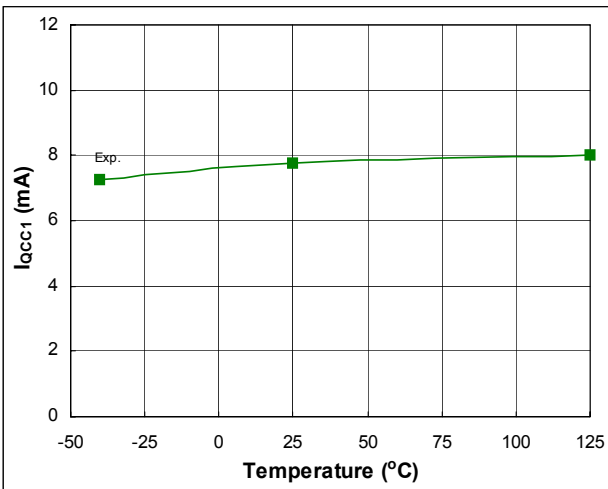


Fig. 56. Quiescent V<sub>CC</sub> Supply Current vs. Temperature

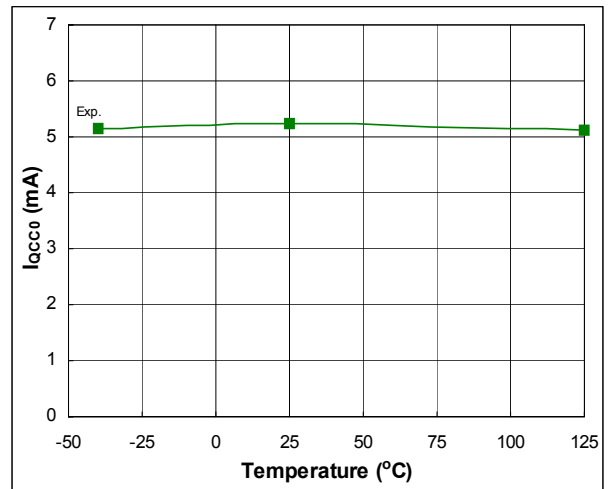


Fig. 57. Quiescent V<sub>CC</sub> Supply Current vs. Temperature

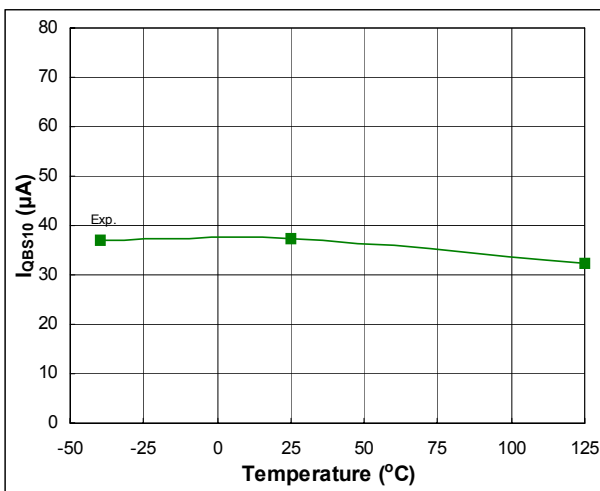


Fig. 58. Quiescent V<sub>BS</sub> Supply Current vs. Temperature

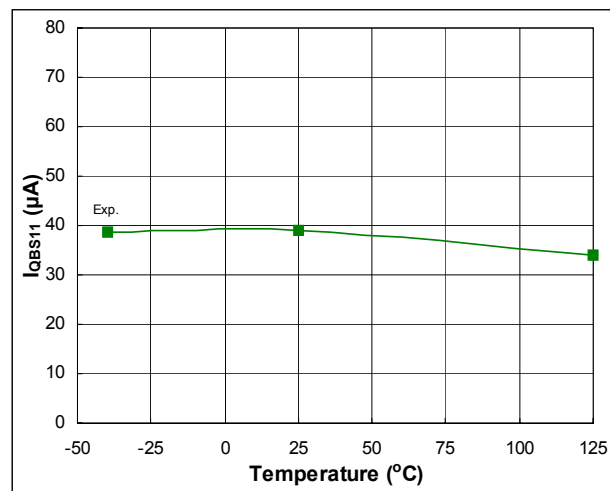


Fig. 59. Quiescent V<sub>BS</sub> Supply Current vs. Temperature

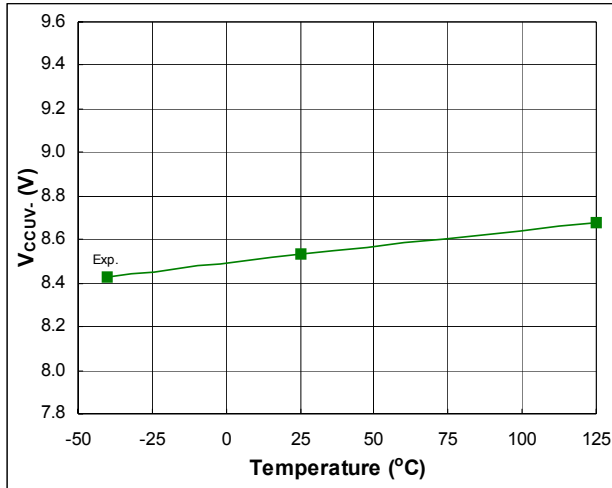


Fig. 60. V<sub>CC</sub> Supply Undervoltage Negative Going Threshold vs. Temperature

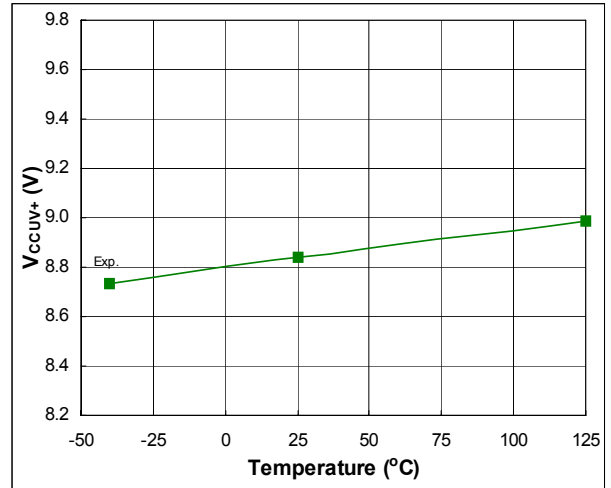


Fig. 61. V<sub>CC</sub> Supply Undervoltage Positive Going Threshold vs. Temperature

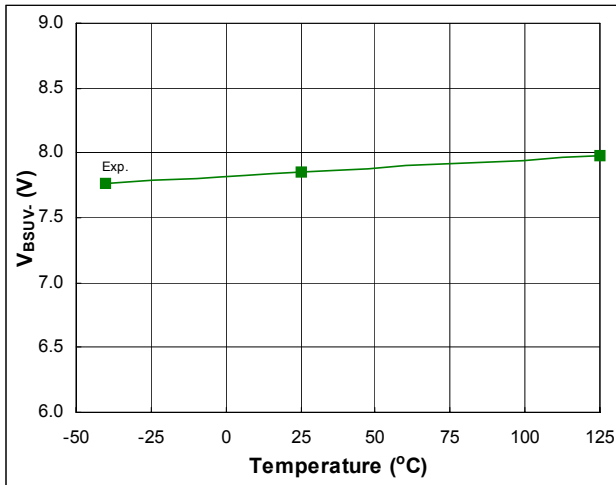


Fig. 62. V<sub>BS</sub> Supply Undervoltage Negative Going Threshold vs. Temperature

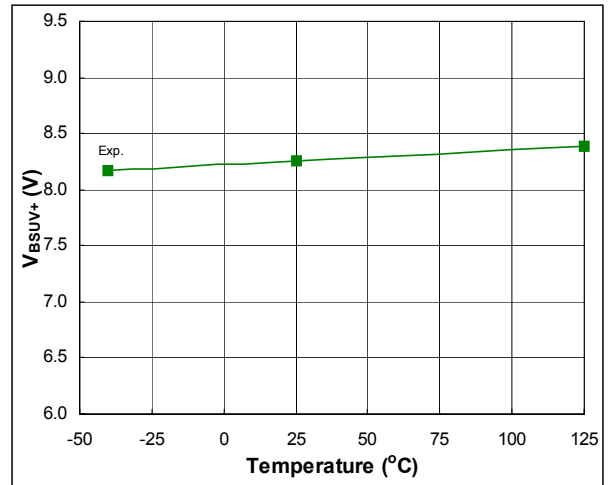


Fig. 63. V<sub>BS</sub> Supply Undervoltage Positive Going Threshold vs. Temperature

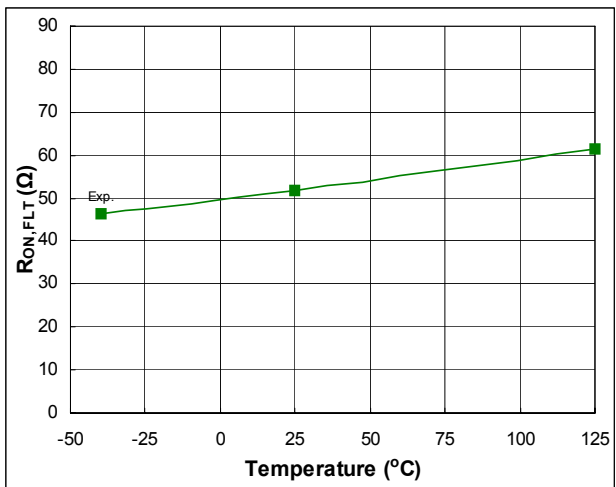


Fig. 64. FAULT Low On-Resistance vs. Temperature

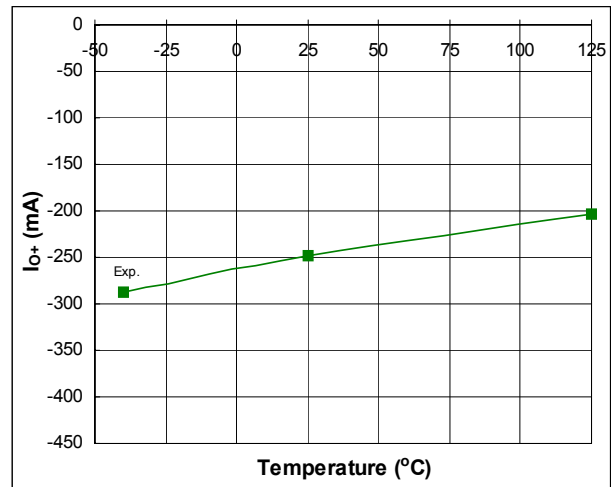


Fig. 65. Output High Short Circuit Pulsed Current vs. Temperature

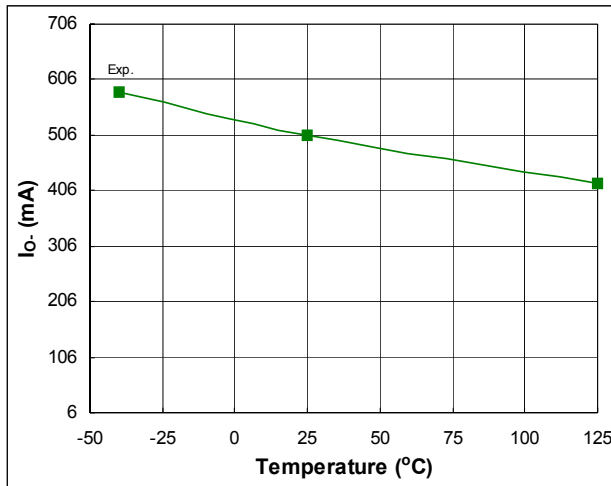


Fig. 66. Output Low Short Circuit Pulsed Current vs. Temperature

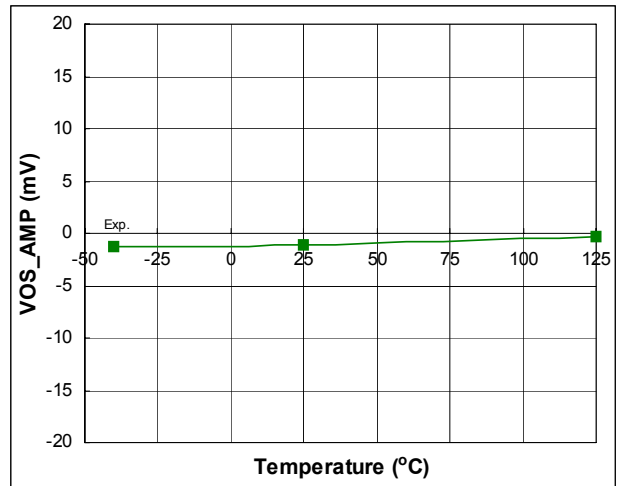


Fig. 67. Offset Opamp vs. Temperature

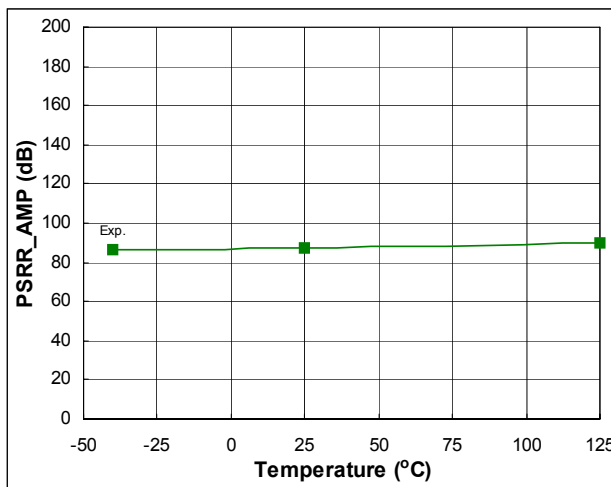


Fig. 68. Operational Amplifier Power Supply Rejection Ratio vs. Temperature

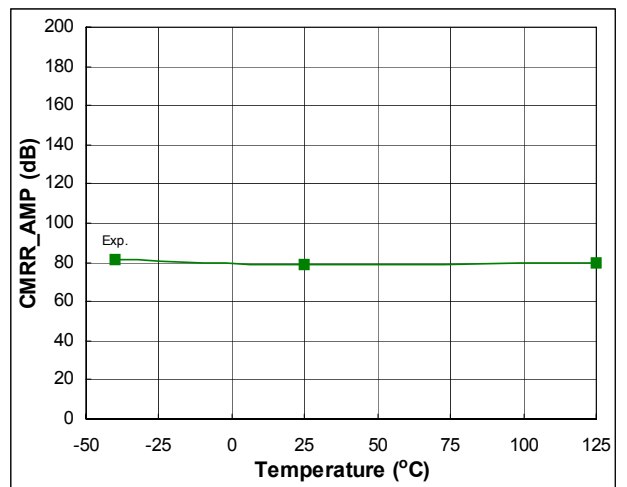


Fig. 69. Operational Amplifier Common Mode Rejection Ratio vs. Temperature

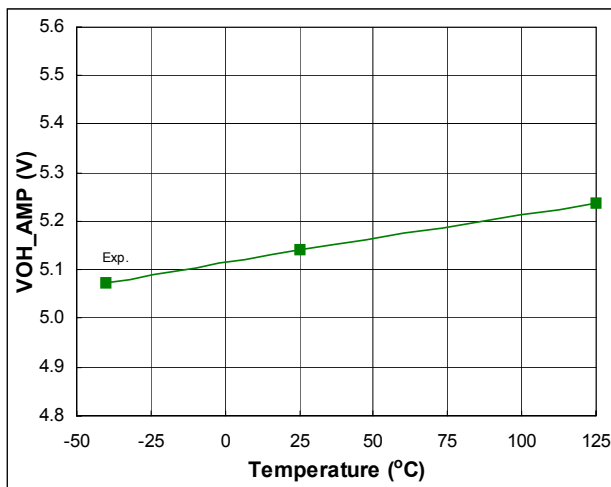


Fig. 70. Operational Amplifier High Level Output Voltage vs. Temperature

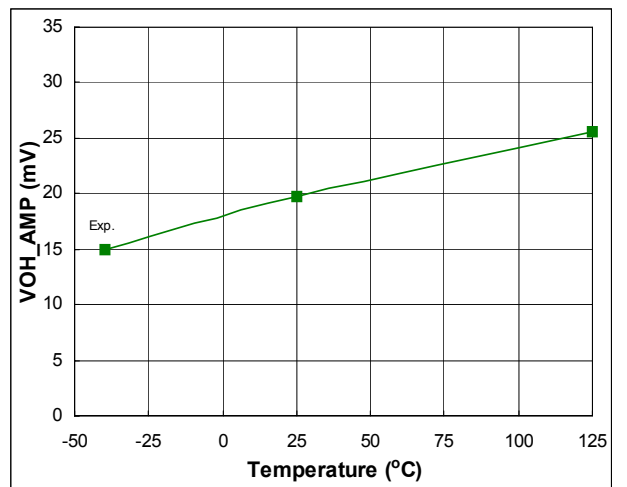


Fig. 71. Operational Amplifier Low Level Output Voltage vs. Temperature

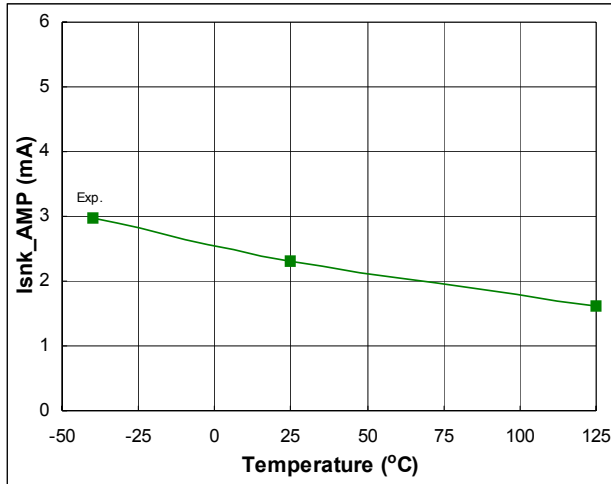


Fig. 72. Operational Amplifier Output Sink Current vs. Temperature

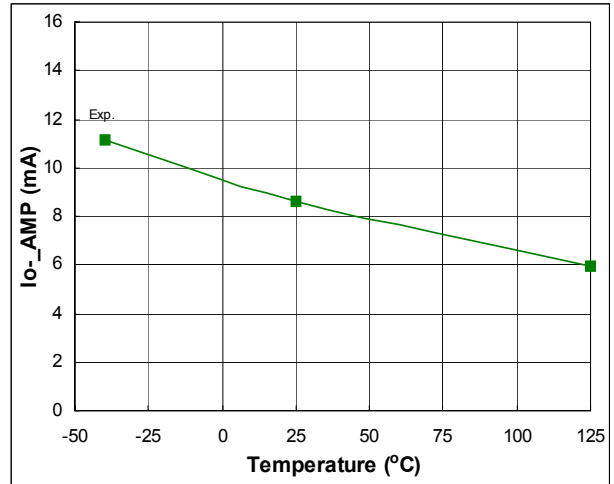


Fig. 73. Operational Amplifier Output Low Short Circuit Current vs. Temperature

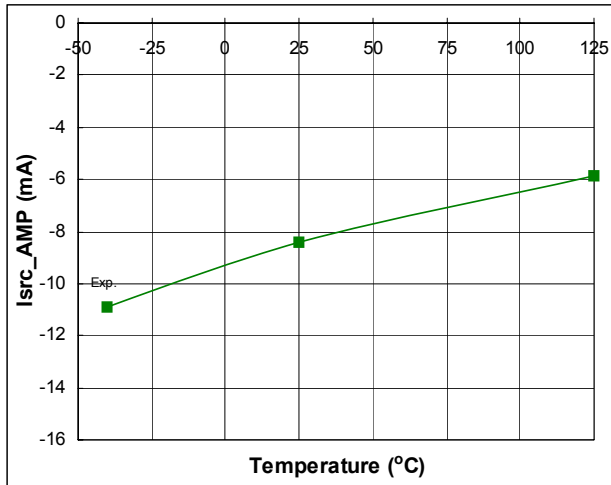


Fig. 74. Operational Amplifier Output Source Current vs. Temperature

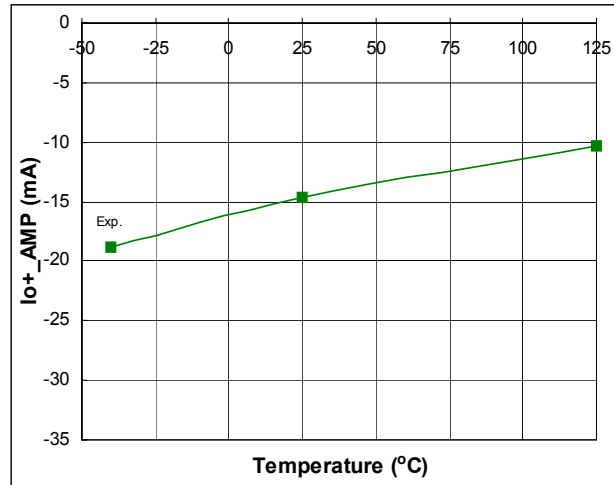


Fig. 75. Operational Amplifier Output High Short Circuit Current vs. Temperature

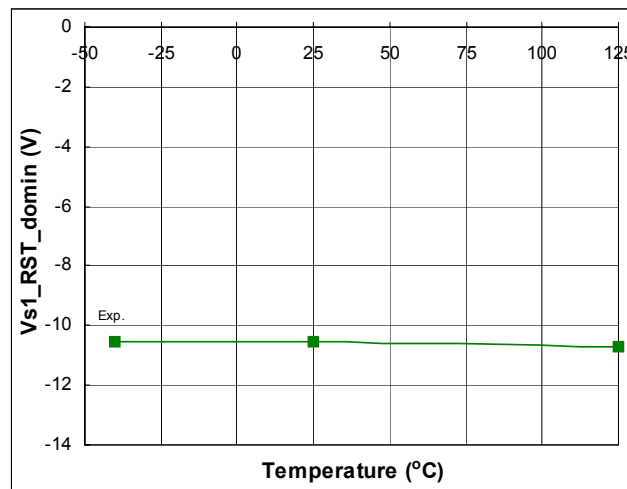
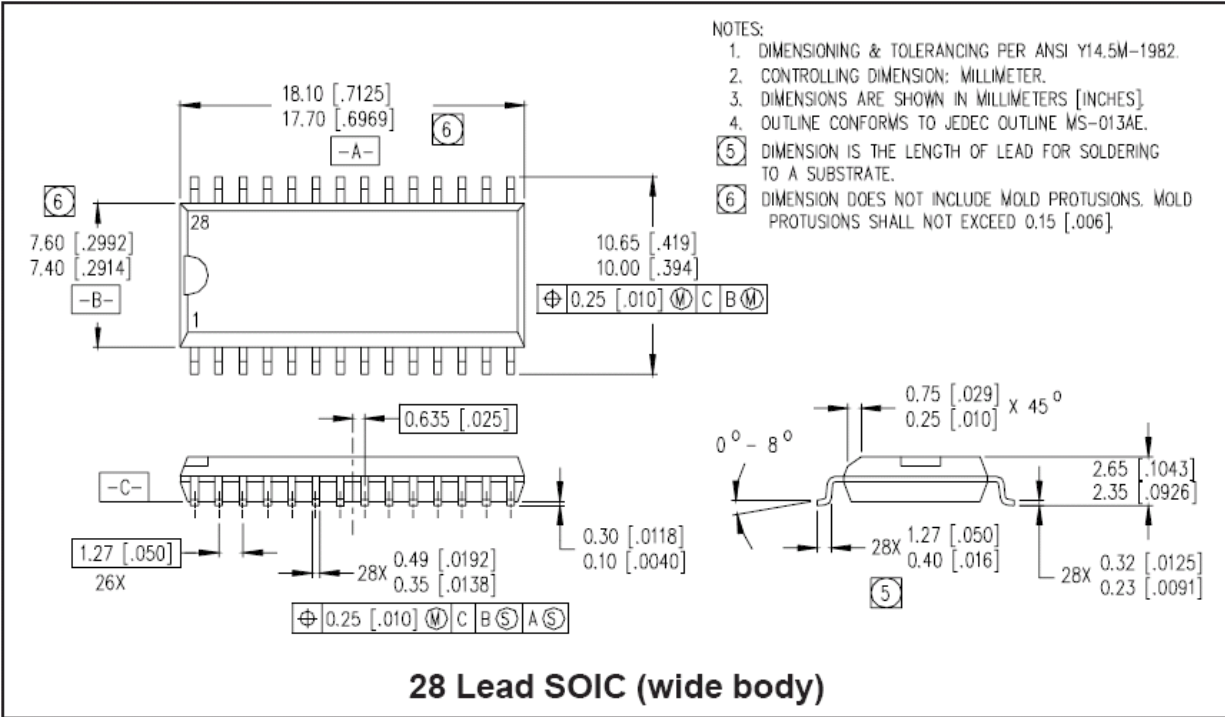


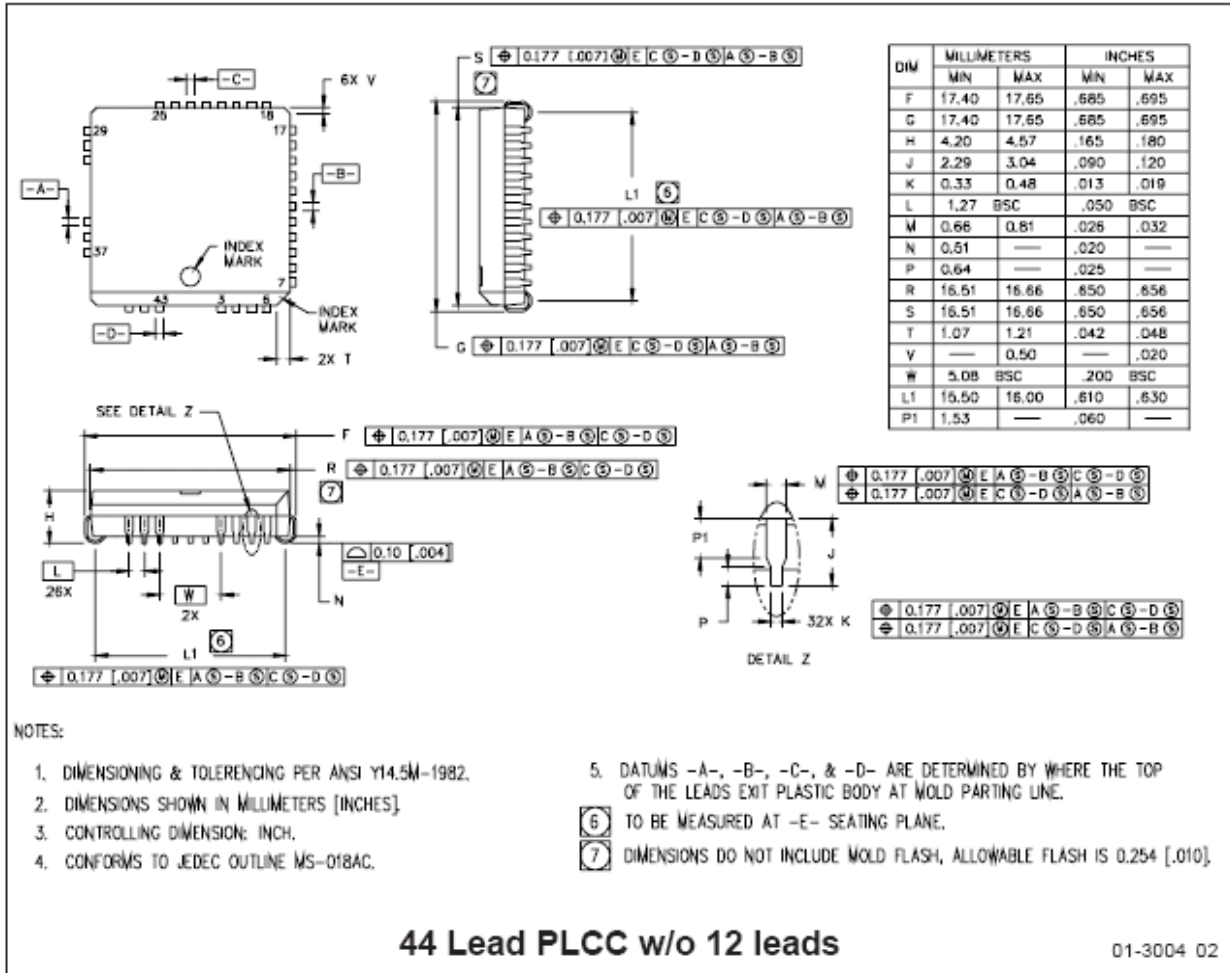
Fig. 76. Max -Vs vs. Temperature

**Case Outlines**

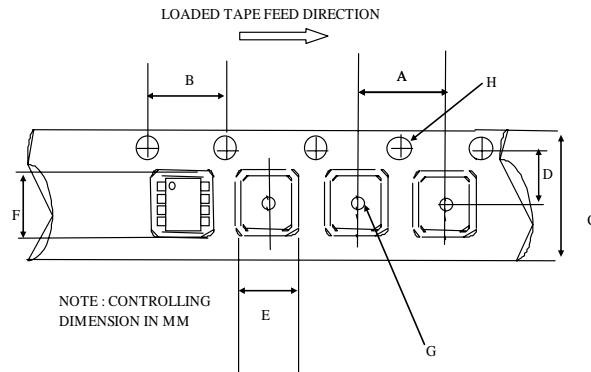




Case Outlines

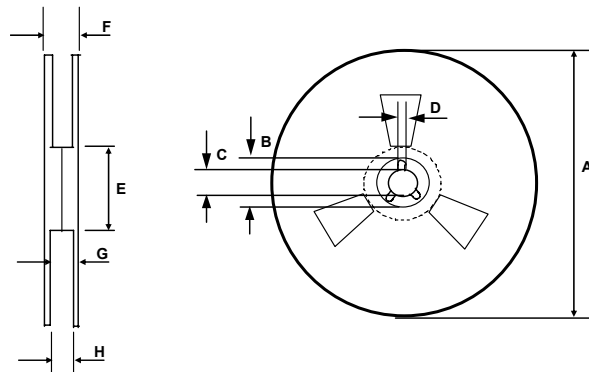


**Tape and Reel Details: SOIC28W**



CARRIER TAPE DIMENSION FOR 28SOICW

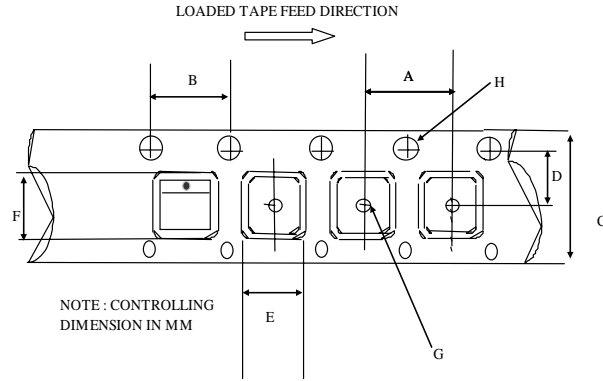
Code	Metric		Imperial	
	Min	Max	Min	Max
A	11.90	12.10	0.468	0.476
B	3.90	4.10	0.153	0.161
C	23.70	24.30	0.933	0.956
D	11.40	11.60	0.448	0.456
E	10.80	11.00	0.425	0.433
F	18.20	18.40	0.716	0.724
G	1.50	n/a	0.059	n/a
H	1.50	1.60	0.059	0.062



REEL DIMENSIONS FOR 28SOICW

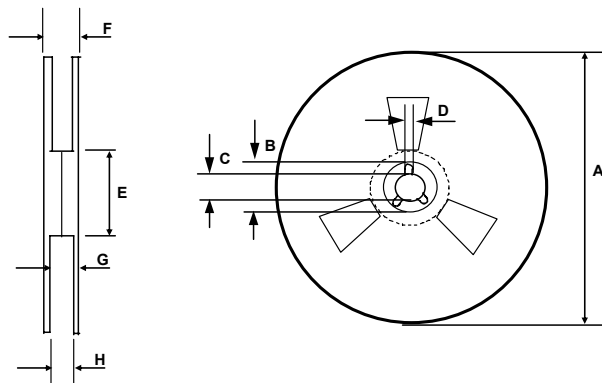
Code	Metric		Imperial	
	Min	Max	Min	Max
A	329.60	330.25	12.976	13.001
B	20.95	21.45	0.824	0.844
C	12.80	13.20	0.503	0.519
D	1.95	2.45	0.767	0.096
E	98.00	102.00	3.858	4.015
F	n/a	30.40	n/a	1.196
G	26.50	29.10	1.04	1.145
H	24.40	26.40	0.96	1.039

**Tape and Reel Details: PLCC44**



CARRIER TAPE DIMENSION FOR 44PLCC

Code	Metric		Imperial	
	Min	Max	Min	Max
A	23.90	24.10	0.94	0.948
B	3.90	4.10	0.153	0.161
C	31.70	32.30	1.248	1.271
D	14.10	14.30	0.555	0.562
E	17.90	18.10	0.704	0.712
F	17.90	18.10	0.704	0.712
G	2.00	n/a	0.078	n/a
H	1.50	1.60	0.059	0.062



REEL DIMENSIONS FOR 44PLCC

Code	Metric		Imperial	
	Min	Max	Min	Max
A	329.60	330.25	12.976	13.001
B	20.95	21.45	0.824	0.844
C	12.80	13.20	0.503	0.519
D	1.95	2.45	0.767	0.096
E	98.00	102.00	3.858	4.015
F	n/a	38.4	n/a	1.511
G	34.7	35.8	1.366	1.409
H	32.6	33.1	1.283	1.303

**Ordering Information**

Base Part Number	Package Type	Standard Pack		Complete Part Number
		Form	Quantity	
IRS233(0,2)(D)	SOIC28W	Tube/Bulk	25	IRS233(0,2)(D)SPbF
		Tape and Reel	1000	IRS233(0,2)(D)STRPbF
	PLCC44	Tube/Bulk	27	IRS233(0,2)(D)JPbF
		Tape and Reel	500	IRS233(0,2)(D)JTRPbF

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