

## Protected Digital Audio Driver

### Features

- Floating PWM input enables easy half bridge implementation
- Integrated programmable bi-directional over-current protection with self-reset function
- Programmable compensated preset deadtime for improved THD performances
- High noise immunity
- $\pm 100$  V high voltage ratings deliver up to 500 W output power
- 3.3 V / 5 V logic compatible input
- Operates up to 800 kHz
- RoHS compliant

### Product Summary

|                           |      |                               |
|---------------------------|------|-------------------------------|
| $V_{\text{OFFSET}}$ (max) |      | $\pm 100$ V                   |
| Gate driver               | Io+  | 1.0 A                         |
|                           | Io - | 1.2 A                         |
| Selectable Deadtime       |      | 15 ns, 25 ns,<br>35 ns, 45 ns |
| Propagation delay         |      | 90 ns                         |
| OC protection delay       |      | 1 $\mu$ s (max)               |

### Description

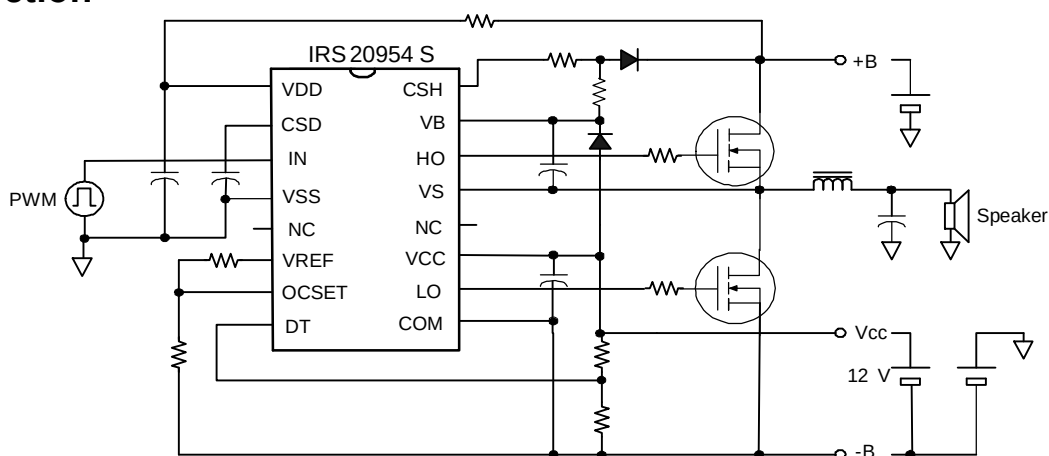
The IRS20954 is a high voltage, high speed MOSFET driver with floating PWM input, specially designed for Class D audio amplifier applications. The bi-directional current sensing requires no external shunt resistors. It can capture over-current conditions at either positive or negative load current direction. A built-in control block provides secure protection sequence against over-current conditions, including a programmable reset timer. The internal deadtime generation block provides accurate gate switch timing and enables optimum deadtime settings for better audio performances, such as THD and audio noise floor.

### Package



16-Lead SOIC (narrow body)

### Typical Connection



(Please refer to Lead Assignments for correct pin configuration. This diagram shows electrical connections only)

## 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  $V_{SS}$ ; all currents are defined positive into any lead. The thermal resistance and power dissipation ratings are measured under board mounted and still air conditions.

| Symbol          | Definition                                                  | Min.             | Max.         | Units |
|-----------------|-------------------------------------------------------------|------------------|--------------|-------|
| $V_B$           | High-side floating supply voltage                           | -0.3             | 220          | V     |
| $V_S$           | High-side floating supply voltage (Note 1)                  | $V_B-20$         | $V_B+0.3$    |       |
| $V_{HO}$        | High-side floating output voltage                           | $V_S-0.3$        | $V_B+0.3$    |       |
| $V_{CSH}$       | CSH pin input voltage                                       | $V_S-0.3$        | $V_B+0.3$    |       |
| $V_{CC}$        | Low-side fixed supply voltage (Note 1)                      | -0.3             | 20           |       |
| $V_{LO}$        | Low-side output voltage                                     | -0.3             | $V_{CC}+0.3$ |       |
| $V_{DD}$        | Floating input supply voltage                               | -0.3             | 210          |       |
| $V_{SS}$        | Floating input supply voltage (Note 1)                      | (see $I_{DDZ}$ ) | $V_{DD}+0.3$ |       |
| $V_{IN}$        | PWM input voltage                                           | $V_{SS}-0.3$     | $V_{DD}+0.3$ |       |
| $V_{CSD}$       | CSD pin input voltage                                       | $V_{SS}-0.3$     | $V_{DD}+0.3$ |       |
| $V_{DT}$        | DT pin input voltage                                        | -0.3             | $V_{CC}+0.3$ |       |
| $V_{OCSET}$     | OCSET pin input voltage                                     | -0.3             | $V_{CC}+0.3$ |       |
| $V_{REF}$       | VREF pin voltage                                            | -0.3             | $V_{CC}+0.3$ |       |
| $I_{DDZ}$       | Floating input supply zener clamp current (Note 1)          | -                | 10           | mA    |
| $I_{CCZ}$       | Low-side supply zener clamp current (Note 1)                | -                | 10           |       |
| $I_{BSZ}$       | Floating supply zener clamp current (Note 1)                | -                | 10           |       |
| $I_{OREF}$      | Reference output current                                    | -                | 5            |       |
| $d V_S / dt$    | Allowable $V_S$ voltage slew rate                           | -                | 50           | V/ns  |
| $d V_{SS} / dt$ | Allowable $V_{SS}$ voltage slew rate (Note 2)               | -                | 50           |       |
| $d V_{SS} / dt$ | Allowable $V_{SS}$ voltage slew rate upon power-up (Note 3) | -                | 50           | V/ms  |
| $P_D$           | Maximum power dissipation                                   | -                | 1.0          | W     |
| $R_{th,JA}$     | Thermal resistance, junction to ambient                     | -                | 115          | °C/W  |
| $T_J$           | Junction temperature                                        | -                | 150          | °C    |
| $T_S$           | Storage temperature                                         | -55              | 150          |       |
| $T_L$           | Lead temperature (soldering, 10 seconds)                    | -                | 300          |       |

Note1:  $V_{DD}$  -  $V_{SS}$ ,  $V_{CC}$  -COM and  $V_B$  -  $V_S$  contain internal shunt zener diodes. Please note that the voltage ratings of these can be limited by the clamping current.

Note2: For the rising and falling edges of step signal of 10 V;  $V_{SS}$ =15 V to 200 V.

Note3:  $V_{SS}$  ramps up from 0 V to 200 V.

## Recommended Operating Conditions

For proper operation, the device should be used within the recommended conditions below. The  $V_S$  and COM offset ratings are tested with supplies biased at  $I_{DD}=5$  mA,  $V_{CC}=12$  V, and  $V_B-V_S=12$  V.

| Symbol      | Definition                                 | Min.     | Max.     | Units |
|-------------|--------------------------------------------|----------|----------|-------|
| $V_B$       | High-side floating supply absolute voltage | $V_S+10$ | $V_S+18$ | V     |
| $V_S$       | High-side floating supply offset voltage   | Note 1   | 100      |       |
| $I_{DDZ}$   | Floating input supply Zener clamp current  | 1        | 5        | mA    |
| $V_{SS}$    | Floating input supply absolute voltage     | 0        | 200      | V     |
| $V_{HO}$    | High-side floating output voltage          | $V_S$    | $V_B$    |       |
| $V_{CC}$    | Low-side fixed supply voltage              | 10       | 18       |       |
| $V_{LO}$    | Low-side output voltage                    | 0        | $V_{CC}$ |       |
| $V_{IN}$    | PWM input voltage                          | $V_{SS}$ | $V_{DD}$ |       |
| $V_{CSD}$   | CSD pin input voltage                      | $V_{SS}$ | $V_{DD}$ |       |
| $V_{DT}$    | DT pin input voltage                       | 0        | $V_{CC}$ |       |
| $I_{OREF}$  | Reference output current to COM (Note 2)   | 0.3      | 0.8      | mA    |
| $V_{OCSET}$ | OCSET pin input voltage                    | 0.5      | 5        | V     |
| $T_A$       | Ambient temperature                        | -40      | 125      | °C    |

Note 1: Logic operational for  $V_S$  equal to -5 V to +200 V. Logic state held for  $V_S$  equal to -5 V to  $-V_{BS}$ .

Note 2: Nominal voltage for  $V_{REF}$  is 5 V.  $I_{OREF}$  of 0.3 mA to 0.8 mA dictates total external resistor value on  $V_{REF}$  to be 6.3 k $\Omega$  to 16.7 k $\Omega$ .

## Electrical Characteristics

$V_{CC}$ ,  $V_{BS}=12$  V,  $I_{DD}=5$  mA,  $V_{SS}=20$  V,  $V_S=0$  V,  $C_L=1$  nF, and  $T_A=25$  °C unless otherwise specified.

| Symbol                           | Definition                                                  | Min. | Typ. | Max. | Units   | Test Conditions           |
|----------------------------------|-------------------------------------------------------------|------|------|------|---------|---------------------------|
| <b>Low-side Supply</b>           |                                                             |      |      |      |         |                           |
| $UV_{CC+}$                       | $V_{CC}$ supply UVLO positive threshold                     | 8.4  | 8.9  | 9.4  | V       |                           |
| $UV_{CC-}$                       | $V_{CC}$ supply UVLO negative threshold                     | 8.2  | 8.7  | 9.2  |         |                           |
| $I_{QCC}$                        | Low-side quiescent current                                  | -    | -    | 3    | mA      | $V_{DT} = V_{CC}$         |
| $V_{CLAMPL}$                     | Low-side Zener diode clamp voltage                          | 19.8 | 20.8 | 21.8 | V       | $I_{CC}=2$ mA             |
| <b>High-side Floating Supply</b> |                                                             |      |      |      |         |                           |
| $UV_{BS+}$                       | High-side well UVLO positive threshold                      | 8.0  | 8.5  | 9.0  | V       |                           |
| $UV_{BS-}$                       | High-side well UVLO negative threshold                      | 7.8  | 8.3  | 8.8  |         |                           |
| $I_{QBS}$                        | High-side quiescent current                                 | -    | -    | 1    | mA      | $V_B=V_S=200$ V           |
| $I_{LKH}$                        | High-side to low-side leakage current                       | -    | -    | 50   | $\mu$ A |                           |
| $V_{CLAMPH}$                     | High-side Zener diode clamp voltage                         | 19.8 | 20.8 | 21.8 | V       | $I_{BS}=2$ mA             |
| <b>Floating Input Supply</b>     |                                                             |      |      |      |         |                           |
| $UV_{DD+}$                       | $V_{DD}$ , $V_{SS}$ floating supply UVLO positive threshold | 8.2  | 8.7  | 9.2  | V       | $V_{SS}=0$ V              |
| $UV_{DD-}$                       | $V_{DD}$ , $V_{SS}$ floating supply UVLO negative threshold | 7.7  | 8.2  | 8.7  |         |                           |
| $I_{QDD}$                        | Floating input quiescent current                            | -    | -    | 1    | mA      | $V_{DD}=9.5$ V + $V_{SS}$ |
| $V_{CLAMP M}$                    | Floating input Zener diode clamp voltage                    | 9.9  | 10.4 | 10.9 | V       | $I_{DD}=2$ mA             |
| $I_{LKM}$                        | Floating input side to low-side leakage current             | -    | -    | 50   | $\mu$ A | $V_{DD}=V_{SS}=200$ V     |

**Electrical Characteristics (cont.)**

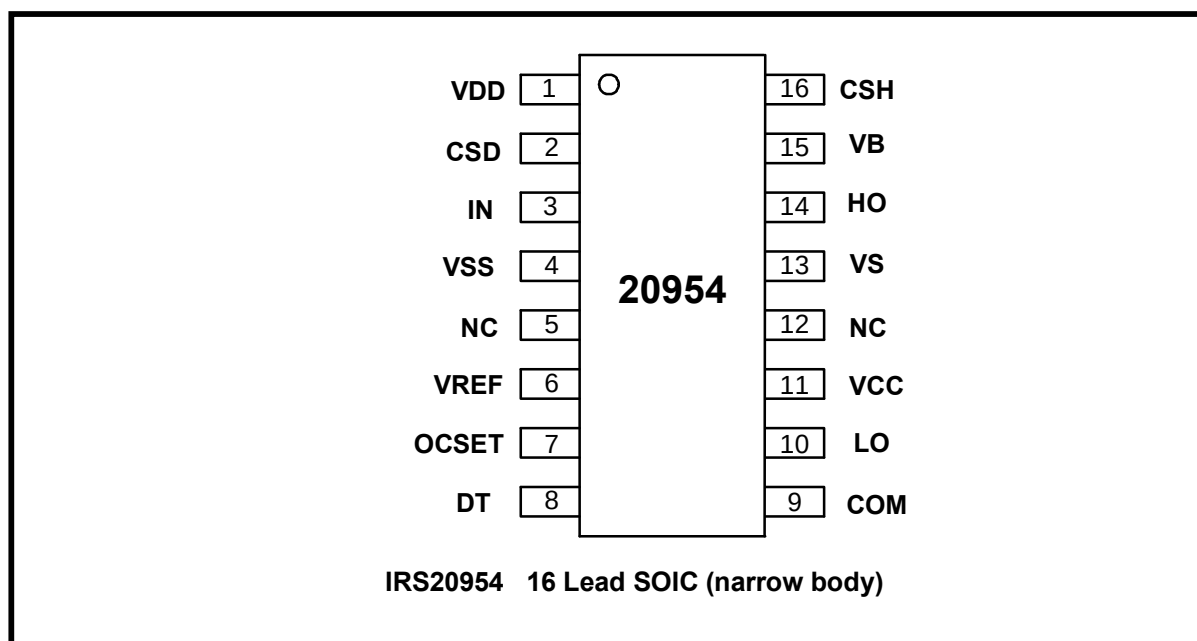
| Symbol              | Definition                                                                                                                                      | Min.                   | Typ.                   | Max.                   | Units | Test Conditions                                                                         |
|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|------------------------|------------------------|-------|-----------------------------------------------------------------------------------------|
| Floating PWM Input  |                                                                                                                                                 |                        |                        |                        |       |                                                                                         |
| V <sub>IH</sub>     | Logic high input threshold voltage                                                                                                              | 2.3                    | -                      | -                      | V     |                                                                                         |
| V <sub>IL</sub>     | Logic low input threshold voltage                                                                                                               | -                      | -                      | 1.5                    |       |                                                                                         |
| I <sub>IN+</sub>    | Logic “1” input bias current                                                                                                                    | -                      | -                      | 40                     | μA    | V <sub>IN</sub> =3.3 V                                                                  |
| I <sub>IN-</sub>    | Logic “0” input bias current                                                                                                                    | -                      | -                      | 5                      |       | V <sub>IN</sub> = V <sub>SS</sub>                                                       |
| Protection          |                                                                                                                                                 |                        |                        |                        |       |                                                                                         |
| V <sub>REF</sub>    | Reference output voltage                                                                                                                        | 4.6                    | 5.1                    | 5.6                    | V     | I <sub>OREF</sub> =0.5 mA                                                               |
| V <sub>th,OCL</sub> | Low-side OC threshold in Vs                                                                                                                     | 1.0                    | 1.2                    | 1.4                    |       | OCSET=1.2 V, Fig. 13                                                                    |
| V <sub>th,OCH</sub> | High-side OC threshold in V <sub>CSH</sub>                                                                                                      | 1.0+ Vs                | 1.2+ Vs                | 1.4+ Vs                |       | Vs=200 V, Fig. 14                                                                       |
| V <sub>th,1</sub>   | CSD pin shutdown release threshold                                                                                                              | 0.62 x V <sub>DD</sub> | 0.70 x V <sub>DD</sub> | 0.78 x V <sub>DD</sub> |       | V <sub>SS</sub> =0 V                                                                    |
| V <sub>th,2</sub>   | CSD pin self reset threshold                                                                                                                    | 0.26 x V <sub>DD</sub> | 0.30 x V <sub>DD</sub> | 0.34 x V <sub>DD</sub> |       |                                                                                         |
| I <sub>CSD+</sub>   | CSD pin discharge current                                                                                                                       | 50                     | 100                    | 150                    | μA    | V <sub>SD</sub> = V <sub>SS</sub> +5 V                                                  |
| I <sub>CSD-</sub>   | CSD pin charge current                                                                                                                          | 50                     | 100                    | 150                    |       |                                                                                         |
| t <sub>SD</sub>     | Shutdown propagation delay from V <sub>CSD</sub> > V <sub>SS</sub> + V <sub>thOCH</sub> to shutdown                                             | -                      | -                      | 1                      | μs    | Fig. 2                                                                                  |
| t <sub>OCH</sub>    | Propagation delay time from V <sub>CSH</sub> > V <sub>thOCH</sub> to shutdown                                                                   | -                      | -                      | 1                      |       | Fig. 3                                                                                  |
| t <sub>OCL</sub>    | Propagation delay time from Vs> V <sub>thOCL</sub> to shutdown                                                                                  | -                      | -                      | 1                      |       | Fig. 4                                                                                  |
| Gate Driver (Fig.5) |                                                                                                                                                 |                        |                        |                        |       |                                                                                         |
| I <sub>o+</sub>     | Output high short circuit current (source)                                                                                                      | 0.8                    | 1.0                    | -                      | A     | V <sub>o</sub> =0 V, PW≤10 μs                                                           |
| I <sub>o-</sub>     | Output low short circuit current (sink)                                                                                                         | 1.0                    | 1.2                    | -                      |       | V <sub>o</sub> =12 V, PW≤10 μs                                                          |
| V <sub>OL</sub>     | Low level output voltage<br>LO – COM, HO - VS                                                                                                   | -                      | -                      | 0.1                    | V     | I <sub>o</sub> =0 A                                                                     |
| V <sub>OH</sub>     | High level output voltage<br>VCC – LO, VB - HO                                                                                                  | -                      | -                      | 1.4                    |       |                                                                                         |
| t <sub>r</sub>      | Turn-on rise time                                                                                                                               | -                      | 15                     | -                      | ns    | V <sub>DT</sub> = V <sub>CC</sub> ,<br>V <sub>S</sub> = 100 V,<br>V <sub>SS</sub> = COM |
| t <sub>f</sub>      | Turn-off fall time                                                                                                                              | -                      | 10                     | -                      |       |                                                                                         |
| ton_1               | High- and low-side turn-on propagation delay, floating inputs                                                                                   | -                      | 105                    | -                      |       |                                                                                         |
| toff_1              | High- and low-side turn-off propagation delay, floating inputs                                                                                  | -                      | 90                     | -                      |       |                                                                                         |
| ton_2               | High- and low-side turn-on propagation delay, non-floating inputs                                                                               | -                      | 105                    | -                      |       | V <sub>DT1</sub> >V <sub>DT1</sub> ,<br>V <sub>SS</sub> = COM                           |
| toff_2              | High- and low-side turn-off propagation delay, non-floating inputs                                                                              | -                      | 90                     | -                      |       |                                                                                         |
| DT1                 | Deadtime: LO turn-off to HO turn-on (DT <sub>LO-HO</sub> ) & HO turn-off to LO turn-on (DT <sub>HO-LO</sub> )                                   | 8                      | 15                     | 22                     |       |                                                                                         |
| DT2                 | Deadtime: LO turn-off to HO turn-on (DT <sub>LO-HO</sub> ) & HO turn-off to LO turn-on (DT <sub>HO-LO</sub> )                                   | 15                     | 25                     | 35                     |       |                                                                                         |
| DT3                 | Deadtime: LO turn-off to HO turn-on (DT <sub>LO-HO</sub> ) & HO turn-off to LO turn-on (DT <sub>HO-LO</sub> )                                   | 20                     | 35                     | 50                     |       | V <sub>DT2</sub> >V <sub>DT2</sub> > V <sub>DT3</sub> ,<br>V <sub>SS</sub> = COM        |
| DT4                 | Deadtime: LO turn-off to HO turn-on (DT <sub>LO-HO</sub> ) & HO turn-off to LO turn-on (DT <sub>HO-LO</sub> )V <sub>DT</sub> = V <sub>DT4</sub> | 25                     | 45                     | 60                     |       | V <sub>DT3</sub> >V <sub>DT3</sub> > V <sub>DT4</sub> ,<br>V <sub>SS</sub> = COM        |

## Electrical Characteristics (cont.)

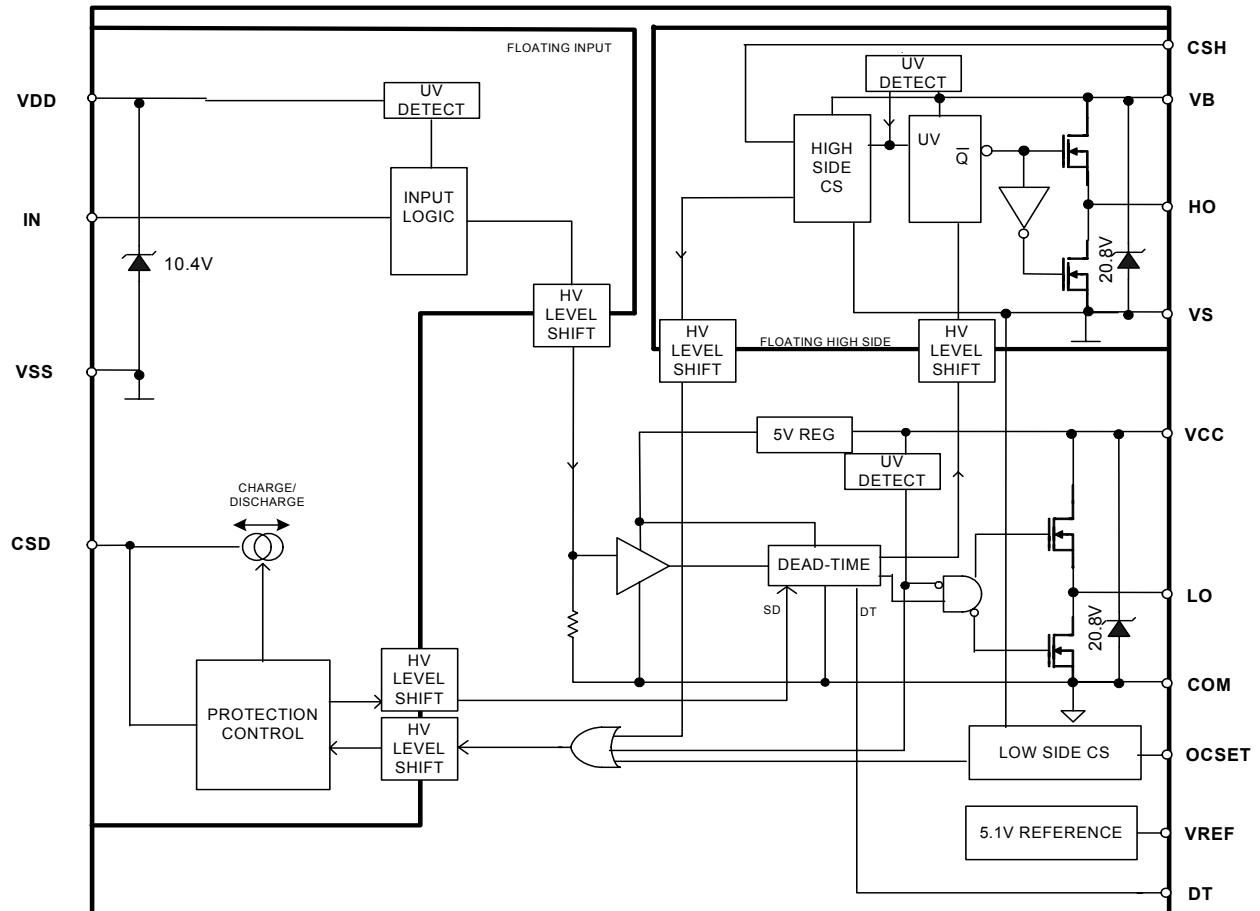
| Symbol    | Definition                 | Min.                  | Typ.                  | Max.                  | Units | Test Conditions |
|-----------|----------------------------|-----------------------|-----------------------|-----------------------|-------|-----------------|
| $V_{DT1}$ | DT mode select threshold 2 | $0.51 \cdot (V_{CC})$ | $0.57 \cdot (V_{CC})$ | $0.63 \cdot (V_{CC})$ | V     |                 |
| $V_{DT2}$ | DT mode select threshold 3 | $0.32 \cdot (V_{CC})$ | $0.36 \cdot (V_{CC})$ | $0.40 \cdot (V_{CC})$ |       |                 |
| $V_{DT3}$ | DT mode select threshold 4 | $0.21 \cdot (V_{CC})$ | $0.23 \cdot (V_{CC})$ | $0.25 \cdot (V_{CC})$ |       |                 |

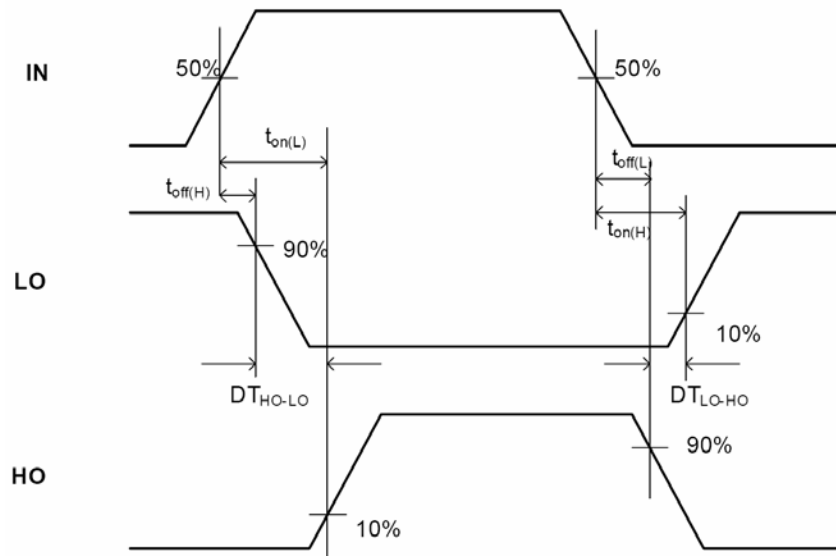
## Lead Definitions

| Pin # | Symbol | Description                                                |
|-------|--------|------------------------------------------------------------|
| 1     | VDD    | Floating input positive supply                             |
| 2     | CSD    | Shutdown timing capacitor, referenced to VSS               |
| 3     | IN     | PWM non-inverting input, in phase with HO                  |
| 4     | VSS    | Floating input supply return                               |
| 5     | NC     |                                                            |
| 6     | VREF   | 5 V reference output for setting OCSET                     |
| 7     | OCSET  | Low-side over-current threshold setting, referenced to COM |
| 8     | DT     | Input for programmable deadtime, referenced to COM         |
| 9     | COM    | Low-side supply return                                     |
| 10    | LO     | Low-side output                                            |
| 11    | VCC    | Low-side logic supply                                      |
| 12    | NC     |                                                            |
| 13    | VS     | High-side floating supply return                           |
| 14    | HO     | High-side output                                           |
| 15    | VB     | High-side floating supply                                  |
| 16    | CSH    | High-side over-current sensing input, referenced to VS     |

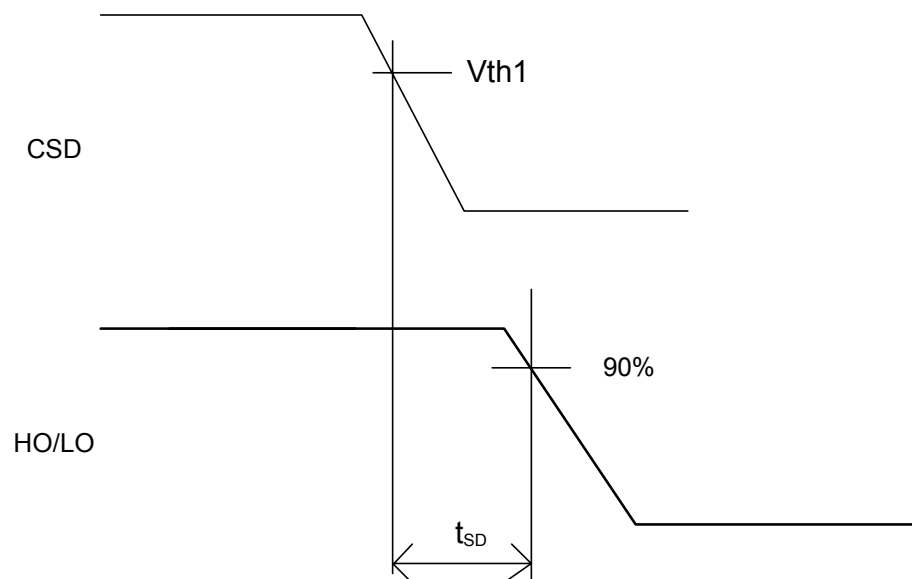


## Block Diagram





**Figure 1: Switching Time Waveform Definitions**



**Figure 2: CSD to Shutdown Waveform Definitions**

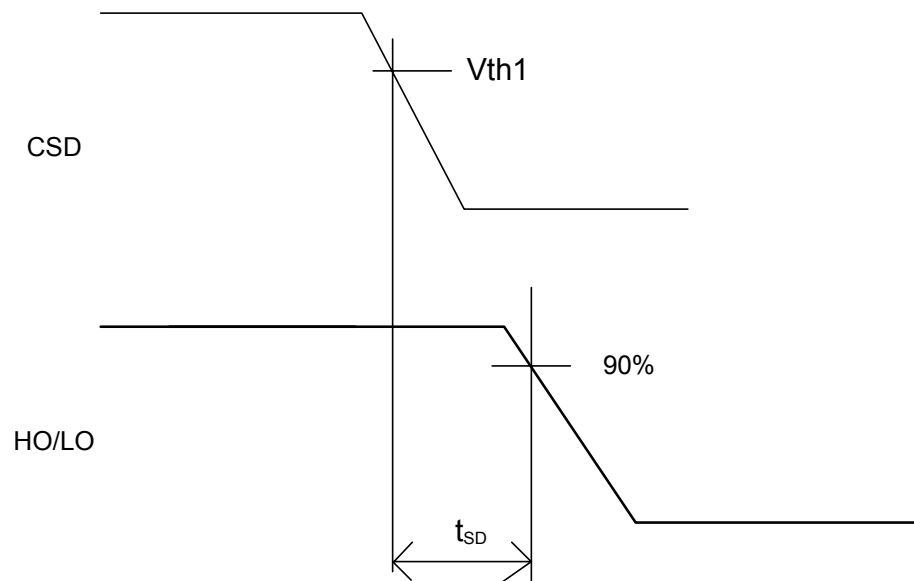


Figure 3: CSH to Shutdown Waveform Definitions

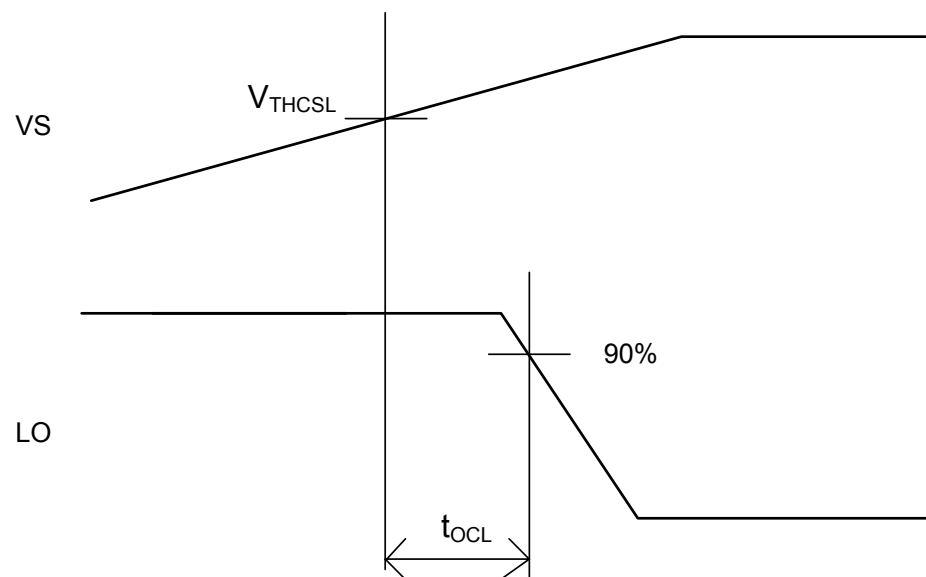


Figure 4:  $V_s > V_{TH,SCL}$  to Shutdown Waveform Definitions



## Functional Description

### Floating PWM Input

The IRS20954 has a floating input interface which enables easy half bridge implementation. Three pins,  $V_{DD}$ , CSD and IN, are referenced to  $V_{SS}$ . As a result, the PWM input signal can be directly fed into IN referencing ground, which is typically middle point of DC bus in a half bridge configuration.

The IRS20954 also has a non-floating input with  $V_{SS}$  tied to COM.

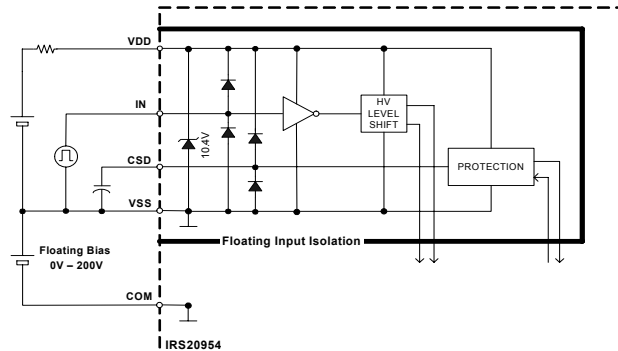


Figure 5: Floating PWM Input Structure

### Over-Current Protection (OCP)

The IRS20954 features over-current protection to protect the power MOSFET from over load conditions. The IRS20954 enters shutdown mode when it detects over-current condition either from low side or high side current sensing. The timing control block measures resume timing interval with an external timing capacitor  $C_t$ . All the critical timing of the over-current protection is specified and guaranteed for secure protection.

The sequence on the over-current detection is:

1. As soon as either high or low side current sensing block detects over-current condition, the OC Latch (OCL) flips and shutdowns the outputs LO and HO.
2. The CSD pin starts discharging the external capacitor  $C_t$ .
3. When  $V_{SCD}$  crosses the lower threshold  $V_{th2}$ , the output signal from the COMP2 resets the OCL.
4. The CSD pin starts charging the external capacitor  $C_t$ .
5. When  $V_{SCD}$  crosses the upper threshold  $V_{th1}$ , the COMP1 flips and enables shutdown signal released.
6. If one of current sensing block detects over-current condition, the sequence is repeated until the cause of over-current goes away.

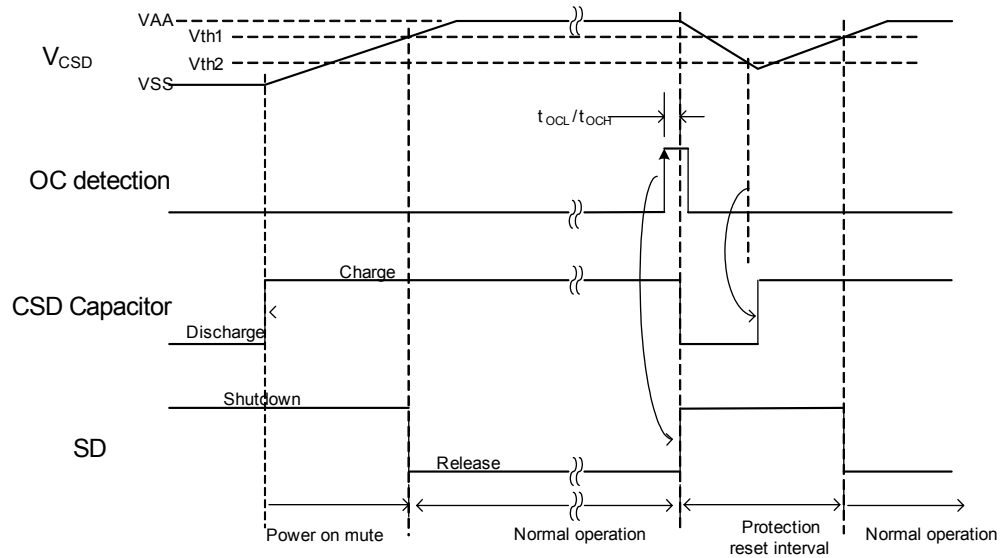


Figure 6: Over-Current Protection Timing Chart

### Protection Control

The internal protection control block manages operational mode between shutdown and normal, with a help from CSD pin. Shutdown mode forces LO and HO to output 0 V to the COM and  $V_S$  respectively to turn the power MOSFET off.

The external capacitor pin, CSD, provides five functions.

1. Power up delay timer for self reset configuration
2. Self-reset configuration
3. Shutdown input
4. Latched protection configuration
5. Shutdown status output (host I/F)

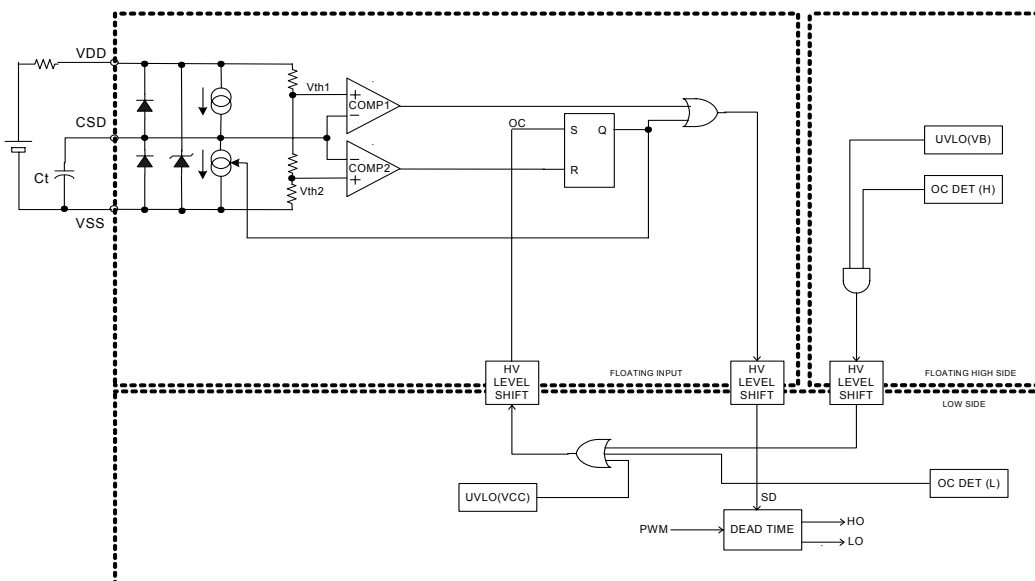
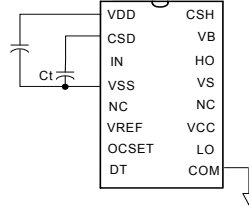


Figure 7: Shutdown Functional Block Diagram

### Self Reset Protection

By simply putting a capacitor between the CSD and V<sub>SS</sub>, the OCP in the IRS20954 acts as a self.



**Figure 8: Self-Reset Protection Configuration**

### Designing Ct

Timing capacitor Ct programs the protection resume interval timing  $t_{PR}$  given as:

$$t_{PR} = 1.1 \cdot \frac{Ct \cdot V_{DD}}{I_{CSD}} \quad [\text{sec}]$$

or

$$Ct = \frac{t_{PR} \cdot I_{CSD}}{1.1 \cdot V_{DD}} \quad [\text{F}]$$

For example,  $t_{PR}$  is 1.2 s with a 10  $\mu\text{F}$  capacitor for  $V_{DD}=10.8 \text{ V}$ . The start-up time  $t_{SU}$ , from power-up to shutdown release, is given as:

$$t_{SU} = 0.7 \cdot \frac{Ct \cdot V_{DD}}{I_{CSD}} \quad [\text{sec}]$$

or

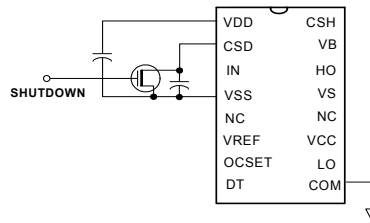
$$Ct = \frac{t_{SU} \cdot I_{CSD}}{0.7 \cdot V_{DD}} \quad [\text{F}]$$

where  $I_{CSD}$  is charge/discharge current in CSD pin, 100  $\mu\text{A}$ .  
 $V_{DD}$  is supply voltage respect to  $V_{SS}$ .

Protection-resume timing  $t_{PR}$  should be long enough to avoid over heating and failure of the MOSFET from the repetitive sequences of shutdown and resume when the load is in continuous short circuit. In most of applications, the minimum recommended protection-resume timing  $t_{PR}$  is 0.1 s.

### Shutdown Input

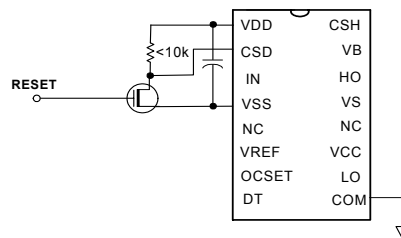
By externally discharging Ct down to below  $V_{th2}$ , for example with a transistor shown in Fig. 9, the IRS20954 enters shutdown mode. The operation resumes when the voltage of CSD pin comes back and cross the upper threshold of CSD,  $V_{th1}$ , by its charging process.



**Figure 9: Shutdown Input**

## Latched Protection

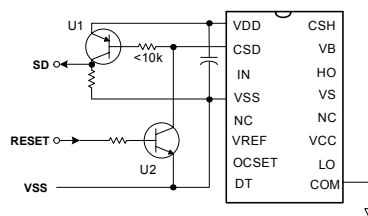
Connecting CSD to  $V_{DD}$  through a 10 k $\Omega$  or less resistor configures the IRS20954 as a latched over-current protection. The over-current protection stays in shutdown mode after over-current condition detected. To reset the latch status, an external reset switch brings CSD pin voltage down below the lower threshold,  $V_{th2}$ . Minimum reset pulse width required is 200 ns.



**Figure 10: Latched Protection Configuration**

## Interfacing with System Controller

The IRS20954 communicates with external system controller by adding simple interfacing circuit shown in Fig. 11. A generic PNP-BJT U1, such as 2N3906, is to send out SD signal when OCP event happens by capturing sinking current in CSD pin. Another generic NPN-BJT U2, such as 2N3094, is to reset the internal protection logic by pulling the CSD voltage below  $V_{th2}$ . Note that the CSD pin is configured as a latched type OCP in this configuration.



**Figure 11: Interfacing System Controller**

## Programming OCP Trip Level

In a Class D audio amplifier, the direction of the load current alternates according to the audio input signal. An over-current condition can therefore happen during either a positive current cycle or a negative current cycle. The IRS20954 uses  $R_{DS(ON)}$  in the output MOSFET as current sensing resistors. Due to the high voltage IC structural constraints, high and low side have different implementations of current sensing. Once measured current gets exceeded pre-determined threshold, OC output signal is fed to the protection block to shutdown the MOSFET to protect the devices.

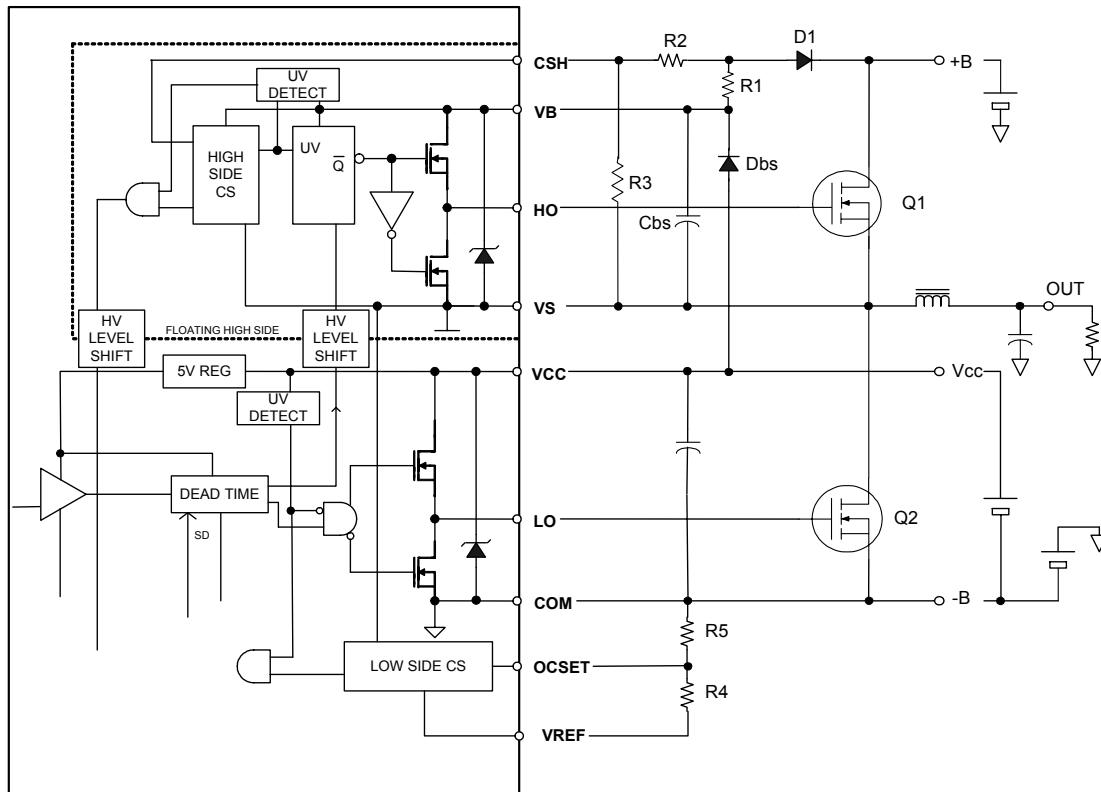


Figure 12: Bi-Directional Over-Current Protection

### Low Side Over-Current Sensing

For the negative load current, low side over-current sensing monitors over load condition and shutdown the switching operation if the load current exceeds the preset trip level.

The low side current sensing is based on measurement of  $V_{DS}$  during the low side MOFET on state. In order to avoid incorrect current value due to overshoot,  $V_S$  sensing ignores the first 200 ns signal after LO turned on.

OCSET pin is to program the threshold for low side over-current sensing. The threshold voltage at  $V_S$  pin turning on the OC protection is the same as the voltage applied to the OCSET pin to COM. It is recommended to use  $V_{REF}$  to supply a reference voltage to a resistive divider, R4 and R5, generating a voltage to OCSET for better immunity against  $V_{CC}$  fluctuations.

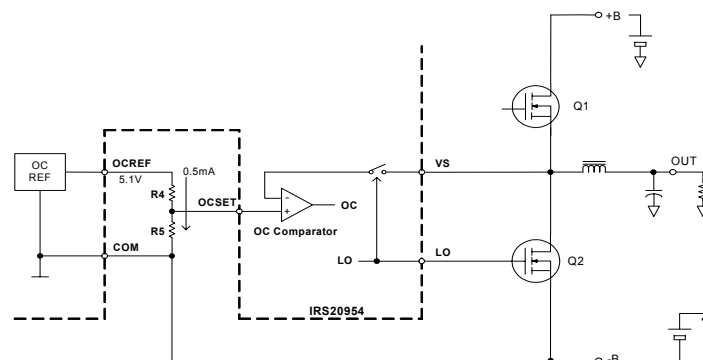


Figure 13: Low-Side Over-Current Sensing

Since the sensed voltage of  $V_S$  is compared with the voltages fed to the OCSET pin, the required voltage of OCSET with respect to COM for a trip level  $I_{TRIP+}$  is:

$$V_{OCSET} = V_{DS(LOW\ SIDE)} = I_{TRIP+} \times R_{DS(ON)}$$

In order to neglect the input bias current of OCSET pin, it is recommended to use 10 kΩ total for R4 and R5 to drain 0.5 mA through the resistors.

### **High Side Over-Current Sensing**

For the positive load current, high side over-current sensing monitors over load condition by measuring  $V_{DS}$  with CSH and  $V_S$  pins and shutdown the operation. The CSH pin is to detect the drain-to-source voltage refers to the  $V_S$  pin which is the source of the high side MOSFET. In order to neglect overshoot ringing at the switching edges, CSH sensing circuitry starts monitoring after the first 300 ns the HO is on by blanking the signal from CSH pin.

In contrast to the low side current sensing, the threshold of CSH pin to engage OC protection is internally fixed at 1.2 V. An external resistive divider R2 and R3 can be used to program a higher threshold.

An external reverse blocking diode, D1, is to block high voltage feeding into the CSH pin while high side is off. By subtracting a forward voltage drop of 0.6 V at D1, the minimum threshold which can be set in the high side is 0.6 V across the drain to source.

**With the configuration in Fig. 14, the voltage in CSH is:**

$$V_{CSH} = \frac{R3}{R2 + R3} \cdot (V_{DS(HIGH\ SIDE)} + V_{F(D1)})$$

Where:

$V_{DS(HIGH\ SIDE)}$  is drain to source voltage of the high side MOSFET in its ON state

$V_{F(D1)}$  is the forward drop voltage of D1

Since  $V_{DS(HIGH\ SIDE)}$  is determined by the product of drain current  $I_D$  and  $R_{DS(ON)}$  in the high side MOSFET.  $V_{CSH}$  can be written as:

$$V_{CSH} = \frac{R3}{R2 + R3} \cdot (R_{DS(ON)} \cdot I_D + V_{F(D1)})$$

$$\frac{R2}{R3} = \frac{V_{DS} + V_F}{V_{th_{OCH}}} - 1$$

The reverse blocking diode D1 is forward biased by a 10 kΩ resistor R1 when the high side MOSFET is on.

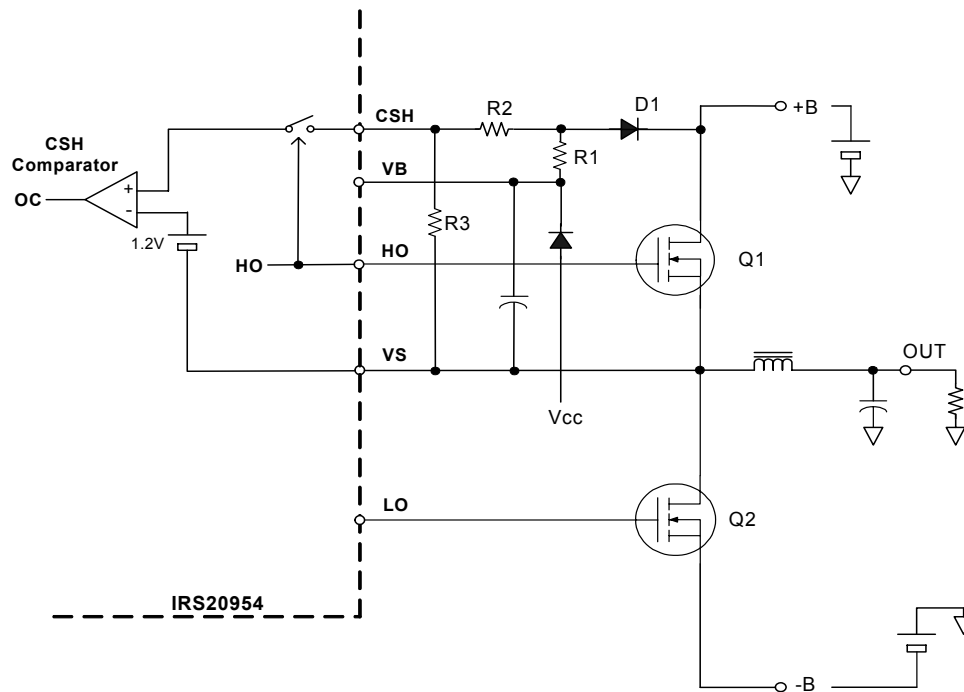


Figure 14: Programming High Side Over-Current Threshold

### OCP Design Example

#### High Side Over-current Setting

Fig. 14 demonstrates the typical peripheral circuit of high side current sensing. For example, the over-current protection level is set to trip at 30 A with a MOSFET with  $R_{DS(ON)}$  of 100 m $\Omega$ , the component values of R2 and R3 are calculated as:

Choose  $R_2 + R_3 = 10 \text{ k}\Omega$ , thus  $R_3 = 10 \text{ k}\Omega - R_2$ .

$$R_3 = 10 \text{ k}\Omega \frac{V_{th_{OCH}}}{V_{DS} + V_F}$$

$$V_{th_{OCL}} = 1.2 \text{ V}$$

$$V_F = 0.6 \text{ V}$$

$$V_{DS@I_D=30A} = 100 \text{ m}\Omega \times 30 \text{ A} = 3 \text{ V}$$

$V_{DS}$  is the voltage drop at  $I_D = 30 \text{ A}$  across  $R_{DS(ON)}$  of the high side MOSFET.  $V_F$  is a forward voltage of reverse blocking diode, D1. The values of R2 and R3 from the E-12 series are:

$$R_2 = 6.8 \text{ k}\Omega$$

$$R_3 = 3.3 \text{ k}\Omega$$

#### Choosing the Right Reverse Blocking Diode

The reverse blocking diode D1 is determined by voltage rating and speed. To block bus voltage, reverse voltage has to be higher than (+B)-(-B). Also the reverse recovery time needs to be as fast as the bootstrap charging diode. The Philips BAV21W, 200 V, 50 ns high speed switching diode, is more than sufficient.

### Low Side Over-current Setting

Designing with the same MOSFET as in high side with  $R_{DS(ON)}$  of 100 mΩ, the OCSET voltage,  $V_{OCSET}$ , to set 30 A trip level is given by:

$$V_{OCSET} = I_{TRIP+} \times R_{DS(ON)} = 30 \text{ A} \times 100 \text{ m}\Omega = 3.0 \text{ V}$$

Choose  $R_4 + R_5 = 10 \text{ k}\Omega$  for proper loading of VREF pin, thus

$$\begin{aligned} R_5 &= \frac{V_{OCSET}}{V_{REF}} \cdot 10 \text{ k}\Omega \\ &= \frac{3.0 \text{ V}}{5.1 \text{ V}} \cdot 10 \text{ k}\Omega \\ &= 5.8 \text{ k}\Omega \end{aligned}$$

Where  $V_{REF}$  is the output voltage of VREF pin, 5.1 V typical.

Choose  $R_5 = 5.6 \text{ k}\Omega$  and  $R_4 = 3.9 \text{ k}\Omega$  from E-12 series.

In general,  $R_{DS(ON)}$  has a positive temperature coefficient that needs to be considered when the threshold level is being set. Although this characteristic is preferable from a device protection point of view, these variation needs to be considered as well as variations of external or internal component values.

### **Deadtime Generator**

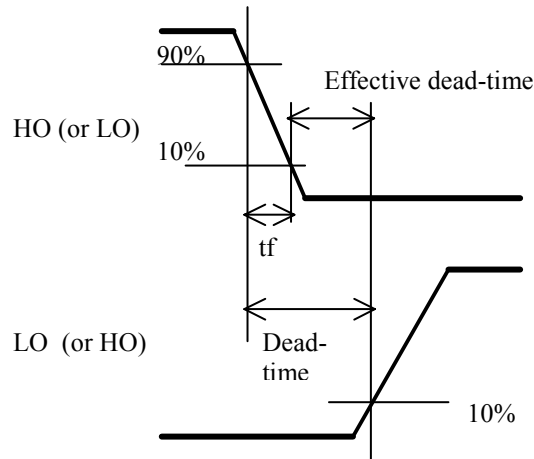
The deadtime generator block provides a blanking time between the high-side on and low-side on to avoid a simultaneous on state causing shoot-through. The IRS20954 has an internal deadtime generation block to reduce the number of external components in the output stage of a Class D audio amplifier. Selectable deadtime programmed through the DT/SD pin voltage is an easy and reliable function, which requires only two external resistors. This selectable deadtime way of setting prevents outside noise from modulating the switching timing, which is critical to the audio performances.

### How to Determine Optimal Deadtime

The effective deadtime in an actual application differs from the deadtime specified in this datasheet due to finite switching fall time,  $t_f$ . The deadtime value in this datasheet is defined as the time period from the starting point of turn-off on one side of the switching stage to the starting point of turn-on on the other side as shown in Fig. 15. The fall time of MOSFET gate voltage must be subtracted from the deadtime value in the datasheet to determine the effective dead time of a Class D audio amplifier.

$$(\text{Effective deadtime}) = (\text{Deadtime in datasheet}) - (\text{fall time, } t_f)$$



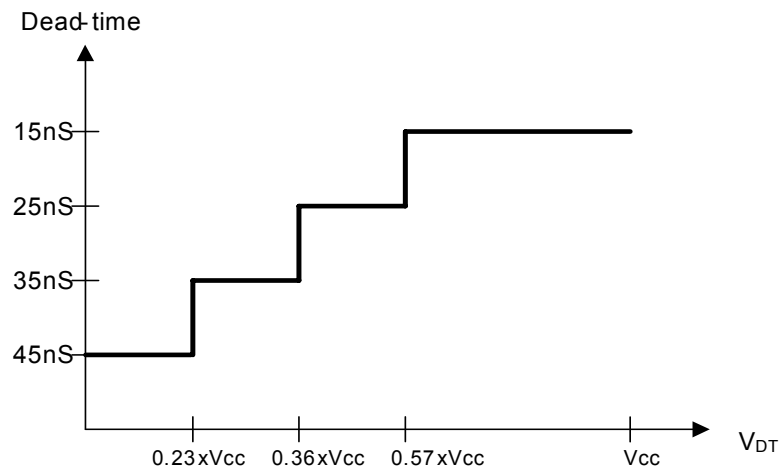


**Figure 15: Effective Deadtime**

A longer dead time period is required for a MOSFET with a larger gate charge value because of the longer  $t_f$ . A shorter effective deadtime setting is always beneficial to achieve better linearity in the Class D switching stage. However, the likelihood of shoot-through current increases with narrower deadtime settings in mass production. Negative values of effective deadtime may cause excessive heat dissipation in the MOSFETs, potentially leading to serious damage. To calculate the optimal deadtime in a given application, the fall time  $t_f$  for both output voltages, HO and LO, in the actual circuit needs to be measured. In addition, the effective deadtime can also vary with temperature and device parameter variations. Therefore, a minimum effective deadtime of 10 ns is recommended to avoid shoot-through current over the range of operating temperatures and supply voltages.

### **Programming Deadtime**

DT pin provides a function setting deadtime. The IRS20954 determines its deadtime based on the voltage applied to the DT pin. An internal comparator translates which pre-determined deadtime is being used by comparing internal reference voltages. Threshold voltages for each mode are set internally by a resistive voltage divider off  $V_{CC}$ , negating the need of using a precise absolute voltage to set the mode. The relationship between the operation mode and the voltage at DT pin is illustrated in the Fig. 16 below.



**Figure 16: Deadtime Settings vs.  $V_{DT}$  Voltage**

Table 1 shows suggested values of resistance for setting the deadtime. Resistors with up to 5% tolerance can be used if these listed values are followed.

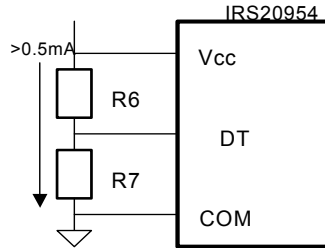


Figure 17: External Resistor

| Deadtime mode | R6     | R7     | DT/SD voltage           |
|---------------|--------|--------|-------------------------|
| DT1           | <10 kΩ | Open   | 1.0·(V <sub>cc</sub> )  |
| DT2           | 3.3 kΩ | 8.2 kΩ | 0.71·(V <sub>cc</sub> ) |
| DT3           | 5.6 kΩ | 4.7kΩ  | 0.46·(V <sub>cc</sub> ) |
| DT4           | 8.2 kΩ | 3.3 kΩ | 0.29·(V <sub>cc</sub> ) |

Table 1: Suggested Resistor Values for Deadtime Settings

## Power Supply Considerations

### Supplying V<sub>DD</sub>

V<sub>DD</sub> is designed to be supplied with the internal zener diode clamp. V<sub>DD</sub> supply current I<sub>DD</sub> can be estimated by:

$$I_{DD} = 1.5 \text{ mA} \times 300 \times 10^{-9} \times \text{switching frequency} + 0.5 \text{ mA} + 0.5 \text{ mA}$$

(Dynamic power consumption)      (Static)      (zener bias)

The resistance of R<sub>dd</sub> to feed this I<sub>DD</sub> therefore is:

$$R_{dd} \leq \frac{V_{+B} - 10.8V}{I_{DD}} \quad [\Omega]$$

In case of 400 kHz average PWM switching frequency, the required I<sub>DD</sub> is 1.18 mA. A condition using 50 V power supply voltage yields R<sub>dd</sub>=33 kΩ.

Make sure I<sub>DD</sub> is below the maximum zener diode bias current, I<sub>DDZ</sub>, at static state conditions such as a condition with no PWM input.

$$I_{DDZ} \geq \frac{V_{+B} - 10.8V}{R_{dd}} - 0.5 \text{ mA}$$

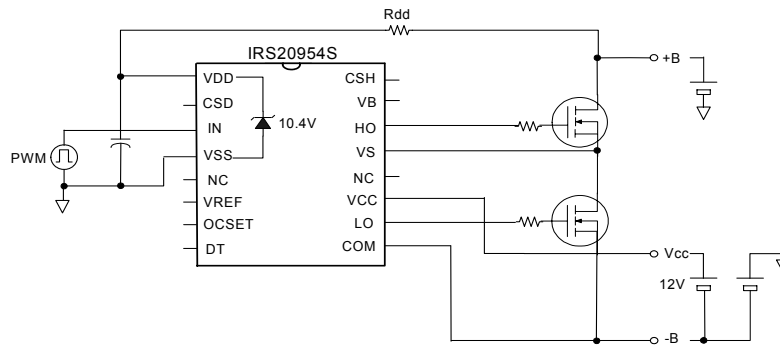


Figure 18: Supplying VDD

### Charging V<sub>BS</sub> Prior to start

The high side bootstrap power supply can be charged up through a resistor from the positive supply bus to V<sub>B</sub> pin by utilizing an internal 20.8 V zener diode clamp between V<sub>B</sub> and V<sub>S</sub>. Advantage of this scheme is to eliminate the minimum duration required for the initial low-side ON.

To determine the requirement for R<sub>charge</sub>, following condition has to be met;

$$I_{CHARGE} > I_{QBS}$$

Where I<sub>CHARGE</sub> is a required charging current through R<sub>charge</sub>  
I<sub>QBS</sub> is high side quiescent current

Note that R<sub>charge</sub> can drain floating supply charge during on state of high side, which limits maximum PWM modulation index capability of the system. R<sub>charge</sub> should be large enough not to discharge the floating power supply during the high side ON.

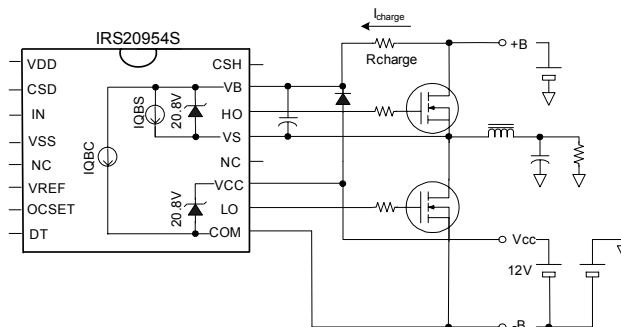


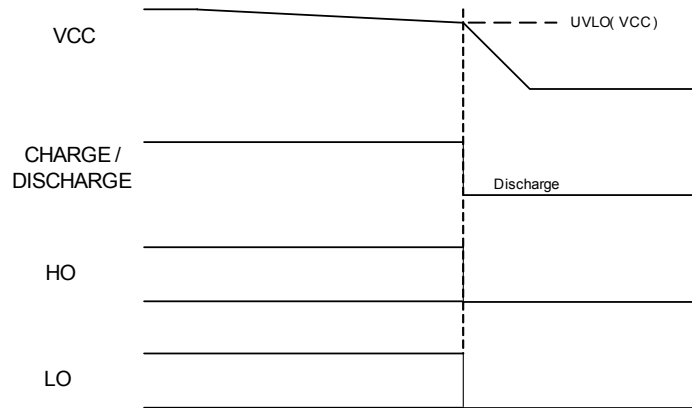
Figure 19: Bootstrap Supply Pre-Charging

### Start-up Sequence (UVLO)

The protection control block monitors the status of the power supply of V<sub>DD</sub> and V<sub>CC</sub> whether the voltages are above the Under Voltage Lockout threshold. The LO and HO of the IRS20954 are disabled by shutdown until the UVLO of V<sub>CC</sub> and V<sub>DD</sub> are released and CSD timer capacitor Ct is charged up. After the UVLO of V<sub>CC</sub> is released, CSD pin resets power-on timer. At the time the voltage at CSD pin reached the release threshold, V<sub>th1</sub>, shutdown logic enables LO and HO. The OC detection blocks for the low side and high side are disabled until UVLO of V<sub>CC</sub> and V<sub>BS</sub> are released.

## Power-down Sequence

As soon as  $V_{DD}$  or  $V_{CC}$  reaches the UVLO negative going threshold, protection logic makes LO and HO 0 V to turn off the MOSFET.



**Figure 20: IRS20954 Power-Down Timing Chart**

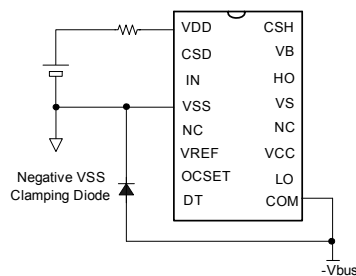
## Power Supply Decoupling

As the IRS20954 contains analog circuitry, careful attention to the power supply decoupling should be taken to achieve proper operation. Ceramic capacitors of 0.1  $\mu\text{F}$  or more close to the power supply pins are recommended.

Please also refer to the application note AN-978 for general considerations of high voltage gate driver IC.

## $V_{SS}$ Negative Bias Clamping

There is a case that  $V_{SS}$  can go below the COM potential such as a case missing negative supply in dual supply configuration. This causes excessive negative  $V_{SS}$  voltage to damage the IRS20954. It is recommended to have a diode to clamp potential negative bias to  $V_{SS}$ , if there is a possibility. A standard recovery 1 A diode such as 1N4002 is sufficient in most cases for this purpose.



**Figure 21: Negative  $V_{SS}$  Clamping**

### **Junction Temperature Estimation**

The power dissipation in the IRS20954 consists of following dominant items;

- $P_{MID}$ : dissipation in floating input logic and protection
- $P_{LOW}$ : dissipation in low side
- $P_{HIGH}$ : dissipation in high side

#### **1. $P_{MID}$ : Dissipation in Floating Input Section**

The dissipation in floating input section is given by;

$$P_{MID} = P_{ZDD} + P_{LDD}$$

$$\approx \frac{V_{+BUS} - V_{DD}}{R_{DD}} \cdot V_{DD}$$

Where

$P_{ZDD}$  is dissipation from internal zener diode clamping  $V_{DD}$  voltage.

$P_{LDD}$  is dissipation from internal logic circuitry.

$V_{+BUS}$  is positive bus voltage feeding  $V_{DD}$  from.

$R_{DD}$  is a resistor feeding  $V_{DD}$  from  $V_{+BUS}$ .

For obtaining a value of  $R_{DD}$ , refer to Supplying  $V_{DD}$  section above.

#### **2. $P_{LOW}$ : Dissipation in Low Side**

The dissipation in low side includes loss from logic circuitry and loss from driving LO, and is given by;

$$P_{LOW} = P_{LDD} + P_{LO}$$

$$= (I_{QCC} \cdot V_{CC}) + \left( V_{CC} \cdot Q_g \cdot f_{SW} \cdot \frac{R_O}{R_O + R_g + R_{g(int)}} \right)$$

Where

$P_{LDD}$  is dissipation from internal logic circuitry.

$P_{LO}$  is dissipation from gate drive stage to LO.

$R_O$  is equivalent output impedance of LO, typically 10  $\Omega$  for the IRS20954.

$R_{g(int)}$  is internal gate resistance of MOSFET.

$R_g$  is external gate resistance.

$Q_g$  is total gate charge of low side MOSFET.

#### **3. $P_{HIGH}$ : Dissipation in High Side**

The dissipation in high side includes loss from logic circuitry and loss from driving LO and is given by;

$$P_{HIGH} = P_{LDD} + P_{HO}$$

$$= (I_{QBS} \cdot V_{BS}) + \left( V_{BS} \cdot Q_g \cdot f_{SW} \cdot \frac{R_O}{R_O + R_g + R_{g(int)}} \right)$$

Where

$P_{LDD}$  is dissipation from internal logic circuitry.

$P_{HO}$  is dissipation from gate drive stage to LO.

$R_O$  is equivalent output impedance of HO, typically 10  $\Omega$  for the IRS20954.

$R_{g(int)}$  is internal gate resistance of high side MOSFET.

$R_g$  is external gate resistance.

$Q_g$  is total gate charge of high side MOSFET.

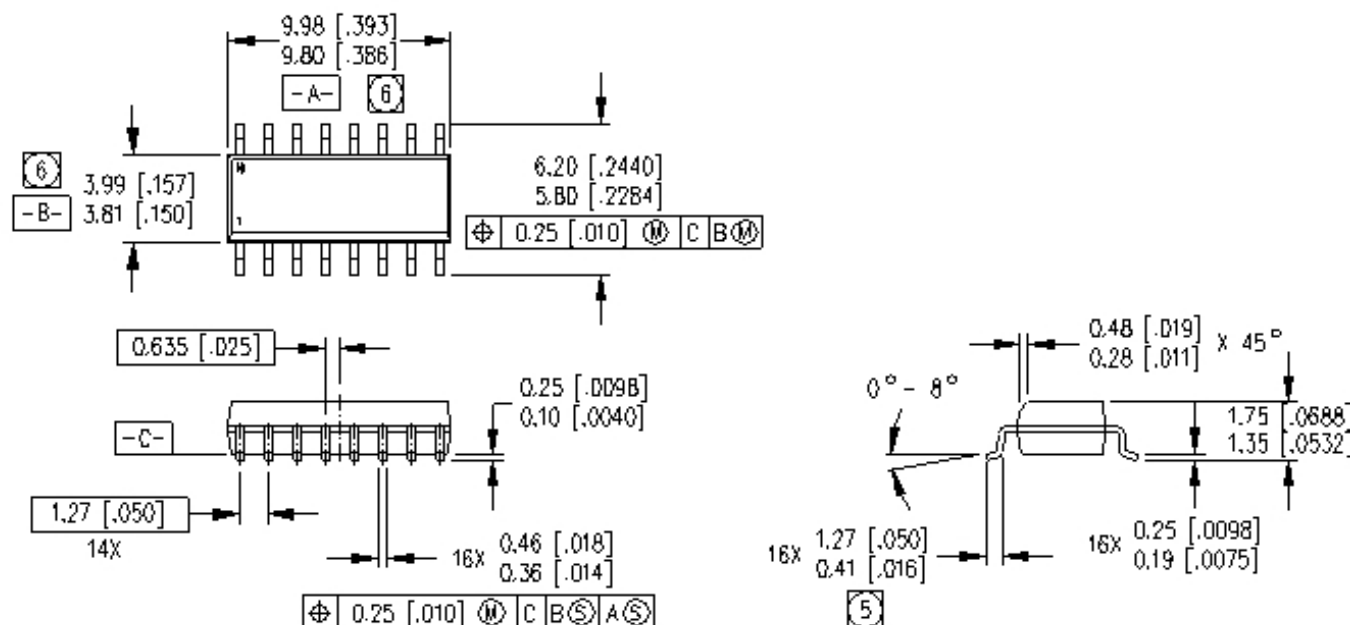
Then, total dissipation  $P_d$  is given by;

$$P_d = P_{MID} + P_{LOW} + P_{HIGH}$$

Estimated  $T_j$  from the thermal resistance between ambient and junction temperature,  $R_{thJA}$ ;

$$T_j = R_{thJA} \cdot P_d + T_A < 150^\circ C$$

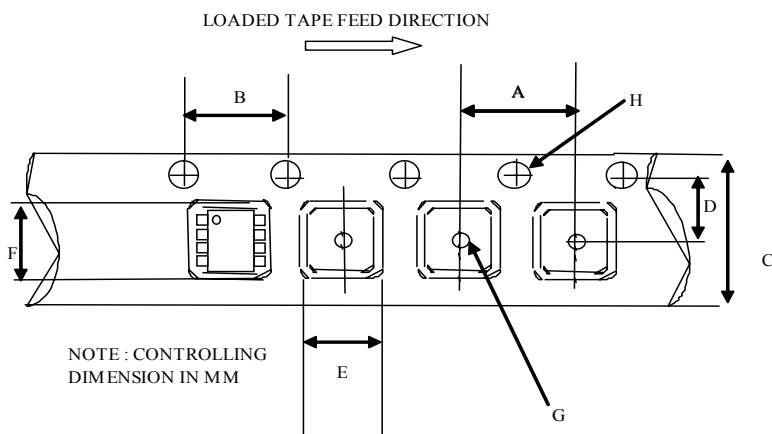
## Case Outline



### NOTES:

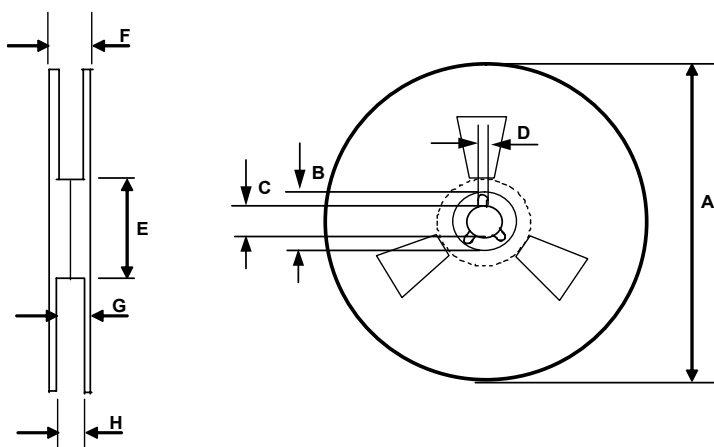
1. DIMENSIONING & TOLERANCING PER ANSI Y14.5W-1982
2. CONTROLLING DIMENSION. MILLIMETER
3. DIMENSIONS ARE SHOWN IN MILLIMETER [INCHES]
4. OUTLINE CONFORMS TO JEDEC OUTLINE MS-012AC
5. DIMENSION IS THE LENGTH OF LEAD FOR SOLDERING TO A SUBSTRATE
6. DIMENSION DOES NOT INCLUDE MOLD PROTUSIONS. MOLD PROTUSIONS SHALL NOT EXCEED 0.15 [.006]

**16-Lead SOIC (narrow body)**



CARRIER TAPE DIMENSION FOR 16SOICN

| Code | Metric |       | Imperial |       |
|------|--------|-------|----------|-------|
|      | Min    | Max   | Min      | Max   |
| A    | 7.90   | 8.10  | 0.311    | 0.318 |
| B    | 3.90   | 4.10  | 0.153    | 0.161 |
| C    | 15.70  | 16.30 | 0.618    | 0.641 |
| D    | 7.40   | 7.60  | 0.291    | 0.299 |
| E    | 6.40   | 6.60  | 0.252    | 0.260 |
| F    | 10.20  | 10.40 | 0.402    | 0.409 |
| G    | 1.50   | n/a   | 0.059    | n/a   |
| H    | 1.50   | 1.60  | 0.059    | 0.062 |

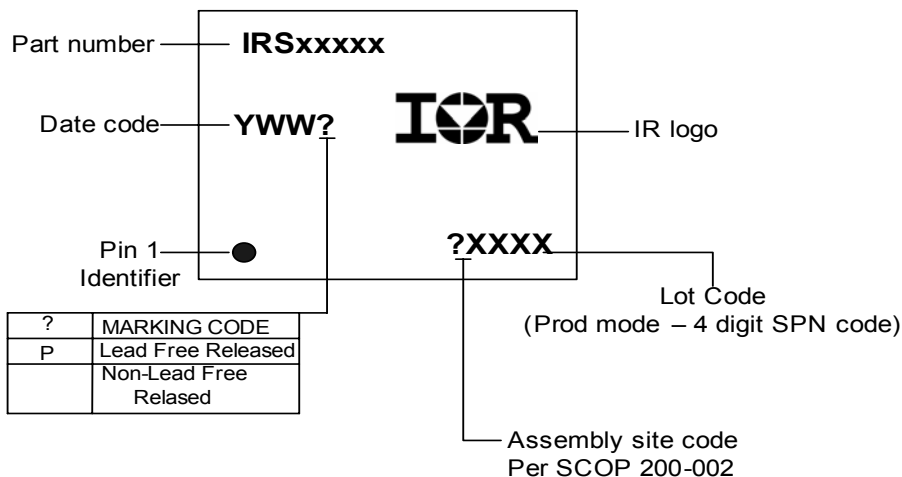


REEL DIMENSIONS FOR 16SOICN

| 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    | 22.40  | n/a      | 0.881  |
| G    | 18.50  | 21.10  | 0.728    | 0.830  |
| H    | 16.40  | 18.40  | 0.645    | 0.724  |



## LEAD-FREE PART MARKING INFORMATION



## ORDER INFORMATION

16-Lead SOIC IRS20954SPbF

16-Lead SOIC Tape & Reel IRS20954STRPbF

International  
**IR** Rectifier

**SO-16 package is MSL3 qualified.**

**This product has been designed and qualified for the industrial level.**

Qualification standards can be found at [www.irf.com](http://www.irf.com)

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*Data and specifications subject to change without notice. 12/3/2006*