Application Note

TAS6584-Q1 Real Time Load Diagnostics

ABSTRACT

TI's digital input automotive Class-D audio amplifier, TAS6584-Q1, offers a complete solution for real time load diagnostics. Real time load diagnostics can detect abnormal speaker load conditions and measure the speaker load impedance. This amplifier uses an internal DSP to perform these duties. This application note will provide insight into the working principles and application of real tiime load diagnostics using the TAS6584-Q1.

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1 Introduction

The safety needs in today's automobile includes the need for audio information to be presented to the passengers as well as pedestrians. There is a necessity to know that the speaker is properly connected at all times even during audio playback. This requires a new capabilities in the amplifier to determine that a speaker is present when audio is present as well as when audio is not present. Real Tiime Load Diagnostics meets these requirements.

2 Defining Real Time Load Diagnostics

Real-time load diagnostics (RTDLG) continuously monitors the load to ensure the load is within the specifications defined in the system. RTDLG is also called dynamic load diagnostics. While AC and DC Diagnostics or static diagnostics verify the status of the load before enabling the output, Real-Time Load Diagnostics monitor the output load conditions while audio is playing and provides feedback to the user through I^2C. By using the integrated current sense capabilities on the load, the TAS6584-Q1 is able to detect Open load, Short load, Short-to-Ground, and Short-to-Power conditions. Real-time load diagnostics has become a necessary diagnostic requirement in automotive audio applications to ensure the availability and status of the automotive speakers in critical safety systems like VESS (Vehicle Engine Sound System) and eCall (Emergency Call).

RTDLG has it challenges. Since the TAS6584-Q1 must be in Play mode for RTDLG, the first challenge is to measure the load without any impact on the audio and audio quality. The second challenge is to determine the type of load condition that is present.

2.1 Short Load/Open Load (SLOL)

The shorted load and open load detection utilize the same test method for these functions. The method is to measure the impedance with a measured voltage and current and utilizing Ohm's law we can calculate the impedance. The voltage would need to be measured when there is no audio present. A stimulus signal or pilot tone is used for this purpose. This pilot tone is infrasonic, so the pilot tone is inaudible.

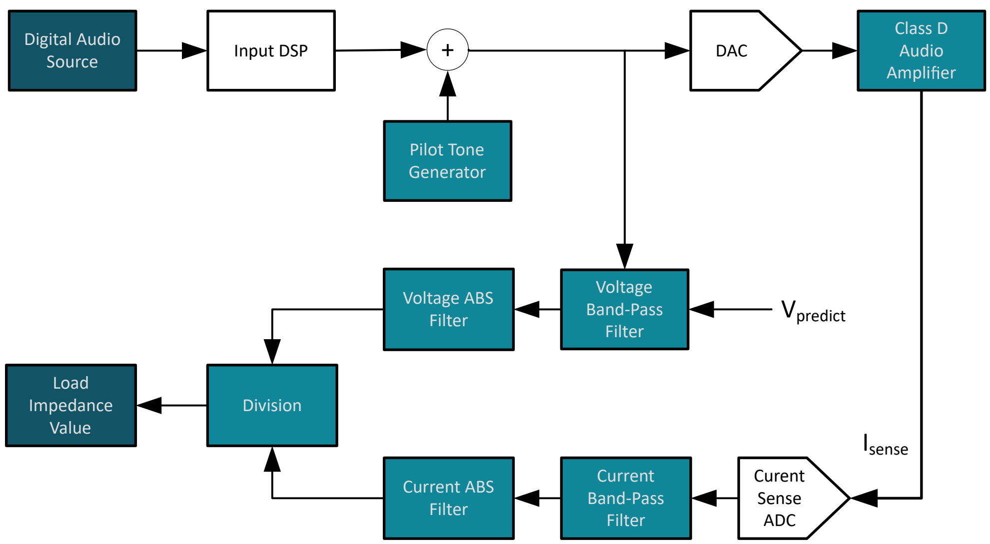


Figure 2-1. Real Time Load Diagnostics Block Diagram

Digital audio is provided by the source to the TAS6584-Q1. The pilot tone is generated internally and summed into the audio signal. The default pilot tone is 5.86Hz with an amplitude of -36dBFS. This frequency is well below the audio band and above the DC offset detection sensitivity.

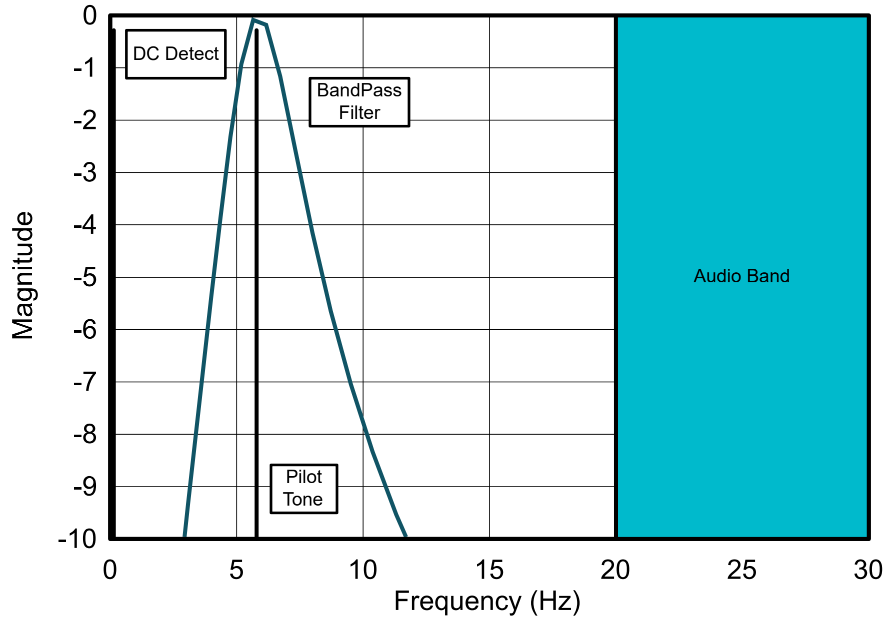


Figure 2-2. Pilot Tone and Bandpass Filter

The summed signal is labeled Vpredict. The gain of the system is known, so the voltage level of the signal at the output is predicted. The Vpredict voltage is used in the calculation as it cannot be voltage clipped. A clipped voltage would interfere with or eliminate the pilot tone and could not be measured correctly.

The current in the output stage is measured and digitized through an ADC, and it is labeled Isense. This is a scaled current through the output stage which is equivalent to the current in the speaker load.

The Vpredict and Isense are passed through their own Bandpass Filters. The bandpass filter removes the audio signal and allows only the pilot tone through to the the absolute value and alpha filter.

The alpha filter is a moving average type of filter. This filter smoothes the sinusoidal output to a DC value.

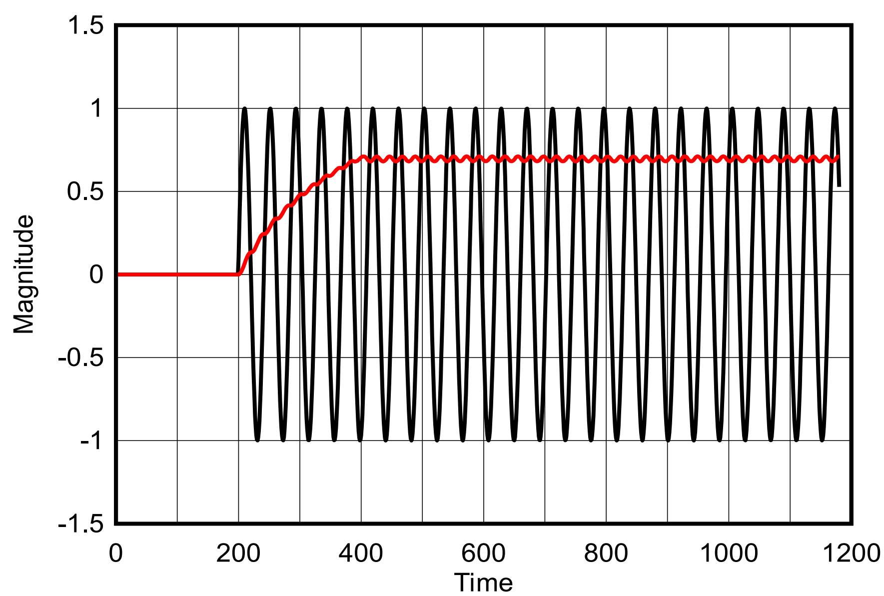


Figure 2-3. Alpha Filter Response

Division is performed on the filter output to provide the load impedance at 5.86Hz. The impedance values for channel 1 and channel 2 are placed in DSP book 78, page 7, register 0xDC through 0xDF and register 0xE8 through 0xEB. The impedance values for channel 3 and channel 4 are placed in DSP book 79, page 7, register 0xDC through 0xDF and Register 0xE8 through 0xEB.. The impedance is in 32 bit, 1.31 format.

Fault protection with individual channel shutdown can be enabled in regiser 0x5B. This impedance value is compared to two thresholds. A low impedance threshold for a short and a high impedance threshold for a short. If the value is below the low threshold or above the high threshold, the output stage of that channel will be placed into Hi-Z and a fault will be indicated in register 0x8B as indicated in the datasheet.

2.2 Pilot Tone

The target of Real-time-load-diagnostic SLOL detection is to acknowledge correct $V_{predict}/I_{sense}$ information regardless of what kind of audio signal is played. To realize this, an out-of-audio-band signal measurement is used. The default frequency of 5.86Hz with the amplitude of -36dbFS sinewave stimulus signal is provided. The measurement of Vpredict and Isense is based on this stimulus frequency and amplitude. This stimulus is called a 'Pilot tone', whose frequency is inaudible to human ear. The Pilot tone is mixed into the normal audio signal. $V_{predict}$ will be generated internally for impedance calculation.

2.3 Current Sense

The current sense measures the current flow through the FETs of the output stage with asigma-delta ADC. The ADC senses the voltage signal from a paralleled small FET to the main switching FET. Current flows into those 2 FETs has a fixed ratio. This provides the $I_{current}$ value needed for the calculations.

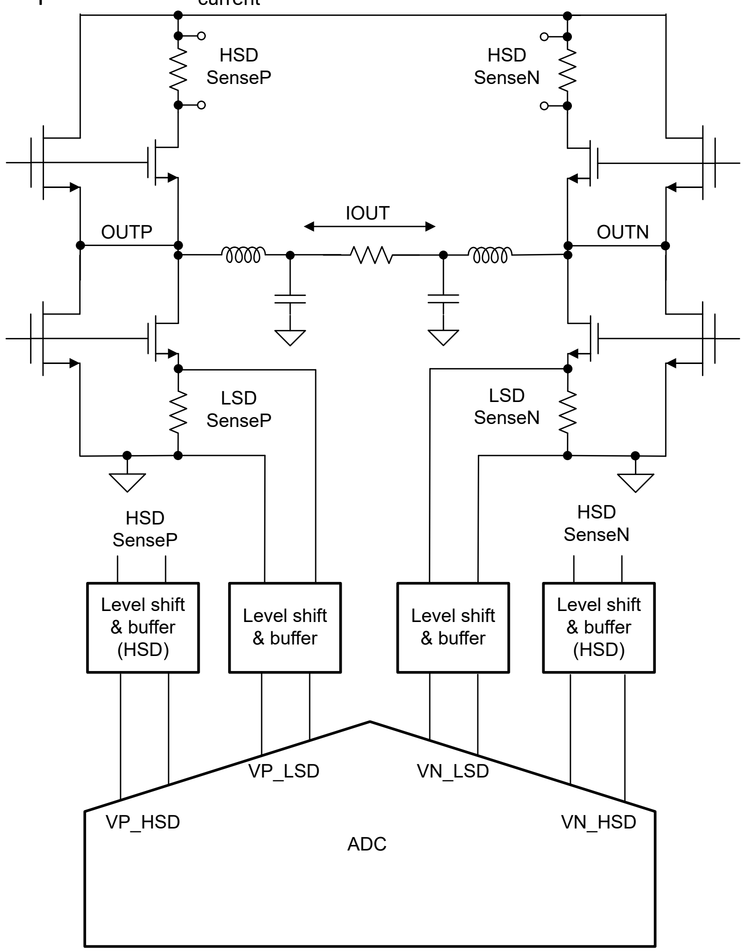


Figure 2-4. Current Sense Schematic

3 Voltage and Current Signal Processing

The Pilot Tone, a 5.86Hz, -36db sinusoid stimulus, is added into the audio path and is measured in both the Voltage ($V_{predict}$) and Current (I_{sense}) spectrum. The next step is to extract the pilot frequency amplitude. The voltage and current amplitudes are used to determine the load impedance. This value is used for Shorted Load and Open Load determination.

For I_{sense}, it is passed through a low pass CIC filter to filter out high band noise before it is converted to a digital signal in the ADC. Separate bandpass filters with narrow bandwidth are used to filter out everything but the pilot tone frequency for both $V_{predict}$ and I_{sense}. The absolute value is taken for the pilot tone frequency for both $V_{predict}$ and I_{sense} and is moved an Alpha filter. The two values are divided and the load impedance is determined.

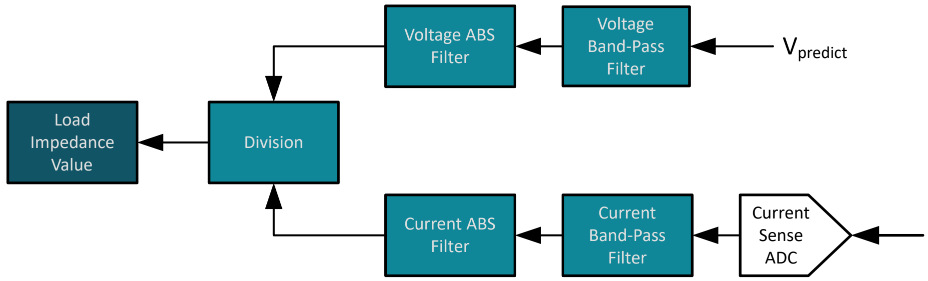


Figure 3-1. Voltage and Current Signal Processing

Once we get the amplitude of pilot frequency in $V_{predict}$ and I_{sense}, they are internally divided and then compared with the threshold setting.

If $V_{predict}/I_{sense}$ is greater than the open load threshold , an open load will be reported Register 0x8B, bits 0 through 3.

If $V_{predict}/I_{sense}$ is greater than the shorted load threshold , an short load will be reported in Register 0x8B, bits 4 through 7.

The thresholds for an open and short are determined separately. The calculation to determine the hexidecimal value for the thesholds is as follows:

(Threshold impedance in ohms)/12910592. Convert the calculated decimal value 32 bit hexadecimal value.

The default value for shorted load is 1 ohm. The default value for open load is 40 ohms. Both of these values would be good for most system designs. The value range for shorted load is 0.5 ohms to 10 ohms. The value range for open load is 20 ohms to 165 ohms. If the threshold value needs to be changed, the DSP values can be changed with the following script using the PPC3 GUI script.

```
Shorted Load example for 2.5ohm threshold
w c0 00 00          #write to register zero so the book can be changed
w c0 7f 8c          #change to book 8c
w c0 00 02          #change to page 02
w c0 88 01 ec 80 00 #Write to register 0x8C, 8D, 8E, 8F:  01 EC 80 00 to set the shorted load
Threshold to 2.5 ohms.  Use the calculated 32 bit hexadecimal value for the needed threshold.
Open Load example for 20 ohm threshold
w c0 00 00          #write to register zero so the book can be changed
w c0 7f 8c          #change to book 8c
w c0 00 02          #change to page 02
w c0 88 0f 64 00 00 # Write to register 0x88, 89, 8A, 8B:  0F 64 00 00 to set the open load
Threshold to 20 ohms.  Use the calculated 32 bit hexadecimal value for the needed threshold.
```

3.1 Smoothing Filter vs Time to Fault

Setting the Smoothing Time in the Advanced OL and SL Configuration dialog box, can be performed by clicking on the Gear Icon in the OL and SL Configuration window in the Real-time Measurement Section of the TAS6584-Q1 GUI.

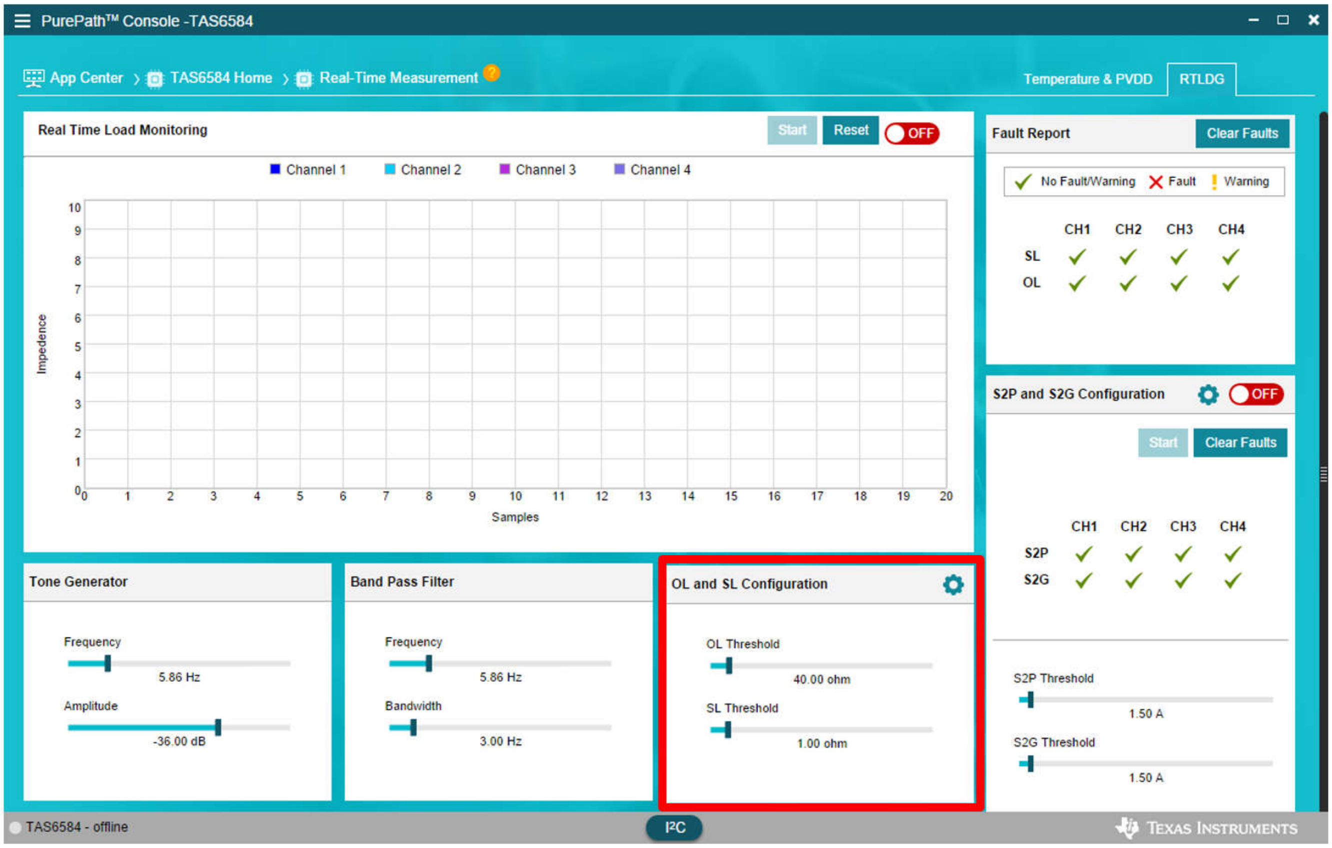


Figure 3-2. OL and SL Configuration

The OL and SL Configuration dialog box provide a method to change the smoothing time for the impedance measurement.

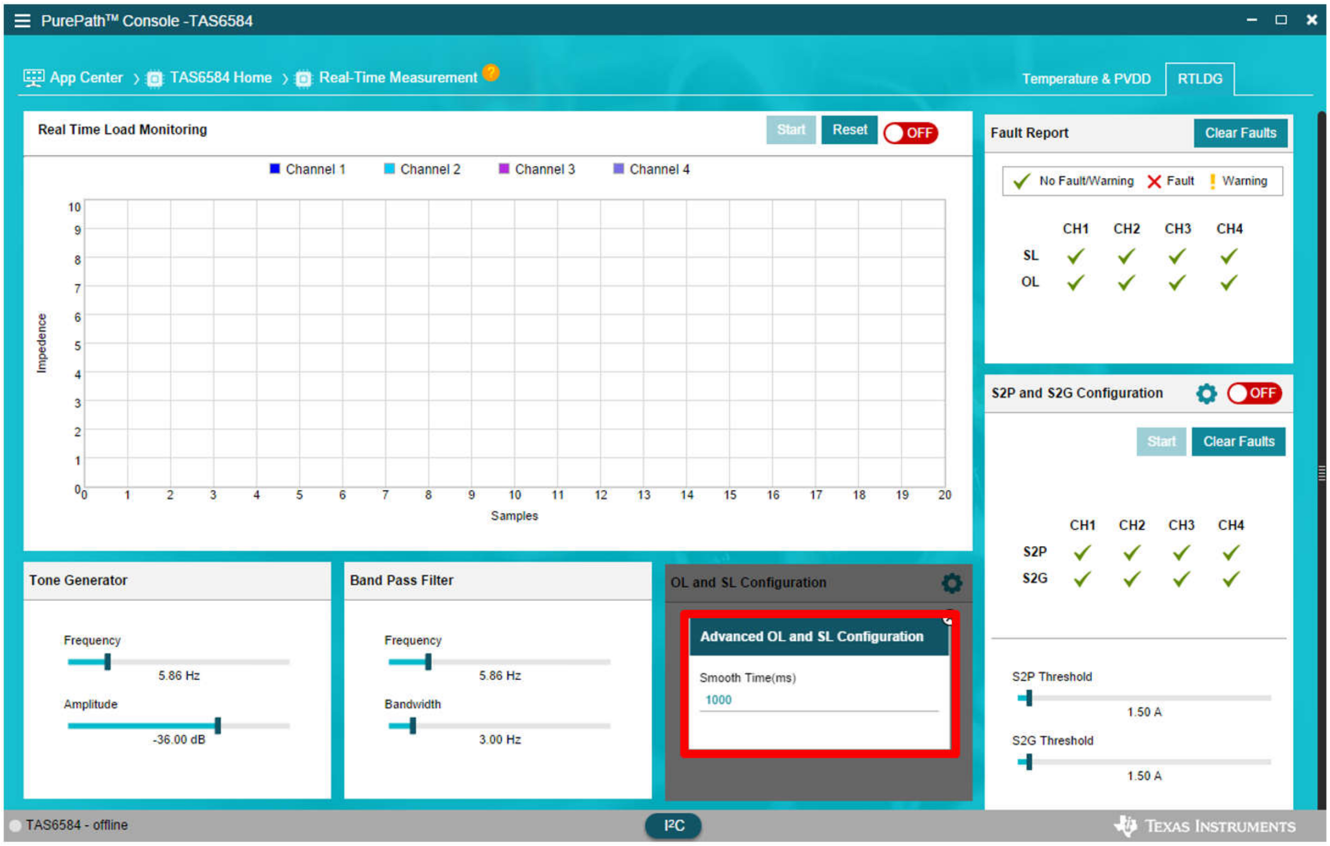


Figure 3-3. Advanced OL and SL Configuration

The smoothing time default is 1000ms. This can be changed to increase or decrease the smoothing time. A longer time will result in a more accurate impedance value. Conversely, a decrease in the smoothing time will result in a less accurate impedance value. The smoothing time also affects the time to fault. If an open load or shorted load is present, the smoothing time is directly proportional to the time for a fault to be set and to place that channel in Hi-Z mode.

The smoothing filter is a digital equivalent of a 1st order RC filter. As more time passes the more the RC filter charges to be more accurate. A separate filter is used on both the Vpredict and Isense. Since the voltage and current waveforms will be in phase at the low test frequency, the Vpredict and Isense will charge the filter at the same rate. So, if the time is changed to 300ms from the 1000ms, the charging will be less and the value will be less accurate. So, if the Vpredict value at 300ms is 0.66Vpredict at 1000ms and Isense is 0.66Isense at 1000ms. We can perform the division of 0.66Vpredict/0.66Isense. As you can see, the 0.66 values cancel out and you are left with a Vpredict/Isense calculation and the proper impedance value.

The calculation for the approximate time to fault in seconds, where α is the smoothing time.

$T_{fault} = 2\alpha + 0.15$

3.2 Fault Determination

Once we get the amplitude of pilot frequency in V**predict** and **Isense**, they are internally divided and then compared with the threshold setting.

Once Vpredict/Isense > open threshold, an open load will be reported Register 0x8B, bits 0 through 3

Once Vpredict/Isense < short threshold, an short load will be reported in Register 0x8B, bits 4 through 7

The measures impedance can be read from the DSP registers. The dual DSPs must first be unganged so they perform independently. Change the book to 78, page 7. The impedance value for channel 1 is in registers DC, DD, DE, and DF. The impedance value for channel 2 is in registers E8, E9, EA, and EB. For channels 3 and

4, change the book to 79, page 7. The impedance value for channel 3 is in registers DC, DD, DE, and DF. The impedance value for channel 4 is in registers E8, E9, EA, and EB. After reading these values it is best to gang the dual DSPs.

3.3 Example Code

The following I2C code uses the PPC3 GUI script style. This is for a 48kHz. The default values for the Pilot Tone and Bandpass filter are set for 5.86Hz and -36dB. Therefore, they are not necessary to write.

I2C Configuration:

```
w c0 03 22            #set to sleep mode
w c0 04 22            #set to sleep mode
###  Enable Current Sense  ###
W C0 00 00            #Must always set to register 00 before changing books
W C0 7F 00            #Set to book 0, the registers in the datasheet
W C0 05 0E            #Enable current sense on all four channels
W C0 5B 08            #Disable RTDLG reporting and enable current sense offset calibration
W C0 5C 40            #Set up for BTL or PBTL, 0x40 for BTL, and 0x48 for PBTL, and calibrated
current sense data

### Pilot Tone and BandPass Filter 48kHz coefficients ###
W C0 00 00            #Must always set to register 00 before changing books
W C0 7F 8C            #Set to book 8C, a DSP register
W C0 00 03            #Go to page 3 in book 8C
W C0 A4 74 FF FD 88   #Write 32 bits to set the first coefficient for the pilot tone frequency
W C0 A8 FF E6 DE 05   #Write 32 bits to set the second coefficient for the pilot tone frequency
W C0 AC 00 00 7F F7   #Write 32 bits to set the third coefficient for the pilot tone frequency
W C0 24 00 20 75 68   #Write 32 bits to set the pilot tone gain, default is -36dB
W C0 00 04            #go to page 4
W C0 1C 00 00 66 EC   #Write these values for the bandpass filter and the bandwidth
W C0 20 00 00 00 00
W C0 24 FF FF 99 14
W C0 28 0F FF 31 DD
W C0 2C F8 00 CD D9   #5.86Hz band pass filter (3Hz BW)
W c0 00 03            #go to page 3
W C0 48 00 00 00 00   #x=1 to disable the pilot tone, x=0 to enable it, set it to 0

### Set Thresholds for OL and SL  ###
W C0 00 00            #Must always set to register 00 before changing books
W C0 7F 00            #Set to book 00
W C0 03 44            #Set channels 1 and 2 to play mode
W C0 04 44            #Set channels 3 and 4 to play mode
W C0 01 08            #Clear any faults
W C0 00 00            #Set to page 0, so we can change the book
W C0 7F 78            #Move to book 78
W C0 00 19            #Move to page 19
W C0 3C 10 00 00 00   #Set the initial value of Re  (set channel 1 and 3)
W C0 48 10 00 00 00   #Set the initial value of Re  (set channel 2 and 4)
W C0 00 00            #Set to page 0, so we can change the book
W C0 7F 8C            #Set to book 8C
W C0 00 02            #Set to page 2
W C0 88 1D 00 00 00   #Set open load threshold, default is 40 ohms
W C0 8C 00 C5 00 00   #Set shorted load threshold, default is 1 ohm
w C0 00 00            #Return to page 0 of book 8C
W C0 7F 00            #Return to book 0, page 0
W c0 00 00

### Enable RTLDG  ###
R c0 8b 01            #read to guarantee it is cleared
R c0 8c 01            #read to guarantee it is cleared
w c0 03 cc            #place in Mute, may not be necessary
w c0 04 cc            #place in Mute, may not be necessary
W C0 03 44            #Set channels 1/2 to Play state
W C0 04 44            #Set channels 3/4 to Play state
W C0 5B 08            #Enable Isense offset calibration
w c0 5b 02            #Enable RTLDG Report, 4 x BTL configuration

### Read back the OL SL Report ###
R C0 8B 01            #Read one byte starting at Register 8B, OL and SL fault reporting

### Read load impedance values ###
w c0 39 10            #Set w/r to ungang
W C0 00 00            #Set to page 0, so we can change the book
W C0 7F 78            #Move to book 78
```

```
W C0 00 07            #Move to page 07
r C0 DC 04            #Read CH1 Resistance, 32 bits
r C0 E8 04            #Read CH2 Resistance, 32 bits
W C0 00 00            #Set to page 0, so we can change the book
W C0 7F 79            #Move to book 79
W C0 00 07            #Move to page 07
r C0 DC 04            #Read CH3 Resistance, 32 bits
r C0 E8 04            #Read CH4 Resistance, 32 bits
w c0 00 00
w c0 7f 00
w c0 00 00
w c0 39 00            #Set w/r back to gang
```

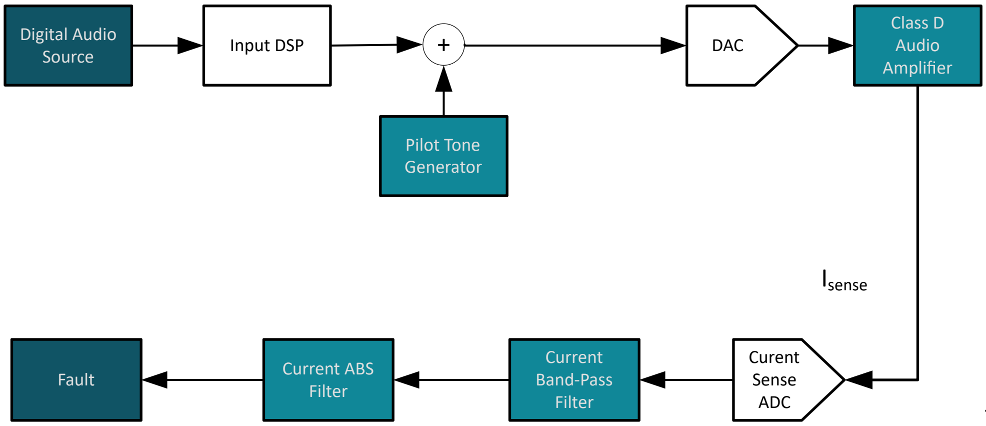
3.4 Tweeter Detection

A capacitive coupled speaker, expecially a tweeter, cannot be properly detected with a 5.86Hz signal. Therefore, we need to create high frequency signal that is inaudible. A 20kHz pilot tone can be created and the bandpass filter can be adjusted to measure this ultrasonic tone. Note that the change will change all channels. The following code can be used for Pilot Tone and Bandpass filter DSP values.

```
### Pilot Tone and BandPass Filter 48kHz coefficients ###
w c0 00 00            #Must always set to register 00 before changing books
w c0 7F 8C            #Set to book 8C, a DSP register
w c0 00 03            #Go to page 3 in book 8C
w c0 a4 91 26 14 5f   #Write 32 bits to set the first coefficient for the pilot tone frequency
w c0 a8 c0 00 00 00   #Write 32 bits to set the second coefficient for the pilot tone frequency
w c0 ac 00 00 00 00   #Write 32 bits to set the third coefficient for the pilot tone frequency
w c0 24 00 20 75 68   #Write 32 bits to set the pilot tone gain, default is -36dB
w c0 00 04
w c0 1c 00 40 eb 5a   #Write these values for the bandpass filter and the bandwidth
w c0 20 00 00 00 00
w c0 24 ff bf 14 a6
w c0 28 f2 93 5d 10
w c0 2c f8 81 d6 b4   #20kHz band pass filter (500Hz BW)
```

4 Short to PVDD and Short to GND Detection

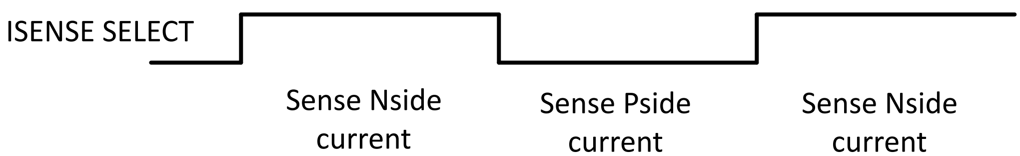
Similar to SLOL detection, S2PG detection collects signal of both OUTP and OUTM to detect short. Since device plays audio signal, there should be no large DC offset current into the output. The RTLDG measure the offset of OUTPM current to monitor the S2PG failure.



figure

4.1 OUTPM I_{sense} Signal Processing

Since both OUTPM signal is required for the S2PG measurement, a MUX is used to select OUTPM signal on the **Isense** data line. The selection is driven by ISENSE_SELECT_M and toggles at approximately 0.68 seconds, which is synchronized with pilot tone, to avoid a frequency mismatch. This will provide the means necessary to separate the current in the negative output side from the positive side current. This ISENSE_SELECT_M toggle is enabled when S2PG detection is enabled.



Once the I_{sense} signal is provided an internal DC offset calibration is performed to remove any DC offset created by the sensing circuitry. As in the Shorted Load and Open Load real time diagnostics, the current is filtered, digitized, and passed through the alpha filter to provide a DC current value that is proportional to the output stage current. Any difference in the two stage currents indicatate a current path to power or to ground. When the threshold is passed a fault will be indicated and the output stage will be placed in Hi-Z.

4.2 Fault Detemination

The fault threshold are I_{sensep} and I_{sensem}. They are set in Book 8C, page 5, register 0x90 through 0x93 for short to ground. And in Book 8c, page 4, register 0x64d through 0x67 for Short to power. Fault report can be readout in Book 0, page 0 register 0x8C.

4.3 S2PG Example Code

I2C Code

```
w C0 00 00              #Page switching (1st 00) to page 0 (2nd 00)
w C0 7F 8C              #Change to book 8C. It's required to be in page 0 before changing a book
w C0 00 05              #Go to the page 05 in book 8C
w C0 90 06 46 46 46     #Set S2G current threshold to 1.5A (configurable)
w C0 00 04              #Go to the page 04 in book 8C
w C0 64 06 46 46 46     #Set S2P current threshold to 1.5A (configurable)
w C0 58 00 00 00 01     #Enable S2P/S2G detection
W C0 00 00              #Must always set to register 00 before changing books
W C0 7F 00              #Set to book 00
R C0 8C 01              #Read the faults if the threshold has been surpassed.
```

5 Appendix

Minimal code for RTDLG fault detection

```
w c0 03 22            #set to sleep mode
w c0 04 22            #set to sleep mode
###  Enable Current Sense  ###
W C0 00 00            #Must always set to register 00 before changing books
W C0 7F 00            #Set to book 0, the registers in the datasheet
W C0 05 0E            #Enable current sense on all four channels
W C0 5B 08            #Disable RTDLG reporting and enable current sense offset calibration
W C0 5C 40            #Set up for BTL or PBTL, 0x40 for BTL, and 0x48 for PBTL, and calibrated
current sense data
W C0 00 00            #Must always set to register 00 before changing books
W C0 7F 8C            #Set to book 8C, a DSP register
W C0 00 03            #Go to page 3 in book 8C
W C0 48 00 00 00 00   #x=1 to disable the pilot tone, x=0 to enable it, set it to 0
### Enable RTLDG  ###
R c0 8b 01            #read to guarantee it is cleared
R c0 8c 01            #read to guarantee it is cleared
W C0 03 44            #Set channels 1 and 2 to Play state
W C0 04 44            #Set channels 3 and 4 to Play state
w c0 5b 02            #Enable RTLDG Report, 4 x BTL configuration

### Read back the OL SL Report ###
R C0 8B 01            #Read one byte starting at Register 8B, OL and SL fault reporting
```

6 References

- datasheet