

How the SmartAmp Speaker Protection Algorithm Compensates the Effects of Series Resistance

Supriyo Palit

Software Engineer

ABSTRACT

This document describes how the SmartAmp speaker protection algorithm can compensate the effect of adding a series resistance with a loudspeaker when used with devices with IV sense capabilities, such as TAS2560, TAS2557, TAS2559 and TAS2770.

Contents

1	Introduction	1
2	Circuit Diagram.....	1
3	SmartAmp Algorithm Implementation	2
4	Summary.....	5
5	References	5

List of Figures

1	Sense Voltage Including Series Resistance	1
2	Sense Voltage Without Series Resistance	2

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1 Introduction

The Texas Instruments SmartAmp speaker protection algorithm monitors the temperature and excursion of the loudspeaker and allows to improve the loudspeaker performance. The voltage across the loudspeaker and the current flowing through the loudspeaker is fed back to the SmartAmp algorithm by the IV sense capabilities integrated in the SmartAmp devices. In some applications the loudspeaker is connected to the SmartAmp amplifier output via a long trace on the PCB, flex cable or long wire, which adds additional resistance in series with the loudspeaker. In some cases a series resistance is intentionally added in the circuit to reduce idle channel noise.

2 Circuit Diagram

2.1 Application Case 1: Sense Voltage Including Series Resistance

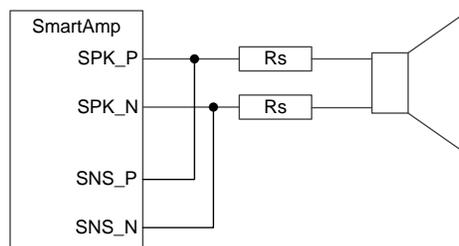


Figure 1. Sense Voltage Including Series Resistance

In this application, the sense pins are connected right at the amplifier terminals, and the sense voltage includes the series resistance.

The series resistance acts as a voltage divider and reduces the idle channel noise across the loudspeaker terminals. This topology also helps in keeping the sense wire traces short.

2.2 Application Case 2: Sense Voltage Without Series Resistance

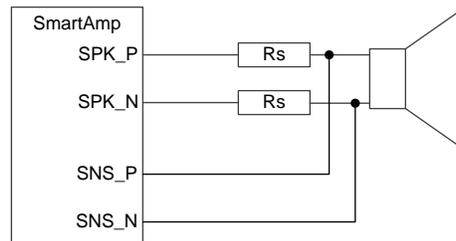


Figure 2. Sense Voltage Without Series Resistance

In this application, the sense pins are connected right at the speaker terminals, and the sense voltage does not include the series resistance.

Although the series resistance acts as a voltage divider, TAS2560, TAS2557 and TAS2559 devices have post-filter feedback circuit configuration, which means that the series resistance is included within the amplifier feedback circuit, hence the idle channel noise of the amplifier will be induced across the terminals of the loudspeaker. Thus, this topology cannot be used to reduce idle channel noise.

3 SmartAmp Algorithm Implementation

One key assumption in all the following analysis is that the series resistor (R_s) does not change value with power or temperature.

Also, it's important to note that any series resistance will result in power loss, for example, for a given input power, the output power available in the speaker will be less, or for a given output power across the speaker, the input power requirement will be higher. This means that the efficiency will reduce.

The expression for power across the speaker is given by [Equation 1](#):

$$P_{\text{spk}} = P_{\text{in}} \frac{R_{\text{dc}_t}}{2 \times R_s + R_{\text{dc}_t}}$$

where

- P_{in} = power delivered by the amplifier
- P_{spk} = power across the speaker
- $2 \times R_s$ = series resistance
- R_{dc_t} = DC resistance of the voice coil of the speaker at any given time (t)
- R_{dc_t} is a time varying quantity because it changes with change in temperature of the voice coil of the speaker
- R_s is assumed to be constant

(1)

Thus, the power loss across the series resistance is:

$$P_{\text{loss}} = P_{\text{in}} - P_{\text{spk}} = P_{\text{in}} \frac{2 \times R_s}{2 \times R_s + R_{\text{dc}_t}}$$

(2)

3.1 Application Case 1: Sense Voltage Including Series Resistance

3.1.1 Temperature

In this case, since, the sensed voltage includes the series resistance, hence, the SmartAmp algorithm will measure the circuit resistance as:

$$R_{msr_t} = 2 \times R_S + R_{dc_t}$$

where

- R_{msr_t} = measured resistance at any given time (t) (3)

Assume the measured resistance at factory calibration time is:

$$R_{msr} = 2 \times R_S + R_{dc}$$

where

- R_{msr} = measured resistance
- $2 \times R_S$ = series resistance
- R_{dc} = DC resistance of the voice coil of the speaker at factory calibration time (4)

Assume, temperature of the speaker voice coil at time (t) is equal to T and at factory calibration time is equal to T_0

Then,

$$R_{dc_t} = R_{dc} \left[1 + \alpha (T - T_0) \right]$$

where

- α = temperature coefficient of resistance of the voice coil material (5)

Hence,

$$\Delta T = T - T_0 = \frac{R_{dc_t} - R_{dc}}{\alpha R_{dc}} \quad (6)$$

Now,

$$\frac{R_{msr_t} - R_{msr}}{\alpha R_{msr}} = \frac{R_{dc_t} - R_{dc}}{\alpha R_{msr}} = \left(\frac{\alpha R_{msr}}{R_{dc}} \right) R_{dc} \quad (7)$$

Define,

$$\alpha' = \frac{\alpha R_{dc}}{R_{msr}} = \frac{\alpha (R_{msr} - 2 \times R_S)}{R_{msr}} \quad (8)$$

Hence,

$$\frac{R_{msr_t} - R_{msr}}{\alpha' R_{msr}} = \frac{R_{dc_t} - R_{dc}}{\alpha R_{dc}} = \Delta T \quad (9)$$

Thus, from R_S and R_{msr} , the SmartAmp algorithm is able to calculate a modified temperature coefficient of resistance (α') to compensate for the series resistance. With this compensation, the SmartAmp algorithm can measure the voice coil temperature accurately even with the series resistance.

3.1.2 Excursion

The addition of series resistance is going to reduce the current flowing through the circuit and hence, for a given input voltage, the excursion (and also the SPL ⁽¹⁾) is going to be less. However, it is not going to affect the SmartAmp speaker protection algorithm reliability.

⁽¹⁾ SPL = Sound Pressure Level is a measure of loudness of sound produced by a loudspeaker.

3.2 Application Case 2: Sense Voltage Without Series Resistance

3.2.1 Temperature

Since the sense voltage does not include the series resistor, hence, the temperature is going to be measured accurately using the original temperature coefficient α ,

$$\Delta T = T - T_0 = \frac{R_{dc_t} - R_{dc}}{\alpha R_{dc}} \quad (10)$$

So, there is no compensation required.

3.2.2 Excursion

Since TAS2560, TAS2557 and TAS2559 devices have post-filter feedback circuit configuration hence the voltage across the sense terminals (SNS_P and SNS_N) will follow the voltage with which the SmartAmp algorithm drives the amplifier. Hence the excursion will be estimated accurately. For devices without post-filter feedback, (for example, TAS2770) the SmartAmp algorithm will estimate the excursion accurately by compensating for the series resistance.

3.2.3 Channel Gain (Only for Devices With Post-Filter Feedback)

With post-filter feedback, the voltage across the SPK_P and SPK_N terminals will be higher than the output of the SmartAmp algorithm (which is equal to the voltage across the SNS_P and SNS_N terminals), for example.

$$V_{algo} = V_{SNS} = V_{SPK} = V_{AMP} \frac{R_{dc_t}}{R_{dc_t} + 2 \times R_S}$$

where

- V_{algo} = SmartAmp output equivalent voltage (including gain of the amplifier)
 - V_{SNS} = Sense voltage across SNS_P and SNS_N
 - V_{SPK} = Voltage across the speaker
 - V_{AMP} = Voltage at the amplifier output across SNS_P and SNS_N
- (11)

Without R_S (which means, $R_S = 0$ in Equation 11), $V_{algo} = V_{SNS} = V_{AMP}$ and the gain of the amplifier is chosen such that

$$V_{algo_max}(\text{maximum value of } V_{algo}) = V_{SNS_max}(\text{maximum value of } V_{SNS}) = V_{AMP_max}(\text{maximum value of } V_{AMP}) = V_{MAX}$$

where

- V_{MAX} is the rated maximum voltage of the amplifier such that there is no clipping.
- (12)

From Equation 11, when, $V_{algo} = V_{SNS} = V_{SPK} = V_{MAX}$,

$$V_{AMP_max} = V_{MAX} \frac{R_{dc_t} + 2 \times R_S}{R_{dc_t}} > V_{MAX} \quad (13)$$

Thus, the amplifier will clip if the gain is kept at the same level as before.

To prevent clipping of the amplifier, the SmartAmp algorithm reduces V_{algo} using a post gain compensation block such that,

$$V_{AMP_max} = V_{MAX} \text{ and } V_{algo} = V_{SNS} = V_{SPK} = V_{MAX} \frac{R_{dc_t}}{R_{dc_t} + 2 \times R_S} \quad (14)$$

Thus, the post gain compensation block is a gain multiplier whose value is

$$\frac{R_{dc_t}}{R_{dc_t} + 2 \times R_S} \quad (15)$$

As an example, assume, $R_S = 1 \Omega$ and minimum value of $R_{dc,t} = 8 \Omega$ (minimum value will cause maximum post gain compensation).

Post Gain Compensation will be:

$$\frac{8}{8 + 2} = 0.8_{(\text{linear scale})} = -1.94 \text{ dB} \quad (16)$$

Thus, the SmartAmp speaker protection algorithm will attenuate the output by -1.94 dB to ensure that there is no clipping at the amplifier output terminals SKP_P and SPK_N.

4 Summary

The document explains how the SmartAmp algorithm is able to compensate the effect of series resistance in the two most commonly used application cases. In application case 1, the compensation is done in the temperature coefficient of resistance (for accurate temperature control) while in application case 2 the compensation is done in the post gain block (to prevent amplifier clipping)

5 References

- Texas Instruments, [SmartPA Speaker Protection Algorithm](#) application report

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