Overview of system-level protection in class-D audio amplifiers

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Class-D audio amplifiers with integrated system protection features help engineers create robust and reliable audio designs.

The class-D audio amplifier topology is designed to reduce power consumption and thermal dissipation compared to traditional linear audio amplifier topologies such as class A, class B and class AB. When class-D amplifier technology was initially developed, designers mainly focused on improving these two specifications.

As class-D amplifier technology matured, class-D products integrated more and more features beyond improved efficiency and thermal performance. One of the key areas addressed is improved system-level reliability, which helps designers ensure that a system operates reliably in its intended application. A typical audio system has several key items that need protection to help ensure reliable system function:

- The audio amplifier integrated circuit (IC) itself needs protection from potentially damaging temperature, voltage, current and input signals.
- The system power supply needs protection from load currents and voltages that exceed the power-supply capability and can cause unintended operation or damage.
- The system needs electromagnetic compatibility (EMC) protection that avoids interference with other devices and allows successful product compliance testing.
- Finally, the system transducer (or speaker) needs protection from electrical and physical damage caused by various stresses.

This paper provides a high-level overview of a number of system-level protection features found in class-D audio amplifiers, and how they help to ensure stable operation.

Overcurrent protection

Overcurrent protection (OCP) detects when a predetermined output current threshold has been exceeded, and shuts the amplifier down to help protect it from damage. The electrical capability of the internal circuits to deliver current without damage determines the output current limits of different class-D amplifiers. Upon a detected shutdown, the amplifier drives a digital output signal to the host processor to communicate that an overcurrent fault has occurred.

Examples of some overcurrent conditions are attributed to shorted wiring, printed circuit board (PCB) traces, component faults or damaged speakers. By limiting the output current of an amplifier to a level that won't damage it, OCP can help protect both the amplifier and system power supply from certain, reliability-based, stress-induced damage. OCP can also protect speakers from overcurrent, as well as provide a protective element to minimize risks of system-related overheating. External current-protection circuits add cost and complexity, and are typically less robust than integrated OCP. **Figure 1** shows an example timing diagram of OCP in a class-D amplifier.

Overtemperature protection

Overtemperature protection (OTP) detects when the temperature of the amplifier exceeds a specified level resulting in the amplifier shutting down to help protect itself from damage. The individual amplifier characteristics help establish an appropriate temperature limitation. Upon shutdown, the amplifier drives a digital output signal to the host processor to communicate that an overtemperature fault has occurred.

OTP events can occur due to abnormally high ambient temperatures, unexpected audio signals or a variety of unanticipated system faults. OTP helps to protect class-D amplifiers from overheating and potentially causing further system-related issues.

Some class-D amplifier devices also have overtemperature warning (OTW) functionality, which warns the system host when the amplifier temperature nears operational limits so that the host can take action, such as reducing gain or shutting down a channel, to decrease system temperature.

AM interference avoidance

Switching amplifiers, including class-D, can produce AM interference by emitting radio energy emissions near the digital amplifier's switching rate as well as the harmonics of that switching rate, meaning that the fundamental frequency and its second harmonic straddle the AM radio band. This can be an issue when the digital amplifier is located by the AM radio (as in an automotive infotainment module or an integrated home audio system).

To alleviate this issue, many newer class-D amplifiers from Texas Instruments (TI) include patented proprietary algorithms that minimize interference with tuned AM radio frequencies or provide the ability to change the switching frequency (via I2C commands) to as high as 2.1MHz (**Figure 2**), thus switching above the AM band. Because these strategies eliminate the tones present from demodulation of the switching frequency by the AM radio, there's no need for complex electromagnetic interference (EMI) avoidance schemes.

Voltage protection

Voltage (over and under) protection is a key design attribute for all class-D amplifiers. In an automotive environment, the typical power supply voltage (PVDD) is the car battery. The battery voltage can have large voltage swings during normal vehicle operation.

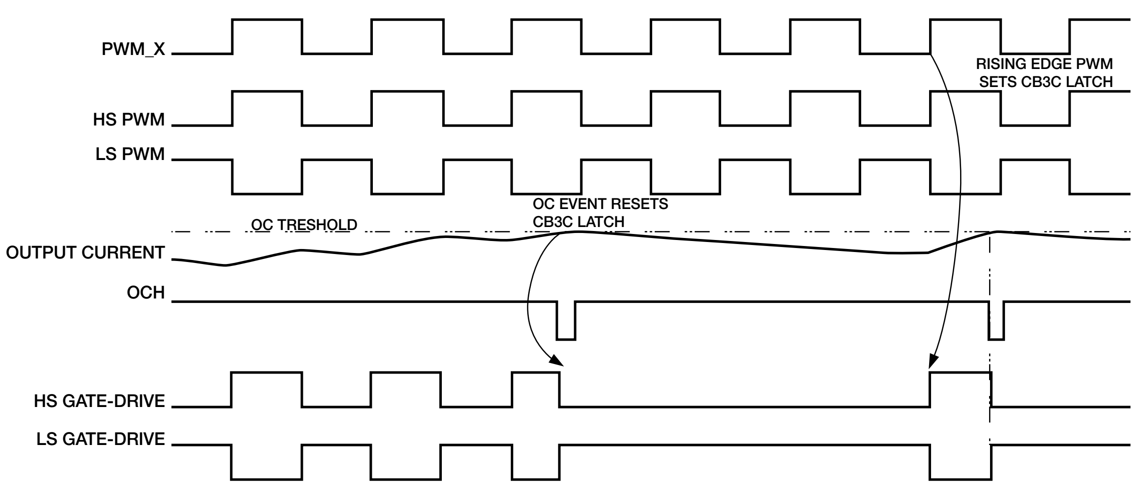

***Figure 1**. TPA3251 OCP timing diagram*

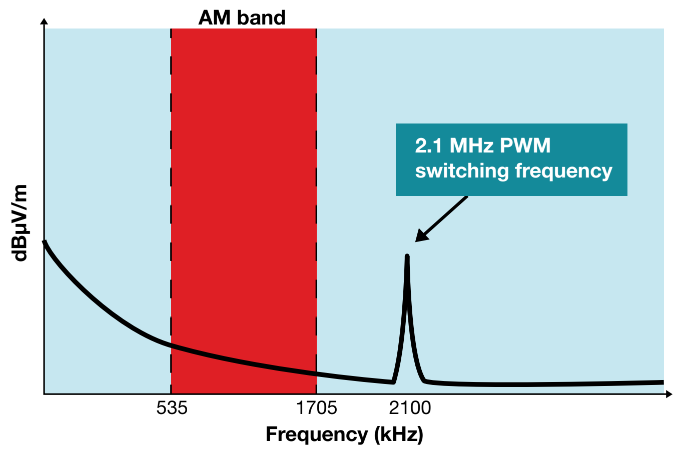

Figure 2. *2.1MHz PWM switching frequency*

There's also the possibility of an unusual event such as a load dump.

TI automotive devices help protect against overvoltage on the PVDD pin for up to 50V load-dump spikes. Undervoltage protection also exists on the PVDD, analog supply voltage (AVDD), digital supply voltage (DVDD) and charge-pump supply voltage (CPVDD) pins. If a CP undervoltage condition occurs, the AVDD voltage turns off and an AVDD undervoltage fault occurs. In this case, both CP and AVDD undervoltage bits will be set and the real undervoltage fault is CP.

TI's general purpose class-D devices contain protection circuit features designed to make system design more efficient as well as to help protect against permanent failures, including short circuits, overload, and over- and undervoltage. **Table 1** lists a typical fault reporting schedule.

Automatic gain limit versus a hard limiter

Automatic gain limit (AGL) is an enhanced dynamic range compression (DRC) function used in many TI class-D audio amplifiers, which essentially compresses the output power without clipping the output waveforms. It has a feedback topology as opposed to the traditional DRC feed-forward topology that enables the AGL algorithm to immediately compress the incoming signal when it is over the threshold in a short amount of time (i.e. a very small attack time).

To implement AGL, simply adjust the desired level for each of its component parameters:

- The threshold specifies the application of AGL (compression).
- The softening filter takes out the harmonics during hard compression.
- The attack and release times specify how quickly compression turns on and off, respectively.

By setting these appropriately, you will find that the output waveforms do not clip as much as under other schemes.

An alternative scheme known as a hard limiter restricts the power by clamping the output to pre-set highs and lows (Vpk-pk) producing a clipped waveform which results in much higher distortion (**Figure 3**).

Fault	Triggering Condition (typical value)	FAULTZ	Action	Latched/Self-clearing
Over Current	Output short or short to PVCC or GND	Low	Output high impedance	Latched
Over Temperature	T_j > 150°C	Low	Output high impedance	Latched
Too High DC Offset	DC output voltage	Low	Output high impedance	Latched
Under Voltage on PVCC	PVCC < 4.5V	–	Output high impedance	Self-clearing
Over Voltage on PVCC	PVCC > 27V	–	Output high impedance	Self-clearing

Table 1. *Typical fault reporting schedule*

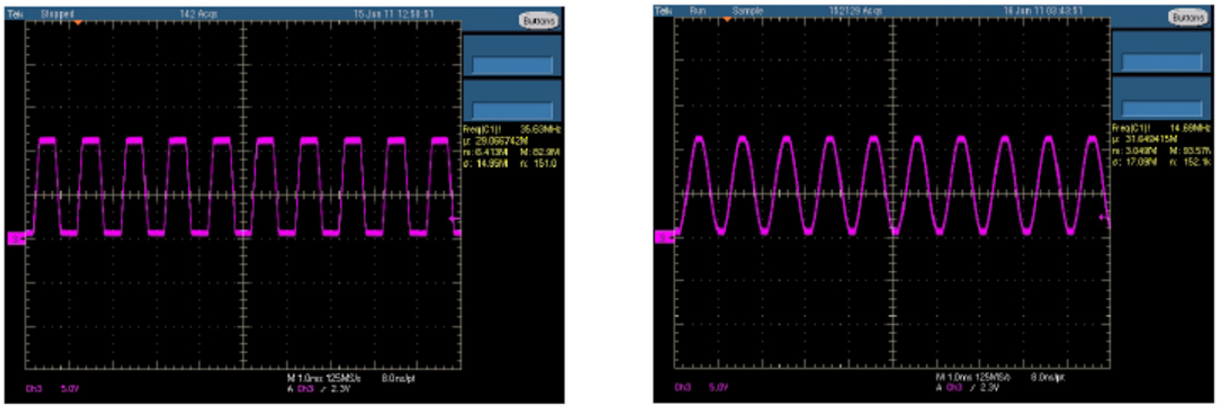

***Figure 3**. Hard limiter versus AGL*

Master and slave synchronization

Many TI devices, like the TPA3128D2 analog input class-D amplifier, are designed to be configurable in master/slave configurations that also enable synchronization by using the SYNC pin between multiple devices. Such configurations enable multiple slaves to be synchronized, thus helping minimize audible induced noise.

In master mode the SYNC pin is an output, while in slave mode the SYNC pin is an input for the clock. The data sheet typical application section describes a 2.1 channel master and slave application where the master is configured as stereo speaker outputs and the slave is configured as mono parallel bridge-tied load (PBTL) output (subwoofer), as illustrated in **Figure 4**.

Automotive load diagnostics

One feature required in automobile assembly and system debugging is the ability to test each channel for the proper load or speaker connection. Four potential problems can occur at the speaker output:

- The speaker is not present or connected properly (open load).

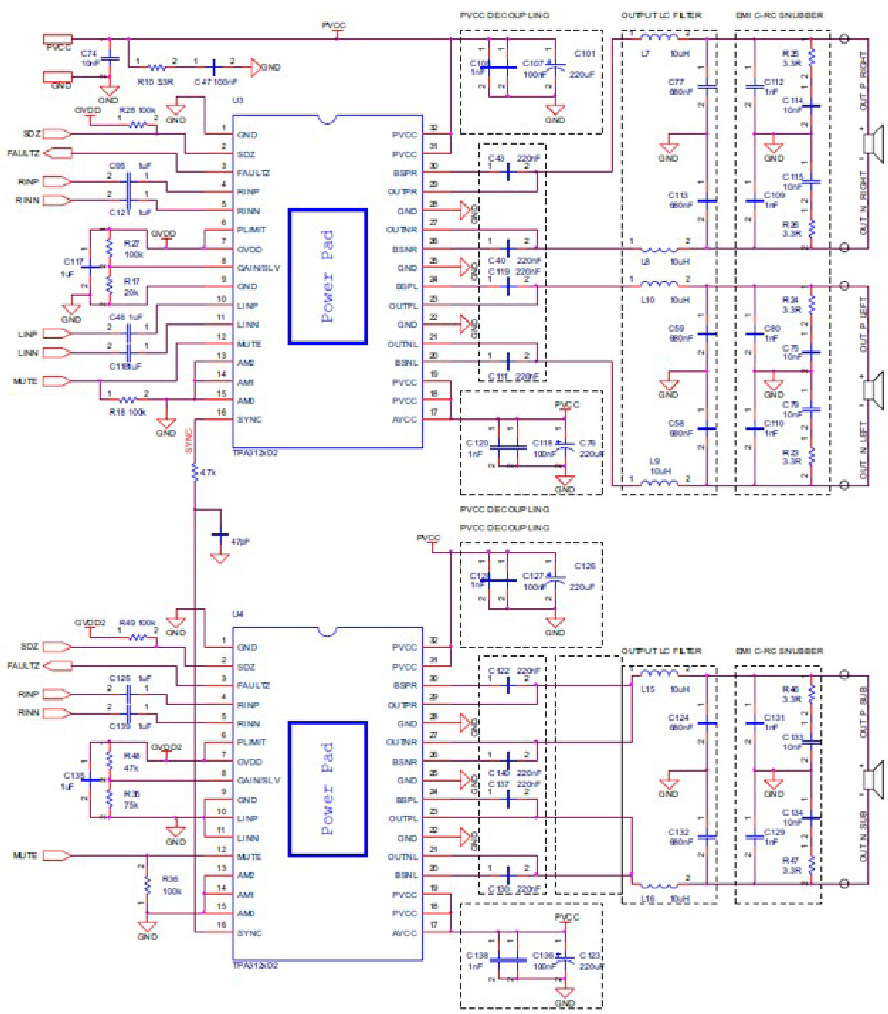

***Figure 4**. Typical 2.1 channel master/slave application with SYNC pin enabled*

• The speaker or speaker wires are shorted (shorted load).
• The speaker wires are shorted to ground.
• The speaker wires are shorted to a power rail or the battery's positive output.

TAS5414C-Q1 class-D amplifiers have the ability to test all four amplifier channels simultaneously or each channel individually for a proper load. An I2C command instigates the load diagnostics; see the flowchart in **Figure 5**.

In a situation where at least one channel is not in high impedance (hi-Z) mode, you can only test the short to ground and short to power. You cannot test the shorted load and open load because the MUTE pin is used to create the signals for these tests. These pins must remain stable for the channels that are not in hi-Z.

When running these tests, the test stops upon the first failure on any one channel. The other channels continue to test until their first respective failures. This diagnostic procedure may not catch a double fault. For example, assume a channel has a short to ground and is an open load. The load diagnostics would detect the short to ground and set the bit in the load diagnostics register, but would not detect the open load. The open load would be detectable after fixing the short to ground and running another load diagnostic.

Figure 6 shows the load-diagnostic waveform according to the TAS5414C-Q1 data sheet; this design guide includes more information.

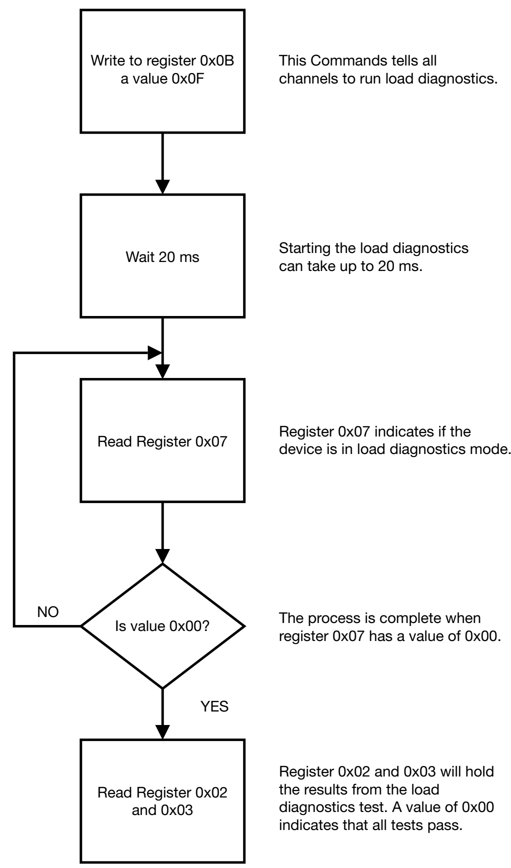

***Figure 5**. Load diagnostics for four channel amplifiers*

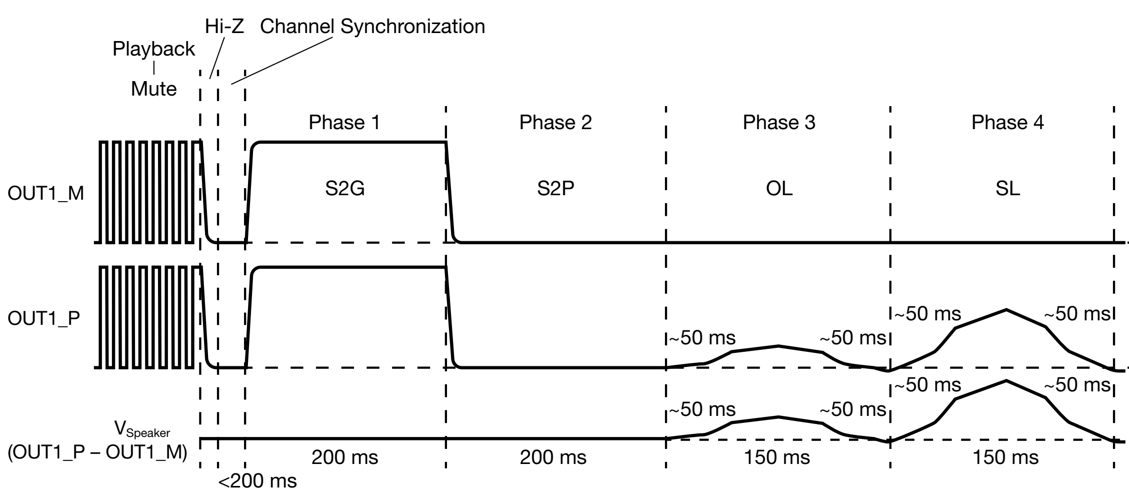

***Figure 6**. Load-diagnostic output waveforms timing diagram*

Note that we presented these waveforms in this form to emphasize how the device applies the load diagnostic signal. The actual amplitude of the applied signals in phase 3 (open load) and phase 4 (shorted load) are highly load-dependent and may have greatly decreased amplitude compared to those shown in **Figure 6** when a load is properly connected.

DC detection

One of the more common fault protections is DC detection, which is designed to minimize risk of damage to the output stage in case of a short circuit or some other similar fault. This protection scheme also helps prevent any rail voltage present from connecting directly to the speaker. The TI amplifier's circuit detects a DC offset at the output of the amplifier continuously during normal operation. If the DC offset reaches the level defined in the I2C registers for the specified time period for a particular device, the circuit triggers a channel shutdown. The I2C conducts the disabling and enabling of the shutdown function. If enabled, the triggered channel shuts down, while the other channels remain in play mode with the FAULT pin asserted.

Clock error handling

TI's digital input amplifiers typically require two or three clock input signals, such as master clock (MCLK), serial clock (SCLK) and left-right clock (LRCLK). One other feature included in the suite of error-handling and protection features of TI amplifiers is related to the detection of clock errors (CLKE). One or more of the following errors has to occur for a clock error to register:

- Nonsupported MCLK to LRCLK and/or SCLK to LRCLK ratio.
- Nonsupported MCLK or LRCLK rate.
- Either MCLK, SCLK or LRCLK has stopped.

The speaker fault (SPK_FAULT) pin and appropriate error status register in the I^2C control port report the status of clock errors. The clock-error-handling behavior of the device is characterized as "nonlatching," which means that once the fault is clear, the device resumes normal operation (such as audio playback). The general clock error mechanism is that once an error is detected, the SPK_FAULT pin will pull low. Once the error has cleared and the clock returns to a valid state, normal operation resumes automatically.

Excursion control

Excursion is the distance which a speaker diaphragm moves in and out from its resting position. It needs to be controlled to avoid the diaphragm from traveling past its excursion limit, which can lead to damage in the speaker. Amplifiers control the excursion in real time by monitoring it via current and voltage (IV) sense feedback or in a feed-forward model created for the speaker, shown in **Figure 7**. Traditional

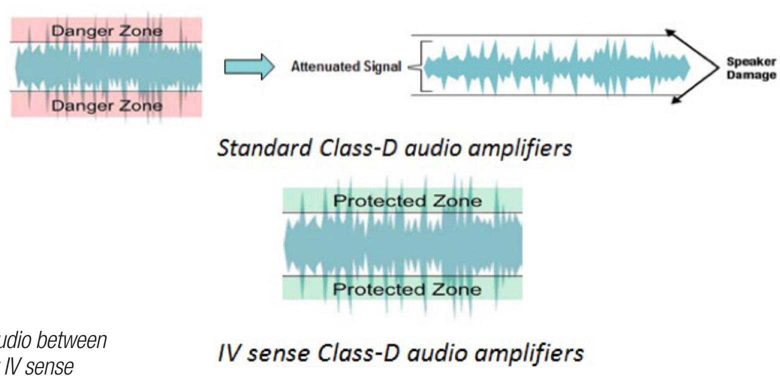

***Figure 7**. Comparison of audio between amplifiers with and without IV sense*

amplifiers attenuate the entire signal as a means for control.

The ability to control excursion enables real-time protection to drive peaks to the excursion limit without damaging the speaker, which results in increased sound pressure level.

Voice coil temperature

Voice coil temperature is the heat generated by the electrical power, delivered by the audio amplifier to the speaker coil while playing audio. If not monitored (especially in small speakers), the coil can heat up past the thermal limit and cause damage to the speaker and surrounding materials. Amplifiers control the temperature in real time by monitoring it via IV sense feedback or in a feed-forward model created for the speaker. **Figure 8** shows an example of estimated voice coil temperature, and how TI's advanced algorithms can control this temperature within its required operating limits.

Speaker protection

Speaker protection is an algorithm used in smart amplifiers to monitor the speaker excursion and voice coil temperature to ensure reliable operation. The algorithm uses IV sense information to update the speaker model in real time, which enables the amplifier to reliably and effectively drive the speaker with higher energy peaks compared to a standard class-D audio amplifier, while keeping the speaker under maximum temperature (Tmax) and maximum excursion (Xmax) operating limits.

Figure 9 illustrates where the speaker protection resides in the smart amplifier signal chain, including the feedback path at the speaker nodes.

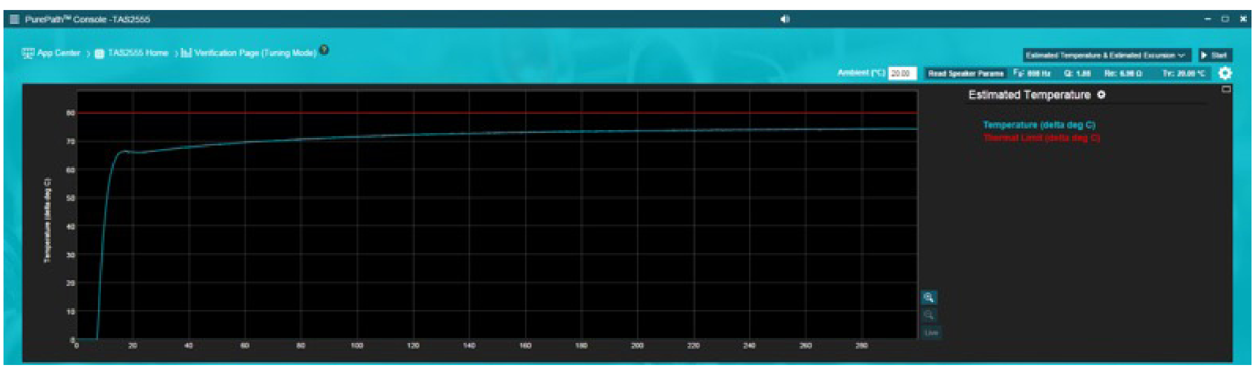

Figure 8*. Voice coil temperature monitoring in TI PurePath™ Console 3 software*

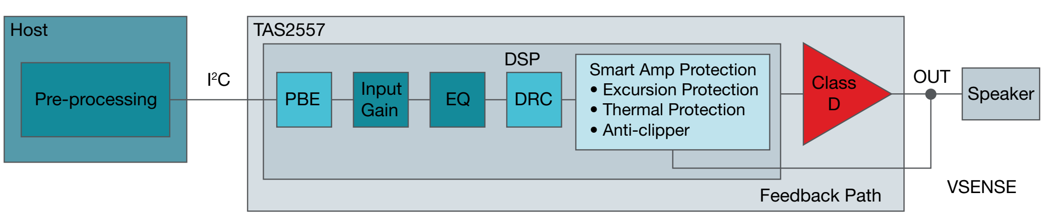

Figure 9*. Example of a smart amplifier system*

Smart bass

Microspeakers are commonly used in compact mobile devices and typically have limited low-frequency bandwidth, resulting in poor bass performance. Smart bass (also known as psychoacoustic bass) enhances the perceived low-end response of the speaker without introducing actual additional excursion at low frequencies – where microspeakers often already have limited excursion headroom.

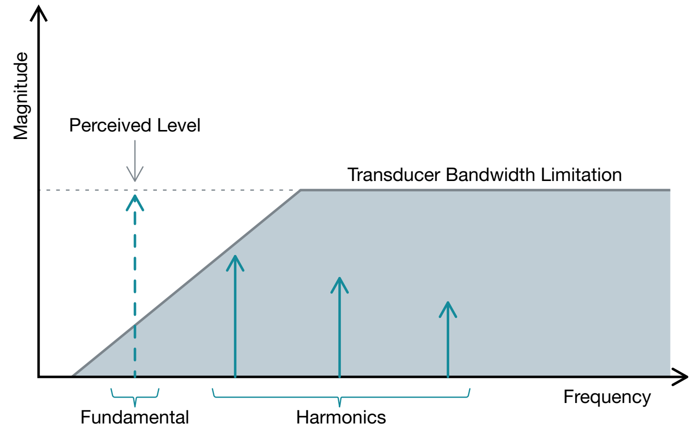

Figure 10*. Bandwidth limitations of microspeakers and how smart bass can improve perceived bass*

Conclusion

In today's advanced audio system designs, class-D audio amplifiers with integrated system protection features can help system designers create robust and reliable products that end customers want to buy. For more information about these features, check out TI's portfolio of audio devices.

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