Application Note

SmartAmp Speaker Protection - Plain Language Guide

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Abstract

Small, mass-produced speakers in phones, tablets, and laptops are expected to sound full and powerful despite being physically limited in both cone movement and power handling. Pushing a speaker past those limits causes damage — either through excessive cone displacement or through overheating of the voice coil — so manufacturers conventionally protect against both failure modes with a single fixed, worst-case limit, which leaves meaningful performance on the table even when the speaker is not near its danger zone. This document describes TI's Smart amp speaker protection technology, which replaces that static limit with continuous, real-time tracking of a speaker's actual excursion and temperature — so the speaker can be driven to its safe limit, instead of a fixed worst-case one. The result is louder, more dynamic sound — particularly in bass — from a smaller, cheaper speaker, with no added hardware and no added risk.

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1 Introduction

Modern phones, tablets and laptops are expected to produce loud, clear, bass-capable sound from speakers that are physically tiny — sometimes barely larger than a coin. That's a challenging problem because sound output is closely tied to how much a speaker cone can physically move and how much electrical power its coil can handle. A small speaker used in many industrial and personal electronics end-equipment is inherently limited on both the above factors compared to a large one. The most direct way to make a small speaker sound bigger is to push more electrical power through it, but pushing too much will damage the speaker.

There are two distinct, and different, ways a small speaker gets damaged:

1. *It gets pushed too far*: The cone (the moving surface that actually creates sound) is only designed to travel a limited distance in either direction. If it is pushed further, then the cone can strike the frame, tear the suspension, or permanently deform. This kind of damage is usually sudden and mechanical, similar to over-extending a spring past its natural range of motion.
2. *It overheats* The coil of wire that drives the cone (the "voice coil") heats up whenever current flows through it, exactly like the heating element in a toaster. Sustained loud volume means sustained current, which means sustained heat. Enough heat will melt the insulation on the wire or the glue holding the coil together, and the speaker fails.

Simply limiting the maximum volume low enough to avoid both types of failure works, but it prevents the speaker from playing loud content even when the speaker isn't close to the danger zone. The job of the smart amp is to replace this conservative fixed limit with a smart, dynamic adjustment, so the speaker can be driven right up to its safe limit whenever conditions allow and pulled back only when it is actually needed.

2 How a Speaker Works

Before getting into how a smart amp protects a speaker, it is worth noting what a speaker actually is: a small, purpose-built motor.



Figure 2-1. How a Speaker Converts an Electrical Signal Into Sound

An amplifier sends a varying electrical signal into a coil of wire that sits inside a fixed magnet. Whenever current flows through a wire inside a magnetic field, a physical push/pull force is generated in the wire using the same principle that makes electric motors spin – in this case the force pushes the coil in a straight line instead of turning a shaft. The cone is glued firmly to the coil, so the cone experiences the same force, pushing and pulling the air in front of it. This moving air is what is heard as sound.

Two properties of the electrical signal map directly onto two properties of the sound: how fast the signal swings back and forth becomes the pitch (frequency), and how wide the coil swings becomes the loudness (amplitude). This is why loud, deep bass is difficult for a small speaker to reproduce safely: low-pitched bass notes require the cone to physically travel much farther per cycle than high-pitched notes do, for the same perceived loudness. Such big cone excursions are risky and can result in over driving and damaging the speaker, but a fixed safety margin deprives the listener from enjoying bass content.

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3 Smart Amp Monitoring

Smart amp has no way of directly measuring how far the cone moves or how hot the voice coil gets. There is no room inside a mass-produced, tiny speaker for that kind of sensor, and adding one would be impractical and expensive. Instead, Smart amp uses two quantities that can be measured cheaply and continuously, at the amplifier end: the voltage being sent to the speaker, and the current flowing through the speaker. By monitoring the voltage and current, and from an understanding of how a particular speaker produces sound, Smart amp can mathematically infer two things it cannot observe directly:

- How far the cone is moving right now (its excursion), and
- How hot the voice coil currently is (its temperature).

No two speaker models move or heat up in quite the same way: stiffness, cone weight, heat dissipation, and other physical traits differ from design to design, and even from unit to unit off the same line. Smart amp keeps an internal *profile* of the specific speaker it's driving, built by characterizing that speaker ahead of time, and then continuously fine-tuning the profile while the device is in use. All of this runs in software using internal amplifier sensing, without any external sensors, or added cost, or added space.

4 Smart Amp Protection

Smart amp runs two protection strategies side by side, because the two failure modes described earlier behave differently. Over-excursion can happen and cause damage within a single loud transient which is a fraction of a second. Overheating, by contrast, builds up gradually over seconds to minutes. Each mechanism is explained below in terms of how it works and what are its benefits to a customer selecting between a standard amplifier and a Smart amp.

4.1 Excursion Protection



Figure 4-1. How Smart Amp's Excursion Protection Decides When to Turn Down the Signal

Using an internal "profile" of the speaker, Smart amp calculates, many times per second, how far the cone is about to move if the incoming signal is passed through unchanged. If that "predicted" movement would cross the speaker's safe limit, the algorithm turns down just the part of the signal responsible — in practice, usually the deepest bass content, since that's what drives the largest cone movements. Everything else passes through completely untouched, so a listener notices the sound staying clean rather than an obvious volume cut.

The word *predict* matters here. Because the correction has to happen before the damaging motion occurs, the audio path includes a very short built-in delay: the signal is held back a few milliseconds while a parallel copy predicts the resulting motion, and any needed correction is applied before the delayed signal is finally sent onward. This is conceptually similar to a car's automatic braking system, which needs a little lead time to sense a hazard and brake before impact, rather than after. Without this protection, an over-driven small speaker will start buzzing and produce rattling distortion, which eventually will cause permanent damage: a torn suspension, a warped cone, or a voice coil that has physically shifted out of alignment with the magnet.

Benefits: Because bass content pushes the cone the farthest – a fixed, worst-case safety margin has significant impact. A Smart amp recalculates that margin continuously based on the speaker behavior, so it can safely allow more bass most of the time, only falling back to the full margin when a loud, deep note threatens to push the cone past its safe limit.

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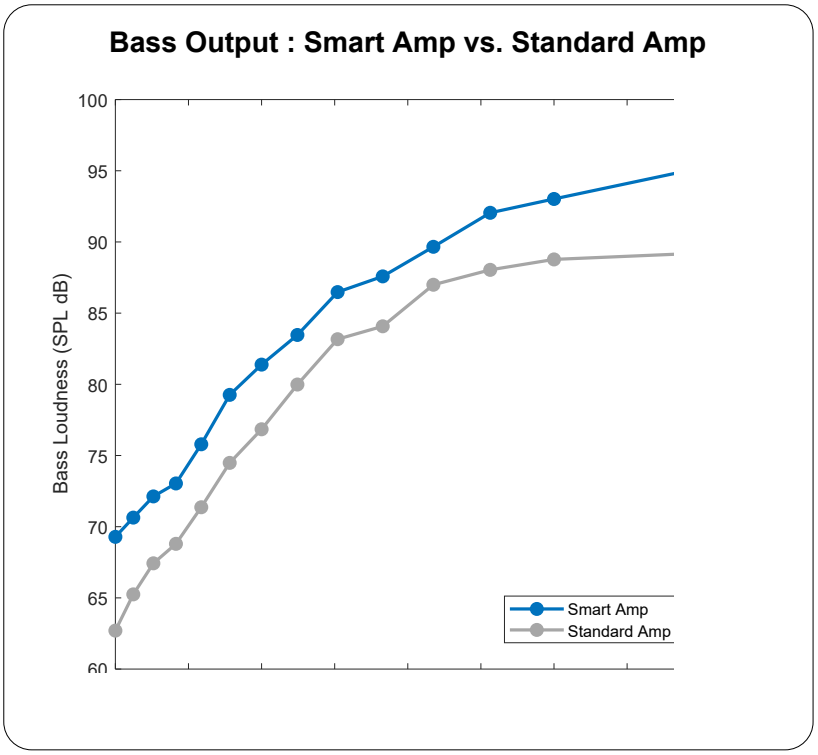


Figure 4-2. Bass Loudness vs. Frequency: Smart Amp vs. Standard Amp

This is illustrated in the above example graph for the low frequency bass region, where a Smart Amp is consistently louder than a Standard Amp – the loudness being expressed as a Sound Pressure Level (SPL) measurement in decibel (dB) scale. Bass is the hardest kind of loudness for a small speaker to deliver in the first place: for any given cone size, SPL output naturally rolls off as frequency drops, so small speakers already sound weakest at the low end before any safety margin is even applied. A fixed, worst-case margin then stacks a second penalty directly on top of this — because this is the frequency range where the speaker has the least headroom due to the largest of cone movements. This makes the extra bass SPL so valuable: it reclaims the frequency range small speakers struggle with most. A few extra dB of bass headroom is the difference between a small speaker that sounds thin at high volume and one that still sounds full.

4.2 Thermal Protection



Figure 4-3. How Smart Amp's Thermal Protection Manages Coil Temperature

Heat behaves very differently from motion. A cone can overshoot its limit in a single loud transient lasting milliseconds, but a voice coil takes time — seconds at least — to heat up or cool down, because heat has to physically build up and dissipate through the materials involved. This difference in timescale is why thermal protection doesn't behave like an abrupt on/off cutoff. It behaves more like a thermostat: if the estimated temperature is climbing towards the limit, the system gradually eases back the power; once things cool off, it gradually lets more through again. This approach is what lets the speaker spend as much time as possible playing at its hottest **safe** level, rather than being held back by a cautious, always-on power ceiling.

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Without this protection, sustained loud use of an unprotected small speaker risks a familiar failure: the sound quality degrades, distortion creeps in, and in the worst case the coil's insulation is damaged — a failure that, unlike a one-time loud transient, is permanent and unrepairable in a sealed consumer device.

One interesting detail is how the temperature is estimated in the first place, without any physical temperature sensor inside the speaker. The electrical resistance of the coil's wire rises in a predictable way as it heats up — the same effect behind why an incandescent bulb's filament behaves differently the instant it's switched on (cold, low resistance, big current surge) versus once it's been glowing a while (hot, higher resistance, current settles down). Smart amp periodically injects a very low-frequency tone, quiet enough that a listener can't hear it, to measure the coil's resistance, and from that it infers temperature — an indirect but reliable measurement, with no extra hardware.

Benefits: The real value of thermal protection is the headroom for peaks. A standard amplifier has to size its continuous power delivery low enough to be safe under sustained loud use, and hold to that ceiling all the time, even during a single loud transient which the speaker could have easily absorbed for a fraction of a second. A Smart amp tracks coil temperature continuously, so it can let a bass hit or a dynamic peak through at full strength the instant there's thermal headroom available — while still keeping the speaker's long-term average power within its rated safe limit.

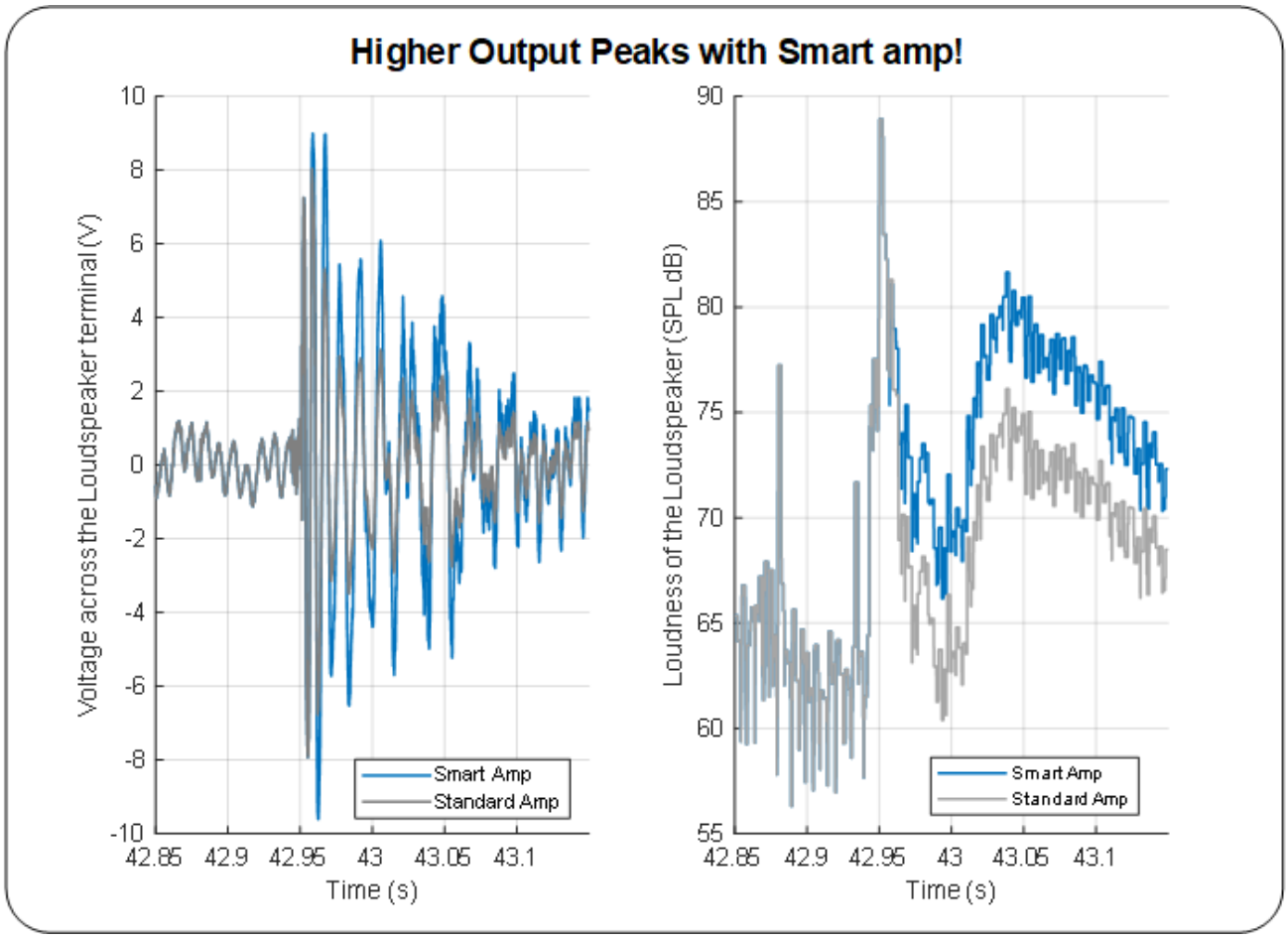


Figure 4-4. Higher Output Peaks With Smart Amp

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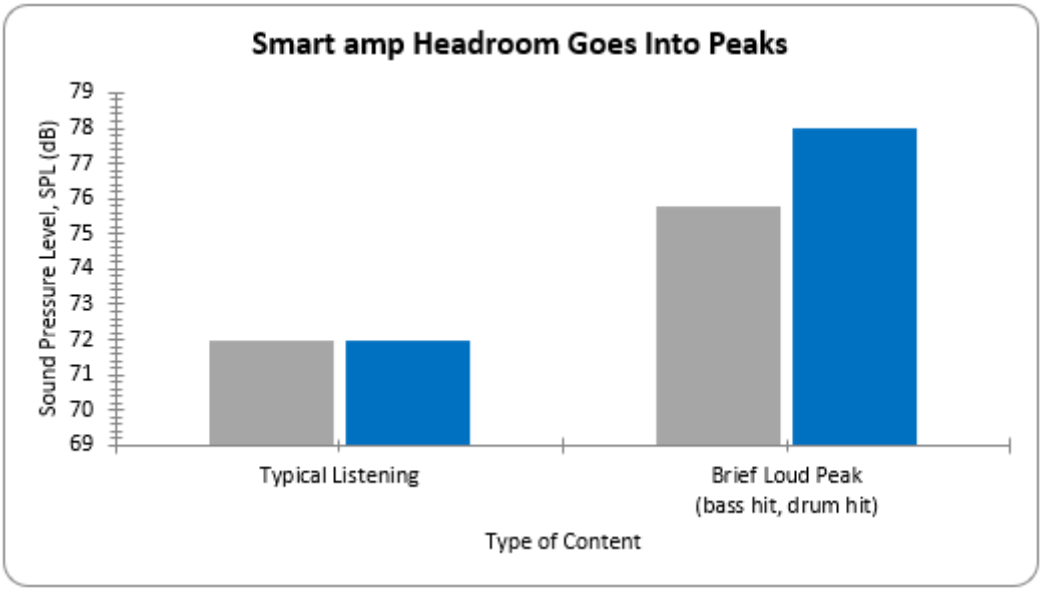


Figure 4-5. Smart Amp Headroom Goes Into Peaks

This is illustrated in the above example graph and the bar plot. During the initial portion, a typical listening passage, both the Standard Amp and Smart Amp deliver the same output because the coil is well within its safe temperature range. Around 42.95s, there is a bass/drum transient hit and the Standard Amp eases back the signal to stay under the fixed conservative ceiling while, the Smart Amp lets the transient through at full strength. The left graph shows the voltage output across the loudspeaker terminal; the right graph shows the resulting loudness SPL, the same comparison is also shown in the bar plot. It is clear how the Smart Amp is able to maintain a higher loudness during the transient bass content compared to the Standard Amp.

In practice, this means punchier, more dynamic playback — transients and bass hits land with their full impact while ordinary content stays well inside the safe zone. The only time the system pulls back further than usual is a genuinely extreme, sustained case — for example, a device that's already been playing loudly for several minutes.

5 Factory-Line Calibration

The resistance-based technique used for thermal protection works if Smart amp knows what *normal temperature* looks like for this specific speaker's coil — a reference point to measure change. No two coils come off the production line with exactly the same resistance: small, ordinary variations in wire length, winding tightness, and material batches mean every individual unit is a little different, even within the same speaker model and the same factory batch. A single generic reference datasheet number would be close enough for some units and noticeably wrong for others.

To fix this, every individual phone or piece of consumer electronics is calibrated once, on the factory line, before it reaches a customer. During final test, each unit measures its own speaker's electrical resistance while the factory floor is held at a known, controlled temperature. This resistance-and-temperature pair, for this specific unit's coil, at a known starting temperature, is then stored permanently in the equipment memory as the personal reference point, unique to the unit.

From that point on, every resistance reading the Smart amp takes out in the field is compared against that unit's own stored reference — the same idea as zeroing a kitchen scale before weighing. Skipping this step will result in the temperature estimate for that unit to end up consistently off in one direction: either too cautious, giving up loudness the speaker didn't actually need to sacrifice, or too permissive, letting the coil run hotter than the system believes it is.

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6 Modelling Accuracy

The effectiveness of the Smart amp depends on the internal profile of the speaker being accurate. But speakers are not static objects: normal manufacturing variation means no two units are perfectly identical, and a given speaker's behavior can shift with age, temperature, and general wear. If the internal profile silently drifts out of sync with the real, physical speaker, the prediction mechanism built on top of it (excursion estimates, temperature estimates, all of it) becomes less trustworthy.

Smart amp addresses this by continuously cross-checking itself. It compares what its internal model predicts the speaker's electrical behavior should look like against what the sensing circuit actually measures. Any mismatch between prediction and measurement is treated as an error signal, and the model's internal parameters are adapted to reduce that error as much as possible. This is conceptually the same idea as a car's GPS navigation constantly re-checking its position against fresh satellite signal rather than trusting a single initial reading for the whole trip — small, continuous corrections keep the system updated, instead of letting small errors accumulate unnoticed over weeks or months of use.

The initial profile of the speaker is generated by sweeping the speaker with test tones across a range of frequencies and measured how its electrical impedance and physical movement changed, tracing out a curve that peaks sharply around the speaker's natural resonant *sweet spot*, the frequency at which it vibrates most easily. Away from that sweet spot, in either direction, the speaker naturally moves less for the same input.

The speaker's heating behavior is measured by driving it with known power and tracking how its temperature rose and fell over repeated test bursts. That agreement between prediction and these measurements is a key point of the Smart amp technology: it is about inferring hidden, unmeasurable quantities (motion, heat) from things that actually can be measured (voltage, current) and working reliably enough with real hardware, in a real product, protecting a real speaker.

7 Blocked-Port Reliability

Excursion and thermal protection cover the two classic ways a speaker fails under normal use. But real products get used in ways a lab test doesn't fully anticipate. Many small speakers rely on an acoustic port or a grille (a small mesh in the enclosure for pushing out the air volume). If that port gets blocked (by a phone case, a sticker, dust, or just being set down on a soft surface) the speaker's acoustic loading changes, and it can experience damaging excursion at volumes that would otherwise have been perfectly safe.

A Smart amp detects this the same way it infers excursion and temperature: a blocked port changes the speaker's electrical signature in a way the system recognizes, and it automatically tightens its protection limits to compensate, protecting the speaker from a hazard caused by real-world use. This results in a more reliable speaker performance with fewer field returns and warranty claims.

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8 Smart Amp: Full System

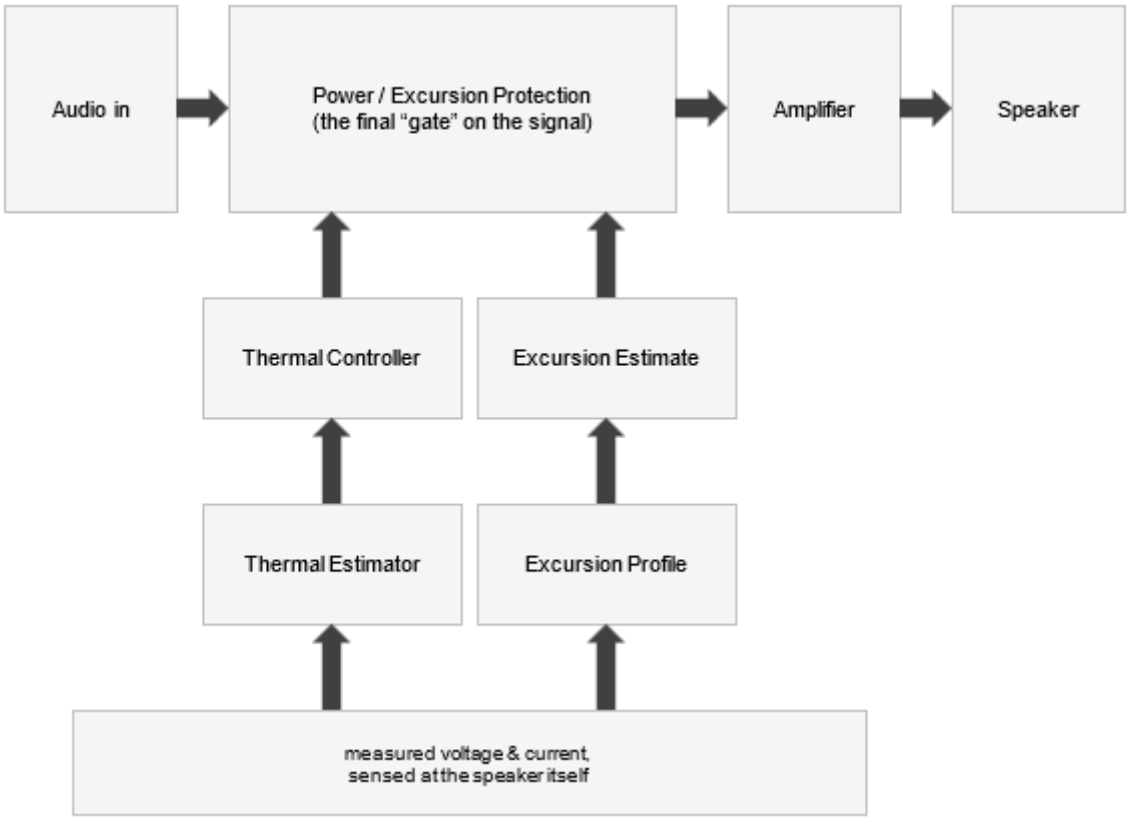


Figure 8-1. Smart Amp's Full System: Excursion and Thermal Protection Working Together

Both the excursion and thermal protection checks — *is this about to move too far?* and *is this too hot?* — feed continuously into the same final gate, deciding how much of the incoming signal is safe to let through. Smart amp continuously compares what the profile predicts the speaker's electrical behavior should look like against what the sensing circuit actually measures, treats any mismatch as an error signal, and adapts the profile's internal parameters to close that gap. The result behaves like a single smooth decision to the listener, even though underneath it's really two independent safety systems, running on different timescales, cooperating on one shared outcome: the loudest, fullest sound the speaker can safely produce at that instant — no more, and equally important, no less than necessary.

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9 System Cost Savings

Smart amp technology also results in systems cost savings. This is because a Smart amp allows platforms to drive small, inexpensive speakers much closer to the true safe limit, there is no longer a need to buy a bigger, reinforced, more expensive speaker to hit the same loudness and reliability target. Looking at bill of materials (amplifier and speaker together), the end-system is both high performance and reliable but also cheaper.

	Cost		Cost
Oversized Speaker	$1.75	Standard Speaker	$0.90
Standard Amp	$0.10	Smart Amp	$0.65
Total ($) — Conventional	$1.85	Total ($) — Smart Amp	$1.55

In this illustrative example, there is a net system saving of approximately $0.30 per unit (even though there is an increase in smart amplifier cost), on top of the loudness and reliability gains.

10 Summary

Dimension	Standard Amp	Smart Amp
Peak bass loudness	Capped by fixed worst-case margin	Dynamic, speaker-specific limit
Performance in heat	Same conservative limit, hot or cold	Adapts in real time to real temperature
Field reliability	Blind to blocked ports/misuse	Detects and compensates automatically
Net system cost	Needs oversized/reinforced speakers Costly Bill-of-material	Works with a smaller, cheaper speaker Reduces System Cost

The Smart amp technology replaces a fixed, worst-case safety margin with audio content that matters most: deep bass and dynamic peaks, the two things a tiny speaker struggles hardest to deliver. By replacing a static limit with continuous, real-time knowledge of the speaker's actual excursion and temperature, Smart amp returns headroom at no added hardware cost, with a net system savings on top, and with the field-reliability benefit under real-world use conditions.

TI is shipping Smart amp solutions across its broad amplifier lineup, from the smallest mobile designs up to higher-power applications. TAS2563 and TAS2573 are boosted Class-D amplifiers with integrated DSP and IV-sense, built specifically for battery-powered, space-constrained designs — delivering 6+W power while running TI's Smart Amp speaker-protection algorithm on-chip, so compact mobile devices get the full excursion and thermal protection without any added board space or cost. For designs that need to scale beyond that, TAS2781 extends the same approach to a 24-V Class-D amplifier with real-time integrated Smart amp speaker protection.

11 References

1. Texas Instruments, *TI Audio Products*, webpage.
2. Texas Instruments, *Smart Amp Video Series*, video.
3. Texas Instruments, *SmartPA Speaker Protection Algorithm*, application note.

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