



## Taction Technology Deep Dive — The Science Behind the Taction Transporter

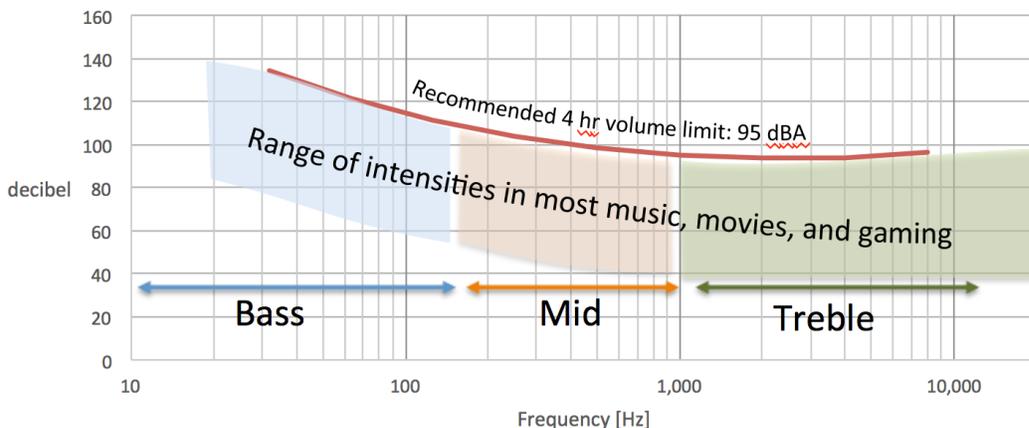
*(Note to the reader: we've tried to cover a wide range of technical subjects in this discussion. We've tried to make it understandable to the novice, but also enlightening for pros who are unfamiliar with tactile driver science, or with Taction Technology.)*

### **Part I: Why listening to headphones without Taction is like drinking wine without your sense of smell**

All sound is really vibration – the reed on a saxophone when Coltrane blows across it. A bass string slapped by Flea. A drum skin pummeled by Keith Moon. (Electronic sounds become vibrations when a speaker or headphone plays them back.)

What we think of as hearing is that vibration being transmitted through the air to our ears: air molecules moving back and forth and transferring changes in air pressure to our inner ear and finally to our brains. Fast vibrations equal high sounds (think flute or cymbals), slow vibrations equal low sounds (kick drum or tuba). Those vibrations are measured in cycles per second, also known as Hertz or Hz.

Engineers and audiophiles talk about the spectrum of sound as spanning from 20Hz (very low) to 20,000Hz (very high).



That's only kinda sorta right. Most adults can't hear 20 kHz anymore. More importantly, humans in general don't actually hear 20 Hz very well, either. But everyone — the deaf and hearing alike— can feel 120 Hz, and 20 Hz, and even lower just fine. In fact, when you think you are "hearing" deep bass, you are mostly feeling it. Bass perceptions happens along an audio-tactile spectrum. The lowest notes are sensed primarily with the skin, and the highest primarily with the ear, but all of them are naturally perceived as a mix of both senses. That's a big part of the reason it is so hard to get that "you are there experience with headphones – normal headphones can't produce a critical aspect of the live experience.

Does frequency response down to 30Hz, 20Hz and below matter? Unless you only listen to Mozart string quartets, the answer is hell, yes. Rock, hip-hop and EDM have huge amounts of energy down there. Lots of jazz and orchestral music do, too. And movies and games – hell, yes. If you've never heard your favorite stuff on a system that can reproduce ALL the frequencies that are present in the recording, you will probably be shocked to learn how much you have been missing.

So how can you get that deep, deep bass? In most good audio systems from home speakers up to the PA systems used in huge stadiums, the audio spectrum gets split up before it gets turned from an electrical signal into sound. High frequencies need small, lightweight transducers. Low frequencies need much bigger transducers, because producing low frequency sound at high volumes means moving a lot of air. A good home theater subwoofer can have drivers that are 15" in diameter. A PA system for a stadium concert can have hundreds of them.

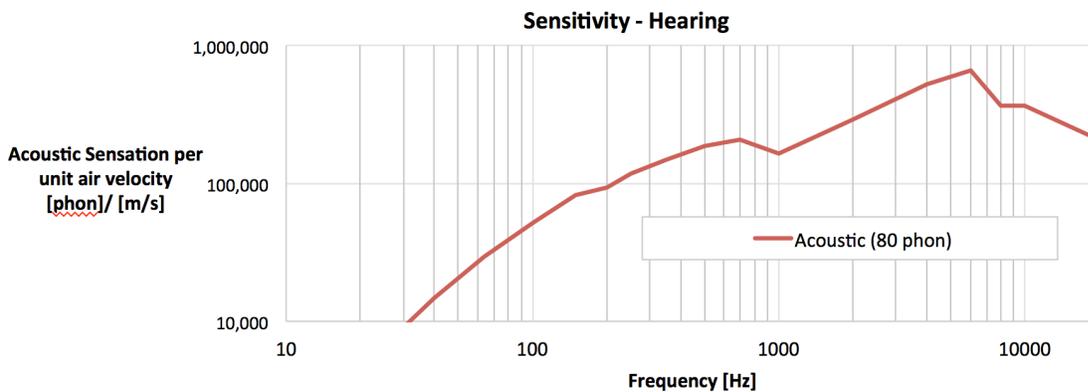


When those giant speakers crank up, you don't just hear them — you feel them. Your skin vibrates. Your organs vibrate. And (for most people) your brain interprets that vibration as sound, even though it mostly isn't being processed by what you normally think of as hearing.

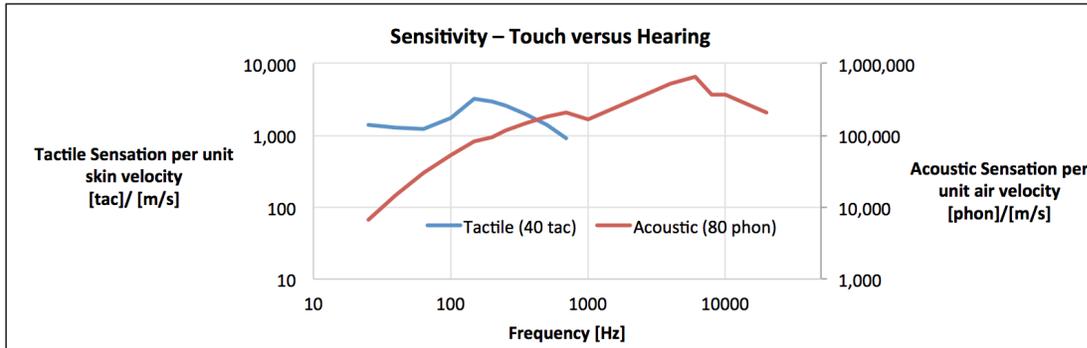
In a sense, perceiving music is like perceiving food. We talk about tasting food, just as we talk about hearing music. But your sense of smell is essential component of the enjoyment of a good meal. If you have a bad cold, or your sense of smell is damaged, food becomes bland and uninteresting. And just as the added input from your nose is what makes a steak or a fine wine a sensory delight, the experience of feeling the bass is what makes going to a concert or dance club so much more powerful than listening to the same music with only your hearing.

Conventional headphones just can't deliver that experience – they're like drinking a Cabernet with your fingers holding your nostrils closed. (The vast majority of home stereo speakers can't do it either, for that matter.)

Audio drivers in most headphones are (at most) only 1-2" in diameter. Some headphones claim to be able to produce sound all the way down to 20 Hz. They may even measure acoustically "flat". But as previously discussed, your ears are very insensitive to deep bass. So headphones that measure "flat" aren't perceived as flat. For a 15 Hz sound to be perceived as equally loud as a 75 Hz sound, it has to be 30 times louder — loud enough to quickly cause serious hearing loss, in fact.



On the other hand, the human sensory system is extremely sensitive to touch. And it is very sensitive to vibration in exactly the frequency range where hearing lets us down. So a 15 Hz signal applied to the skin (depending on the part of the body) only needs velocity 2 times higher than one at 75 Hz to seem equally strong.



1 tac is the sensation of 1dB of normal skin vibration at 250 Hz on the base of the thumb with contactor area of 2.9 cm<sup>2</sup>, where 0dB is 0.0002 m/s velocity. Curve derived from data in [Verillo, IEEE Transactions Man Machine Systems, 1970].

So using a tactile transducer to produce deep bass should, in theory, deliver a much better, more immersive experience. In practice, it is damned hard to do right.

## Part II: How Taction Does It (moving in the right direction)

In part I we covered why you need tactile stimulation to fully appreciate your music. Now let's talk about the complexity involved in actually doing that.

The Taction Transporter (the magic in our Kannon headphones) is designed to work with the main audio driver in your headphones (kind of like the way a subwoofer works with satellite speakers in a home theater setup) by vibrating your skin to produce deep bass. It does this by subtly moving the cushions of the headphones against your head.

Seems simple right? But if done wrong, that movement creates a bunch of problems. Other headphones have tried to do this before, with disappointing results. One problem is that their transducers weren't as good as Transporters. (More about that in Part X below.)

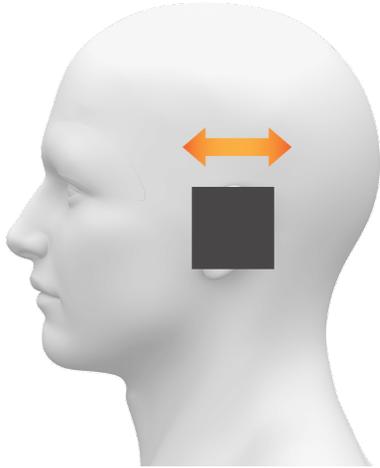
HOW you move the cushions matters too. Most tactile bass transducers to date have tried to move the headphone cup in the same plane as the audio transducer works, which means moving the headphone cup toward and away from your skull.



(Looks like fun, eh?)

That kind of motion interacts with the sound generated by the main audio driver in ways that significantly increase distortion. It's kind of like pushing a plunger against your ear. That can really screw up the sound of voices, guitars, etc.

Taction Transporters work differently. They move the headphone cups in the sagittal plane – that is front-to-back along the surface of your skin.



With this approach, distortion is dramatically reduced. It is also a more efficient way to transmit vibration. So – for the first time – Taction gives you epic, subterranean bass without screwing up the acoustic response.

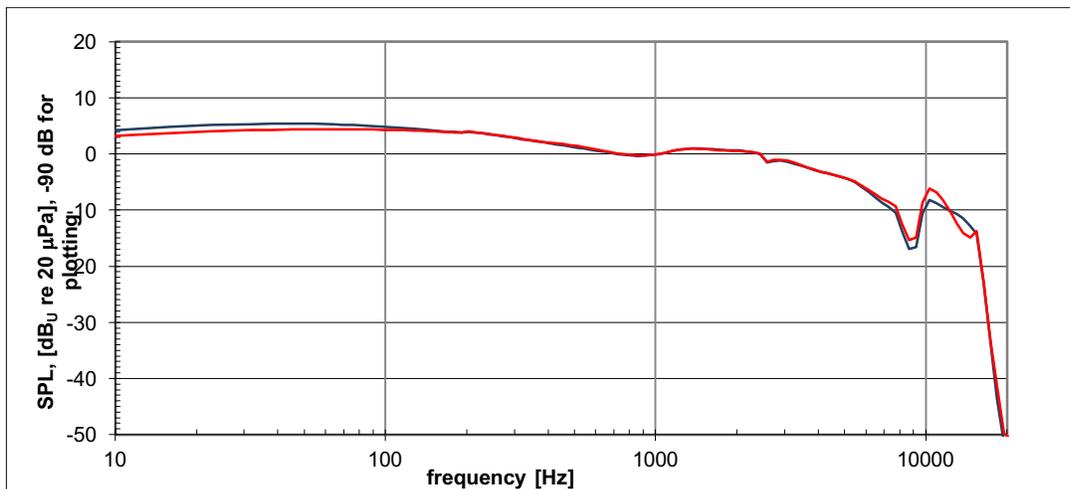
But none of that would matter if our transducer wasn't the most powerful, flattest tactile driver ever produced.

### **Part III: Flat Frequency Response and Why It Matters**

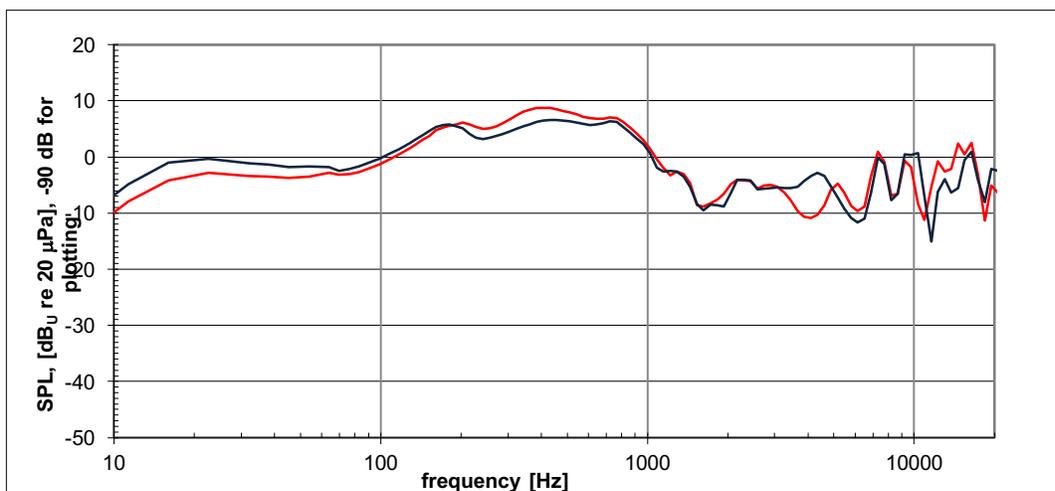
How loud should that note be? Musicians and sound engineers try hard to get every sound recorded at just the right level. If your speakers or headphones aren't flat, you hear something different from what they intended. (Note: there is some debate in headphone circles about what the ideal perceptually flat response is. But the disagreements are pretty minor.)

When you listen to a headphone that has uneven response, some sounds are emphasized, others are buried – not what the creators intended. Flatter is more accurate – closer to the source.

So an acoustic frequency response that looks like this:



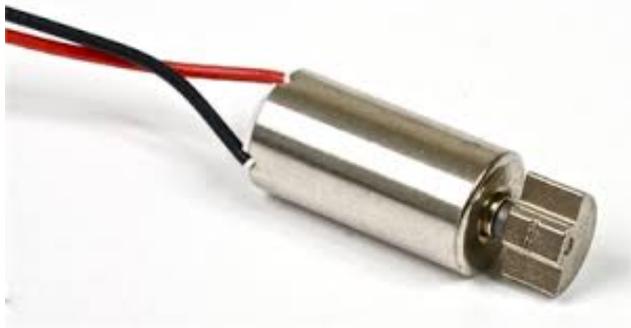
Is going to get you much closer to the intent of the musicians than this:



(Both of these response curves are actual measurements of other well-regarded products as measured by us.)

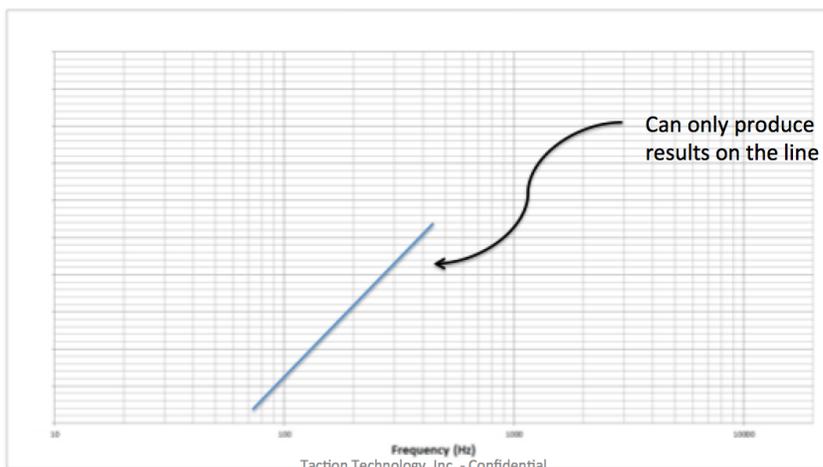
Flat frequency response matters for audio drivers. Does it matter for tactile drivers? We think it every bit as important.

If you aren't worried about accuracy, it's pretty easy to make a low-fidelity bass driver. So some folks have offered headphones that use a device kind of like the doohickey in your cellphone that vibrates in silent mode. It may be efficient at telling you when someone's calling, but it's certainly NOT a high-fidelity transducer. Those things look like this:

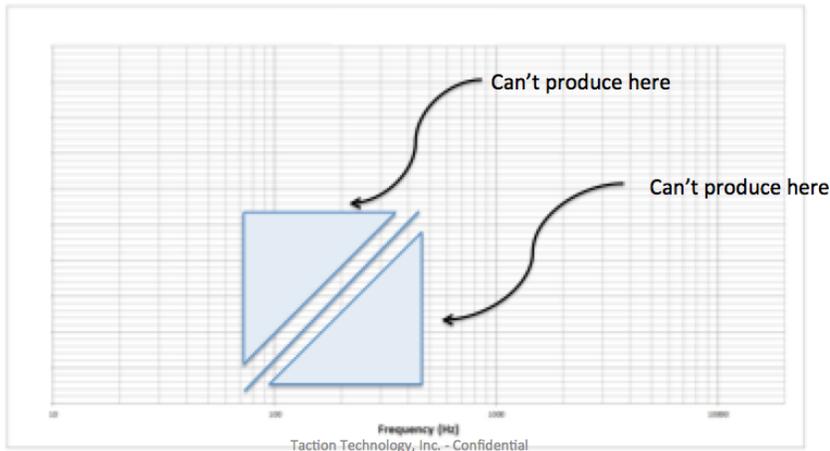


A few companies have used that kind of transducer (called an ERM, or Eccentric Rotating Mass motor) in things like game controllers and headphones. While they can produce a range of frequencies, they have a major limitation: they can only produce a single frequency at a given power output. So if you want it to go louder, it has to produce a higher frequency. If you want it to play a lower frequency, it has to get quieter. Its output looks like this:

**ERMs Can Only Produce a Single Volume Level for Each Possible Frequency; They CANNOT Play Louder or Quieter Without also Changing Frequency**



Want a strong vibration at a low frequency? Sorry. A subtle vibration at a higher frequency? Can't get there from here. ERMs can only produce output along a single line – there is no “area under the curve.” So the range of possible outputs from an ERM is really quite small, and the effect won't sound much like music for most program material. And if you are playing a game that has a critical signal that is more than a tiny bit higher or lower than the tuned frequency of the ERM, you won't get the cue you need.



You can imagine why that's a problem for music, gaming or pretty much any other sound-related application. Bass lines get louder and softer not because the musicians or sound designer intended it, but because the physics of the ERM dictate it.

Another device that's been tried in headphones is called an LRA, or Linear Resonant Actuator. They often look like this:



Like ERMs, they can be small and cheap. But also like ERMs, they are incapable of delivering high-fidelity bass response. The biggest problem with ERMs is right there in the name: resonance.

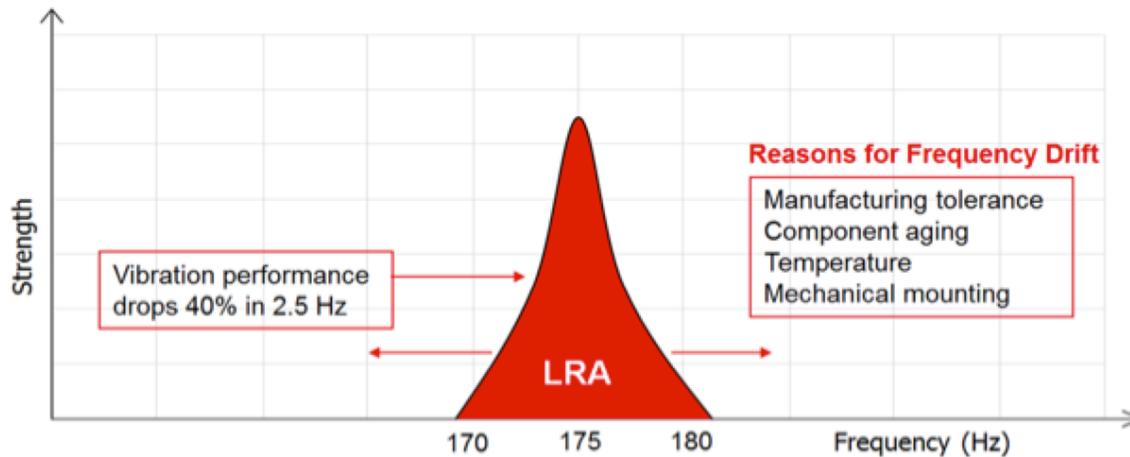
Every mechanical system has at least one resonance: a frequency at which it naturally vibrates. Bigger, heavier things usually resonate at lower frequencies than smaller, lighter things. You play a melody on a guitar by changing the length of the string with your fingers, and the shorter the string, the higher the note you play – the string's resonance changes each time you change frets.



Speaker drivers have resonant frequencies, too. Without very careful design and tuning, those resonances will affect the sound, and some frequencies will be louder than others. They can make voices sound thick, bass sound muddy, or cymbals sound harsh and edgy. Speaker and headphone designers work hard to eliminate (or at least compensate for) such resonances so they don't color the sound.

Linear Resonant Actuators, on the other hand are all about resonance – that's pretty much their whole job description. It makes them very efficient at playing a single note. If an LRA is tuned to middle C on a piano, it can play middle C very loud with very little power. But C sharp will be barely audible, and so will B. And that's all folks – all the other notes on the piano will be inaudible. Their frequency response looks like this:

## LRA's Are So Resonant That Power Can Drop 40% Just 2.5Hz Away From Resonant Peak



174.6Hz = musical note F<sub>3</sub>, F#<sub>3</sub> = 185Hz  
Average listener would have trouble detecting the difference between 175 and 177.5

If LRA is tuned to match a specific sound effect in a game, drift will make LRA ineffective

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So if you use an LRA as a secondary bass transducer, you'd better like the note it is tuned to, because that's all you are going to hear from it.

Some LRAs used in headphones are so resonant that they ring like crazy if you just tap the cup of the headphone with your finger – even when the headphones aren't plugged into anything.

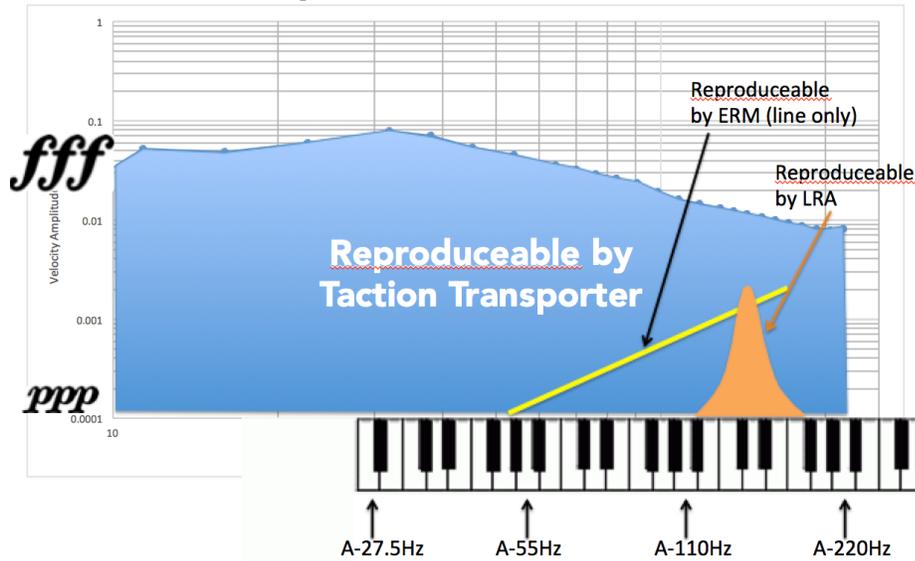
So LRAs and ERMs are not capable of high-fidelity tactile response. And that pretty much covers commercially available off-the shelf tactile transducers. So founder S. James Biggs, Ph.D. knew he had to create his own transducer from scratch if he wanted to finally bring tactile response that is both powerful AND accurate.

Did he succeed?

Duh.

Let's start by comparing them in terms of frequency response.

## Low-Frequency Reproducible Output: Transporters, ERMs and LRAs



Taction Transporters are flat +/- 4dB from 15Hz-85Hz. They can produce output at any level from the threshold of perceptibility up to shaking that will blur your vision at any of those frequencies. No tactile transducer has ever come close to this kind of frequency response.

Wide frequency response is critical to good tactile performance. But that's only one of several important parameters. Now let's talk about two others: speed and power.

### Part IV: Power that Doesn't Corrupt

As previously discussed, your skin includes some pretty sensitive receptors for tactile signals. But there is threshold below which those signals will go unnoticed. If a headphone manufacturer goes to all the trouble and expense of adding tactile transducer to a pair of headphones, the system had better be capable of producing enough tactile output to be felt.

There are several different ways of measuring power as delivered by a tactile transducer. Acoustic drivers are measured with conventional tests of acoustic pressure, usually expressed in decibels, or dB. These measurements are not appropriate for tactile transducers -- remember, tactile transducers don't (intentionally) produce changes in air pressure. You can measure tactile output as acceleration; you can measure it as velocity, or you can measure it as displacement. The measurement that best correlates with user experience, in our opinion, is velocity. A transducer that delivers constant velocity over a given frequency range will be perceived by a user as providing flat frequency response.

So how much velocity is required? The threshold for perception of a tactile signal varies from person to person, and is different for different parts of your body. But we think a good baseline is 5 millimeters per second.

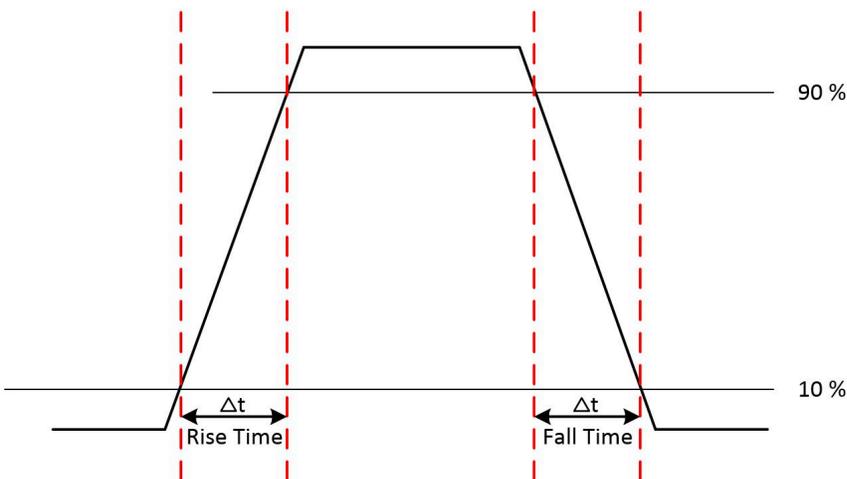
The ERMs and LRAs used in other headphones that claim tactile output are actually severely challenged on this score. The LRA used in one well-known headphone produces a tactile signal above the perceptual threshold only for the narrow range of notes around the resonant frequency. Unfortunately, when it's doing this, acoustically it rings like a bell tuned to one note (75Hz), that is extremely loud (140 dB). The effect is like a one-note kettle drum banging along with the music.

An ERM could theoretically deliver strong output at the top end of its frequency range, but (a) as previously discussed, the only way to increase the output of an ERM is to increase its frequency, which obviously doesn't deliver flat output, and (b) the ERMs used in existing headphones just aren't that powerful.

## Part V: The Need for Speed

If all you ever listen to with your headphones is steady-state signals (like holding the lowest note on the pedals of a church organ for a few minutes), the ability of your tactile transducer to turn on and off quickly doesn't matter. But if you like the visceral slam of a kick drum, or want to react as fast as possible to footsteps or an explosion in your favorite game, the ability of the driver to quickly go from 0-60, and from 60 back to zero, is absolutely critical.

Audio engineers talk about this characteristic in terms of things like rise time, fall time and impulse responses. Whether you are listening to music or playing a videogame, you want to perceive a signal as soon as it appears in the input signal. And when the deep bass signal stops, you want the bass transducer to get out of the way for whatever is next – silence, a different signal, whatever.



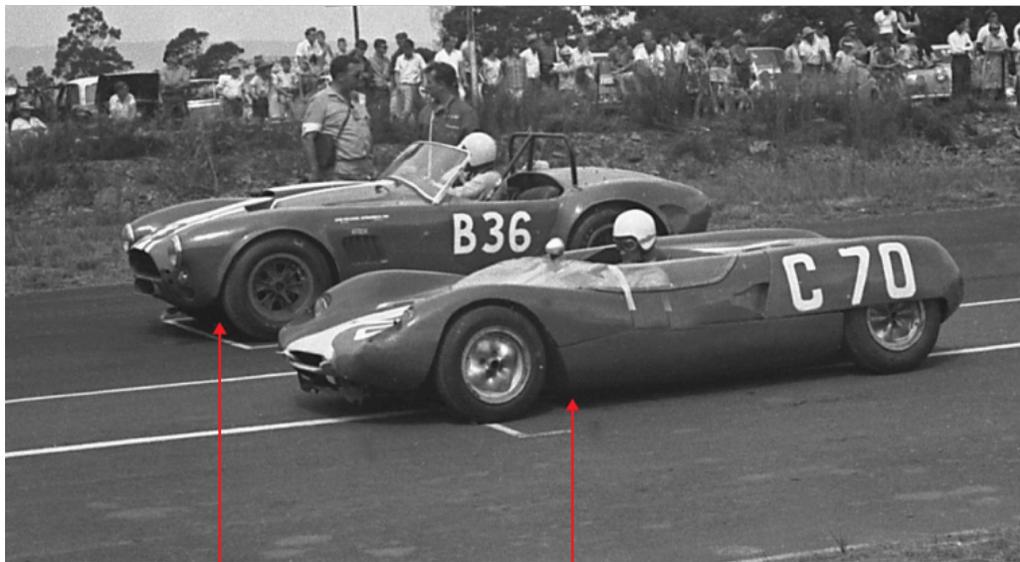
How quickly a driver can go from nothing to something in terms of output is called its rise time. Drivers with quick rise times make music sound more dynamic, but rise time is really important for gaming. Saving a few milliseconds of reaction time can mean the difference between killing and being killed. There's some great science out there that shows that your body processes tactile inputs faster than audio inputs. Let's make that point again: a tactile

transducer can make you better at the game. (Link to more detailed discussion of reaction time advantage)

But.

A faster path from skin to brain to action does no good if it takes forever for the signal to become strong enough to reach your skin's perceptual threshold. Fast rise time is key.

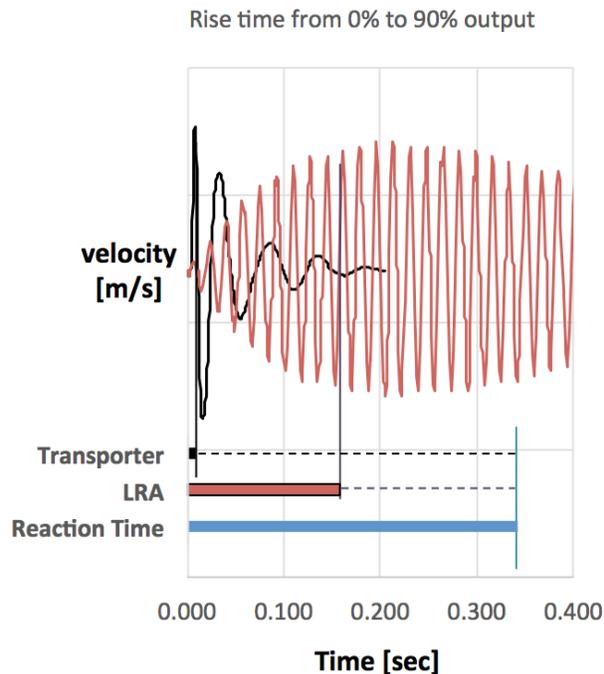
Three aspects of transducer design are critical to achieving quick rise and fall times: power, mass and damping. The first two are pretty simple. Think of power and mass when accelerating a car: is a 300 HP sports car faster to 60MPH than a 200 HP sports car? It depends: if they both weigh the same, probably. If the 300 HP car weighs 4000 pounds, and the 200 HP car weighs 2000 pounds, probably not. The same applies to braking: a 2000-pound car is a lot easier to slow down than a 4000-pound car.



**Shelby Cobra 289:**  
260HP, 2300 lbs.

**Lotus 23B:**  
100HP, 1000 lbs. On some  
courses, the Lotus could run  
rings around the Cobra.

LRAs and ERMs have trouble starting and stopping quickly. ERMs have loooong rise times – on the order of 150 milliseconds or more. (LRAs rise faster than ERMs, but only at their resonant frequency. At other frequencies the rise time is effectively “never.”) It takes many cycles for the LRA to generate enough oomph to deliver its strongest output. That’s because they tend to have a lot of mass relative to the power of their motors. If they are just letting you know you received a text on your smart phone, that isn’t a problem. And the bazillions of smart phones sold every year do help to make LRAs pretty inexpensive. But they don’t do so well playing music, and they are too slow to give you any reaction time advantage in gaming.



The LRA takes about 160 milliseconds to reach 90% of its potential output. That kind of delay is easily noticeable. (Audio-tactile mismatch gets noticeable when its around 40 milliseconds or larger). That's bad for music. It's even worse for gaming, because it's a big fraction of normal human reaction time. Without a tactile cue, human reaction time is about 350 millisecond. It's what we might hope to speed up with a tactile cue. But, as they might say in Texas, you can't be the first in the burger line if the bar-b-que is already half over when you hear about it. That's how it is with a conventional LRA. (And note again – that's the best-case scenario: at other frequencies, there's virtually no output at all.)

By comparison, a Kannon headphone, driven by a Taction Transporter reaches 90% of its potential output in just 8 milliseconds. That means the audio and tactile perceptions feel perfectly synchronized. For music, that means the kick of a kickdrum feels tight and natural. For gaming, it means reaction time can actually be sped up, because the cue reaches a perceptible level right away.

So how did we create a tactile transducer with fast rise times? The obvious solution is to reduce mass, like the 1000-pound Lotus.

So should a tactile transducer have low mass?

If only.

There is an important difference between the two contexts. For a performance car, mass is always the enemy, because all it has to move is itself. A loudspeaker is kinda like that. (Technically, it has to move air, but that's not a big issue.)

The problem is that we don't just want to move the transducer. We want the transducer to transfer energy to your body. To go back to the vehicle analogy, imagine a superlight bulldozer. It would move around easily, but would be pretty useless as a bulldozer. Big piles

of dirt and rocks have inertia, and a featherweight 'dozer would try to move them and be stopped dead. In order to move the rocks, it has to apply force.



The solution? Behold Newton's 2nd Law:

$$force = mass \times acceleration$$

Accelerating something with no mass isn't very effective for bulldozers, and it doesn't work very well for tactile transducers, either. To be useful, the transducer needs to have mass – significantly more mass than other tactile transducers have used. The Transporter's moving mass weighs 18 grams.

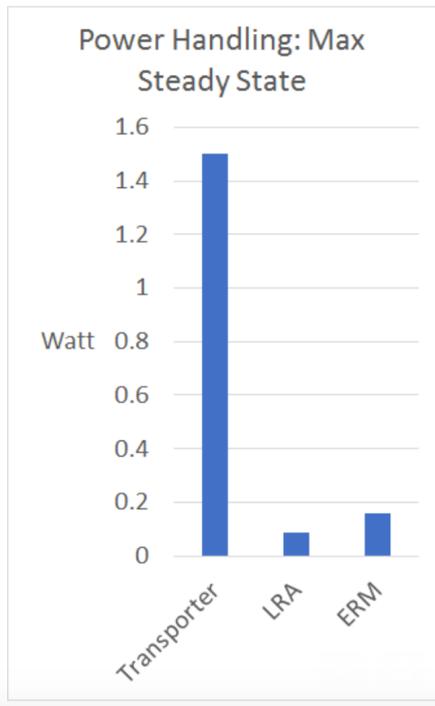
To make that mass move quickly, we also need some serious acceleration. And that means a powerful motor.



Merlin V-12. The 1,650 cubic inch motor that won the Battle of Britain. (Not included with your Kannons).

The motor in the Transporter is 20 times more powerful than the motor used in any other current tactile headphone transducer we know about, and 10 times stronger than the most powerful potentially usable ERM we know of.

So more mass, plus more acceleration, equals more force. Enough force (at the highest setting) to literally blur your vision.



The third critical factor in building a responsive transducer is damping. In any mechanical system that involves moving a mass back and forth, there is going to be a suspension, just like your car uses springs to allow the wheels to move relative to the body. The larger the mass, the stronger the spring needs to be to control the moving mass. Every spring has a

natural resonance. And every spring-loaded system (like the combination of the spring, wheel & tire and other suspension pieces at each corner of your car) has at least one resonance. If you remove the shock absorbers from your car's suspension, it will hobby-horse down the road, bouncing at the resonant frequency of the car-spring system, which is both dangerous and amusing to watch. (Our lawyers insist that we tell you: don't try this at home.)



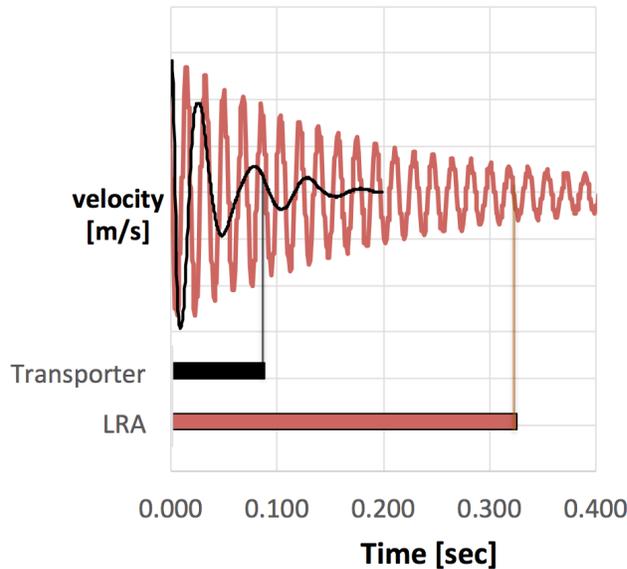
This is a short video of a car with no shocks:  
<https://www.funscrape.com/Fail-Win/23274>

That's why your car has shock absorbers (or as the British often refer to them, dampers).

Dampers resist movement. There are many ways to do this, and the properties of damped systems can be very complex. But for purposes of our tactile transducer, you can think of damping as a method for (a) reducing resonances and (b) helping the transducer stop moving, which improves fall times.

Transporters use proprietary damping techniques that have never been applied to tactile transducers. They give Transporters unprecedented control, and excellent rise and fall times. Do those techniques work? Here's a comparison between the fall time of the Taction Transporter and the LRA used on a competitor's headphone:

### Fall Time from 100% to 20%



That kind of fall time is critical to reproducing music, and to making sure that sounds like explosions get out of the way of other important cues in gaming.

There you have it: Transporters offer dramatically improved transient response compared to all previous attempts at using tactile transducers in headphones.

### Part VI: The Most Advanced Tactile Base Transducer Ever Used in a Headphone

So now we can finally describe the characteristics of the ideal tactile transducer.

- It would be equally strong at all relevant frequencies – from as low as 10 Hz to as high as 100 Hz or so.
- It would be able to produce any sound in that range at any volume level — loud, soft or anywhere in between.
- It wouldn't distort the output of the main audio driver.
- And it would start and stop on a dime.

Ladies and gentlemen, the Taction Transporter: 200 pounds of subwoofer in a 1-ounce module.



**Specifications:**

- Lowest tactile bass note (>5 mm/s): 12 Hz
- Highest tactile bass note (>5 mm/s): 120 Hz
- Rise time: 0.008 sec
- Fall time: 0.090 sec
- Top speed of ear cup: 50 mm/s
- Intensity: Adjustable 0-50 mm/s, flat to  $\pm 3$ dB, 15Hz-85Hz