WOOFER SPEED by Dan Wiggins

There's a common misconception out there that heavy woofers must be "slow", and light woofers must be "fast". If a woofer A's moving mass is higher than woofer B's, then woofer A is probably going to be sloppy, or slow and inaccurate. Can't keep up with the bass line. Woofer A simply can't respond as fast as woofer B.

There's also this concept that the "acceleration factor" (BL/Mms) is an indicator of woofer speed/transient response. High BL, combined with a low Mms, should give great transient response, right?
Well, on surface these might sound like logical assumptions. However, they are in fact incorrect! More to the point, moving mass has precious little to do with woofer speed or signal response! And we'll prove it... Go back to good old Newtonian physics... We're going to start with the famous law:

F=ma (eq 1)

Or force equals mass times acceleration. Anyone who's been through introductory physics (or watched a bit of PBS) should be familiar with the equation above. It's pretty much the bedrock equation of Newtonian physics - it's number 2 of the Big 3 Newtonian equations (the first being about interia, and the third being about complementary/opposed actions).

Now, let's look at a loudspeaker... What do we have? We have a coil of wire which creates an alternating magnetic field which interacts with the static magnetic field in the gap (see our page on DVC subs for a bit more information on this). How does the alternating magnetic field of the coil come into being? Well, the magnetic field is created by passing a current through the voice coil. As the current through the voice coil changes, the magnetic field created by the coil changes. This field interacts with the static magnetic field of the permanent magnet, and you get a force - the cone moves in and out. Just like two permanent magnets will attract/repel each other depending upon how they are oriented. And a bigger current means more force. Just like bigger/stronger permanent magnets mean stronger attraction/repulsion.

Additionally, what if we make the field of the permanent magnet stronger? Well, that's call the B field in the gap. Increase B, we increase the force as well. Or, what if we could somehow make the magnetic field from the voice coil stronger? We can - increase the number of turns of the voice coil (increase the Length of the wire in the gap). Guess what - in both cases, we increased the BL of the speaker (yes, this is the BL of the T/S parameters - now you know where it comes from!).

Now, let's go back to equation 1... Let's define each of the terms in that equation so we know what we're talking about:

F= Force
m = mass (moving mass)
a = acceleration

So, what is the Force (NO Star Wars jokes, please!). From above, we see that the force on the cone is the motor force factor (BL) times the current. So, let's rewrite equation 1 in these terms that are applicable to the loudspeaker:

BLi = ma (eq 2)

So, the Motor Force Factor BL times the current i equals the moving mass of the driver m times the acceleration of the driver a. Note that we have italicized i and a. There's a reason for it!
Now, back to the original question - transient response of a driver. What is transient response? Simply a measure of how fast the driver can respond to the input signal. That means that - inherently - there is a time dependency on the driver. How much TIME elapses before the driver responds. So, let's look at equation 2, and cancel out all terms that are not based on time. After all, if a quantity is time-invariant, then it won't affect time-variant effects like transient response (think of this as a simple offset).

Or, to put it in an analogy, does the 1/4 mile time of a vehicle depend upon where you start? No, the distance over which you measure is still 1/4 mile. So whether you start in front of your house and go straight 1/4 mile, or motor on down to the dragstrip and go 1/4 mile doesn't really affect the car's 1/4 mile time. The 1/4 mile time is strictly dependent on how fast the car can accelerate from a dead stop over a 1/4 mile length.

So, looking at equation 2 we see that:

BL is time invariant, assuming small excursions (assume an ideal motor with a flat BL curve; I know, most drivers don't have that, but assume that it does, like our XBL2 enabled motors). So BL is essentially a constant.

i is the current into the driver (we used italics to indicate a parameter that is time-variant). This is the music, or test tone sweep, or whatever signal is coming from the amp. It's an AC waveform so by definition it changes with time.

m is mass. Well, if the moving mass of the driver is changing as you operate, you've got big problems! The weight of the cone, dustcap, former, voice coil, surround, and spider are pretty much fixed. The don't change either. So m is essentially a constant.

a is the acceleration. This is what we're after. After all, the rate of change of acceleration IS the transient response - it's what dictates how fast the driver can change speed, which also means it dictates how fast the driver can move from position to position. And note that it's in italics, too. After all, acceleration in the time-variant parameter we care about here!

So, let's rewrite equation 2, and replace the time-invariant parameters with a simple "C" to indicate a constant (a parameter that does not change with time):

Ci = Ca (eq 3) or i :: a (eq 4)
(note: the "::" symbol is the mathematical symbol for proportionality; that is, i is proportional to a).

Interesting! This says that the change in acceleration of a driver - how fast it can change position - is strictly a function of the current through the driver. In fact, if you could make the current change infinitely fast, then the driver would accelerate infinitely fast, and we'd have infinite transients - zero time to change between states. Infinite frequency response.

So, now that we know that current is the driving force (pun somewhat intended) behind driver acceleration changes, let's look at what limits how fast we can ramp current through the driver. Because if we are not restricted in how fast we can change the current, then we are not restricted in how fast the driver can accelerate - transient response is not limited at all.

So, back to that loudspeaker model... A loudspeaker is a coil of wire wound on a former that attaches to the cone. The current flows through the coil, creating an alternating magnetic field that interacts with the static magnetic field of the permanent magnet. So, what could limit current flow? Well, what does a voice coil look like?

How about an inductor? You know, those coils of wire (hey, isn't that what a voice coil is) that you use in crossovers? Guess what - a voice coil IS an inductor! In fact, an inductor stores its energy in the magnetic field (as opposed to a capacitor which stores its energy in the electric field). It is this magnetic field of the voice coil "inductor" that interacts with the permanent magnet field we talked about above. Hey, a loudspeaker is an inductor hung on the end of a cone in a static magnetic field!

So, what about an inductor will alter the way current flows? Well, inductors don't like to have the current flowing through them change. They like to hold the current constant. They will allow you to change the current flowing in them, but the bigger the inductor (or, the higher the measured inductance) the longer it will hold the current before it starts to change (I'll leave it to the reader to go research inductance on their own, to learn why this happens).

So, the voice coil is an inductor. And we see that inductors don't like to change current. But we also see from equation 4 above that we need to change the current if we want to change the acceleration. So, the voice coil doesn't want us to change the current. How good is it at holding the current? Depends upon the inductance! The higher the inductance of the driver, the longer it can hold the current flowing through it. Which means the more time elapses before it starts to respond to the amplifier's applied voltage. Which means we have slower transient response.

Guess what - we just answered the original question! It turns out that transient response of a woofer is not a function of the moving mass, as is commonly espoused (one of the most infamous audio myths). In actuality, it is based upon the inductance of the driver. And the greater the inductance, the slower the driver - the lower the transient response.

So let's put this to the test - let's add some mass to a driver, and also increase the inductance to see what happens. Out to the lab! This is what we did:

- Used a prototype Extremis 6-8 (8 Ohm 6.5" woofer). Note that we had Klippel data measured by the good Dr. Wolfgang Klippel himself at CES 2004.

- Added mass was 28.5 grams (Mms of the Extremis 6-8 is 24.39 grams per Klippel). Mass added to dustcap only; none was placed on the cone itself (all within the diameter of the former).

- Added inductance was a 10 AWG, 0.47 mH inductor (inductance of the Extremis 6-8 is 0.6 mH per Klippel)

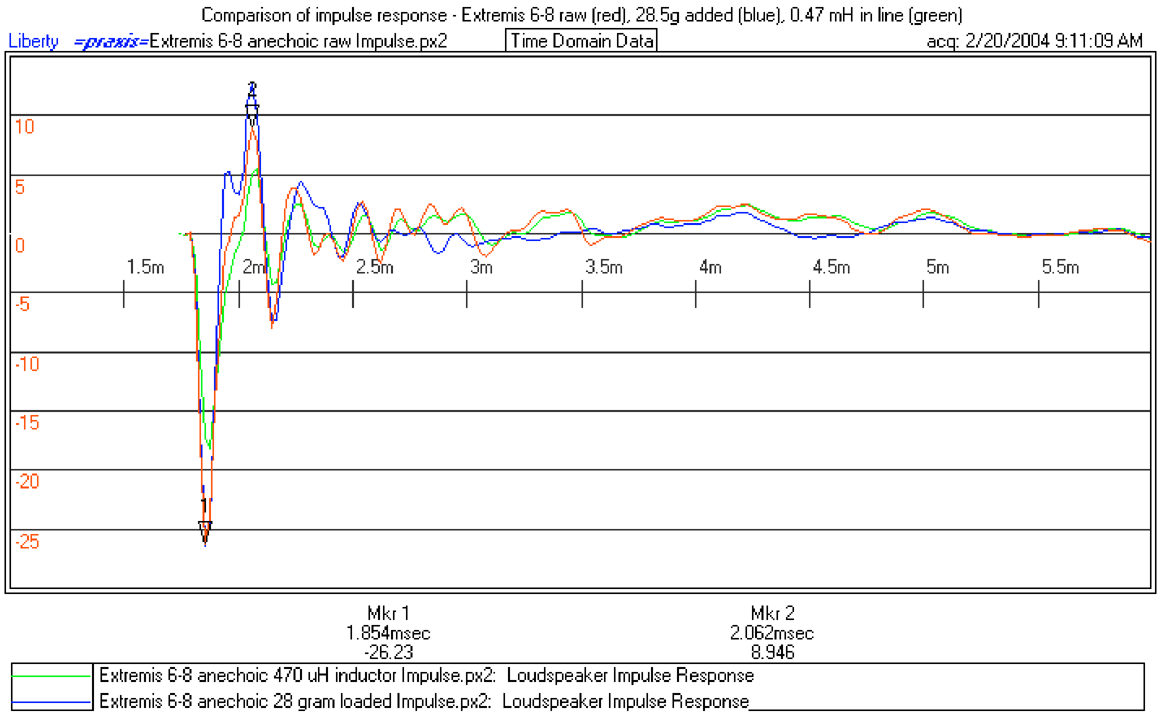
We left the driver mounted in our test baffle, which is 48" square. Driver centered on baffle (not flush mounted), anechoic (no box). Nearest reflective surface is 6 feet from the speaker, for good results down to 90 Hz.

Test gear used was:

- Praxis measurement system
- M Audio Audiophile USB sound card
- AudioControl MP200 test mic and preamp (last cal at factory November 2002 - time to get another cal!)
- QSC PLX3402 amplifier

We measured the impulse response of the driver raw, with 28.5 grams added (more than doubled the moving mass), and with 0.47 mH in series (78% increase in inductance). In other words, we more than doubled the mass, and didn't double the inductance. So the mass - if it really limits transient response (and hence frequency response) should really stand out compared to the inductive changes.

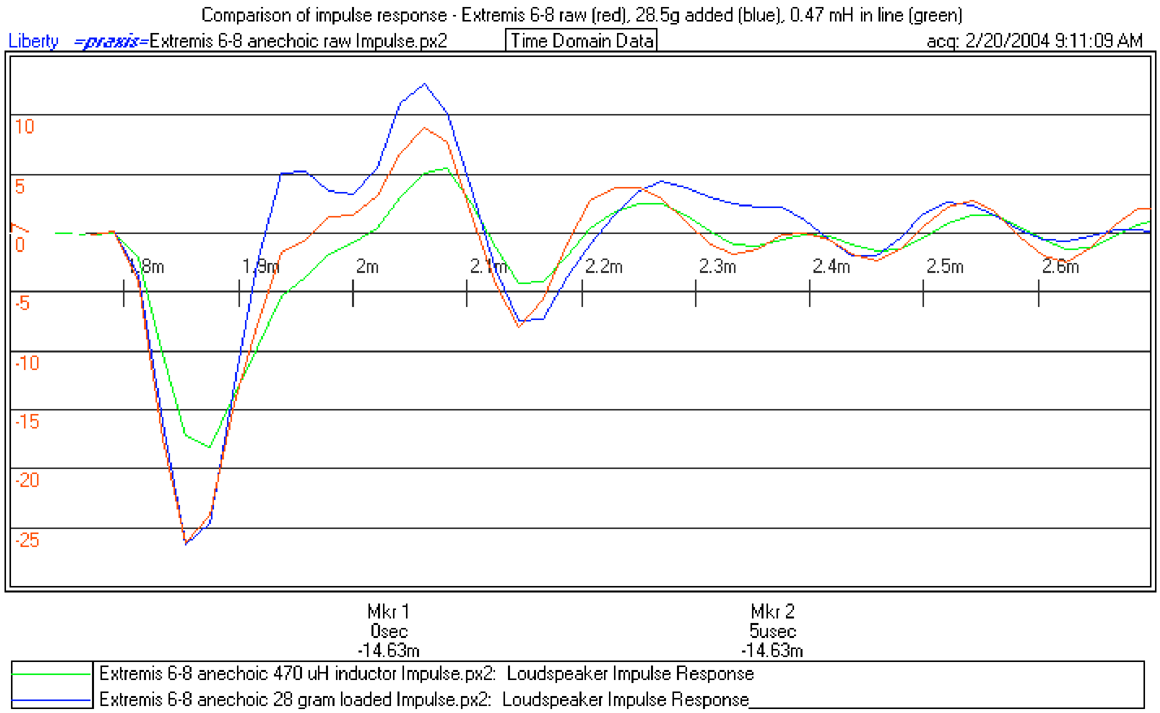
Here's what the impulse tests show:



Raw image dump from Praxis. Red is the raw driver - nothing added. Blue is the driver with 28.5 grams mass added. Green is the driver (no added mass) with the inductor in series.

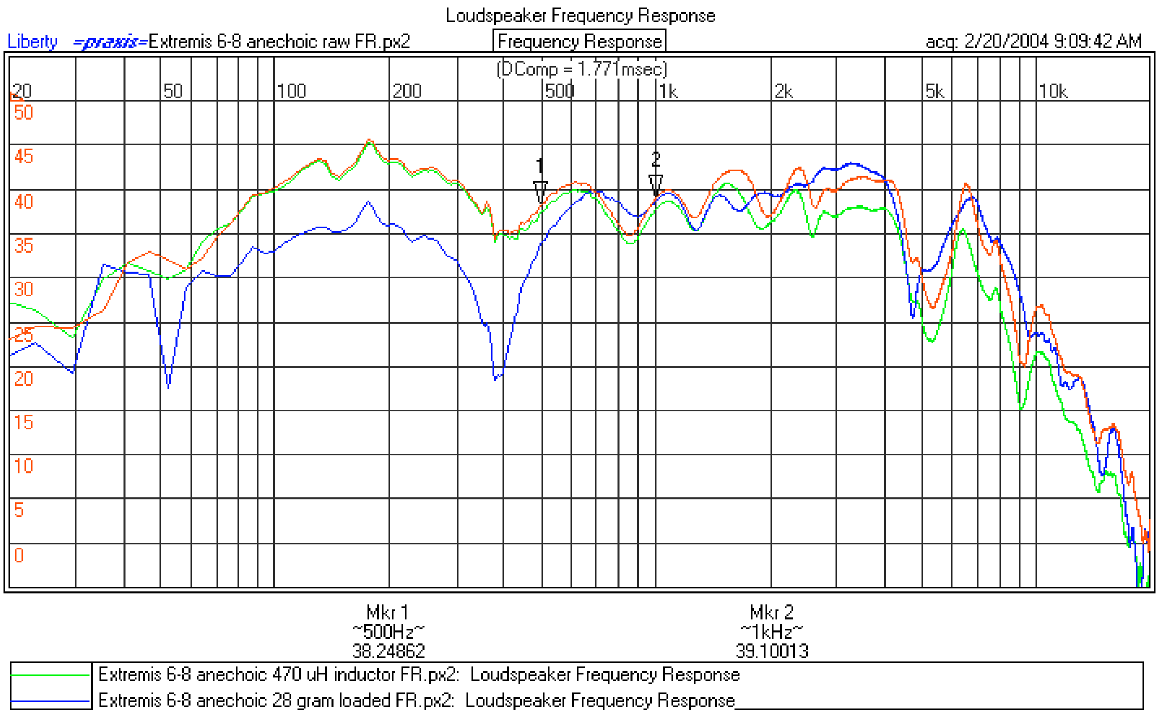
Now, look at the time of the peaks. I've set the markers where the raw driver has its turn-on transient peaks. The mass (blue line) corresponds nicely. The inductor (green line) has a delay in the negative AND positive peaks.

Here's a zoomed in view of the start (note the sampling time is ~21 microseconds, a 48 kHz sampling rate):



You can clearly see that the raw and mass loaded transient peaks - first negative and first positive peaks - occur at the same time. The inductively loaded (green) peaks are definitely delayed in time. As one would expect!

Now, how would this translate to frequency response? Here's a graph of the raw (unsmoothed, wide gate) frequency response for the same 3 cases:



Note the red and blue - raw and mass loaded, respectively. They are pretty much equal from 700 Hz and up (I assume we all accept the Fourier transforms, and that the Fs/efficiency of the driver is affected by the added mass, accounting for the differences down low.

Now look at the green. It is 5+ dB down at 4+ kHz. The high frequency - the transient part of transient response - is reduced! The inductance cut the high frequency extension - mass did not!

Mass isn't the problem - inductance is. So if you want faster transient response, ignore that moving mass parameter that some manufacturers push - look at the inductance! And if they don't list the inductance, ask yourself why - is there something they don't want to show? Inductance is the key to driver transient response - ask for it when transient response comes up!