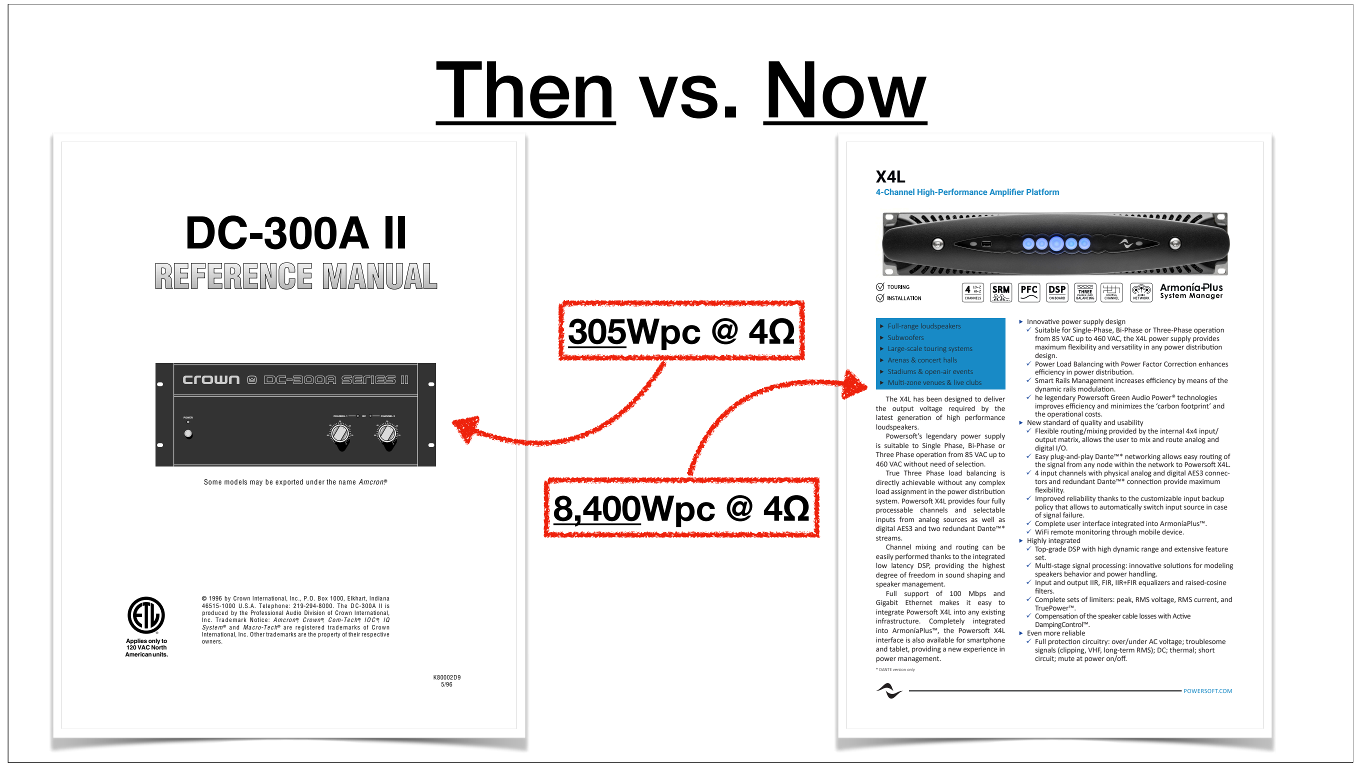
Woofer design goals, and techniques to evaluate whether we've met them.
We have tested a lot of woofers and materials! 180 closed projects / year.
    Simulation helps, but in the end must test… to destruction. Repeatedly.
Very physical in the end. Woofers are made of basic materials… cloth, paper, and metal.



DC300 from 1967, so 51 years between it and X4L and ≈ 28x increase in power output.
Plus 1/2 the height, twice as many channels, DSP, limiting, networking… you name it.
DC300 was $1 / watt then ($685 in 1967, $5,300 now). X4L is around 58¢ / watt now.

Then vs. Now

JBL D130 c. 1955

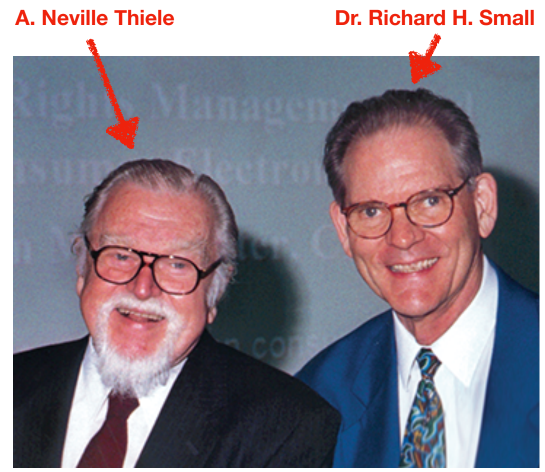
	D130	15FW76
Fs	40 Hz	40 Hz
Re	6.3Ω	5.1Ω
Qts	0.25	0.21
Vas	297.3 L	138.0 L
Le	0.6 mH	1.4 mH
Mms	60 g	117 g
Bl	18.0 Txm	26.2 Txm
Xmax	6.3 mm	7.0 mm
Power	75 W	500 W

B&C 15FW76 c. 2015

T-S parameters don’t capture 60+ years of innovation, mostly what happens once the cone moves.
Fed the same amp output the D130 will quickly catch fire and/or shake apart - paper former!
Modern coils can handle 330°C, forced air cooling helps a lot, suspension aging really stable.
Clearly something has improved: modern woofers drive modern amp requirements, and vice versa.

But those improvements are not reflected in woofer spec sheets.

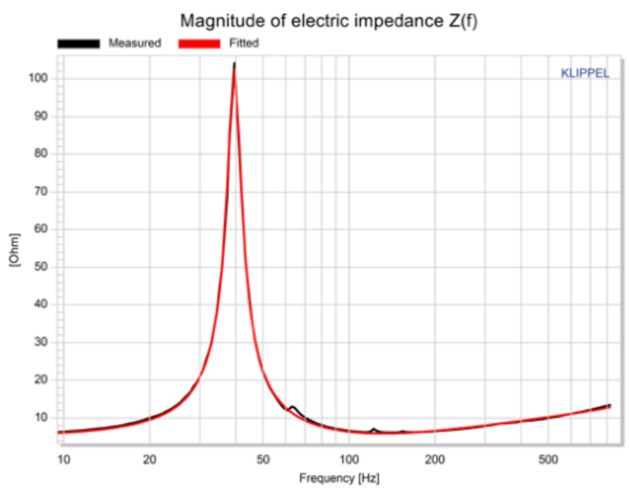
Thiele-Small Parameters



- Defined in 1960s by Thiele
- Brought to international attention in 1970s by Small
- Model of small-signal loudspeaker behavior
- For calculating resonant systems before computers, measurement, EQ.

What are these things anyway, and why are they used to evaluate woofers? History lesson.
Designed to model woofers at small signal and near resonance. Invalid at more than 1W or a few hundred Hz.
Even 1W could be too much in some cases, coil must be stationary.
Calculate box / woofer combo for desired voltage sensitivity response.

Key T-S Parameters



- **Mms** – Mass of moving parts, including air load.
- **Cms** – Compliance of suspension.
- **Re** – DC resistance of the voice coil.
- **Bl** – Magnetic field strength (B) multiplied by length of wire (l) - in the gap.
- **Fs** – Resonance frequency of woofer.
- **Qts** – Total Q of the driver at Fs.

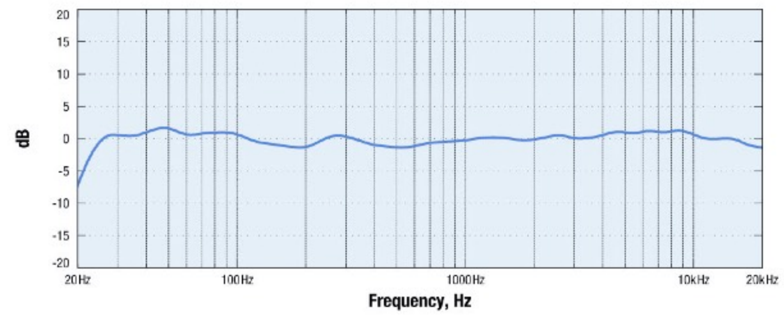
T-S model is matched to a measured impedance curve.
For our data we use an average of several woofer responses with different component batches, after break in.
Note what's not on the list: Xmax, Power Handling, Sensitivity, Distortion… none are T-S parameters.

T-S Parameters are Linked

- Can’t just reduce **Mms**. Need sturdy cone for durability, damping.
- Can’t just increase **Cms**. Need stiff suspension to keep coil in gap.
- Can’t just lower **Fs** without increasing Cms or adding Mms.
- Can’t just lower **Vas** without decreasing Cms or increasing Bl.
- Can’t just increase **Bl** or **Xvar**, they are expensive and in some cases may not be technically feasible.

Woofers are a balance of cost, size, weight, and performance.
Many “desired” parameter changes make the woofer less durable or sound worse!
Aiming for a specific voltage sensitivity response ignores many mechanical constraints.

Everyone wants flat response

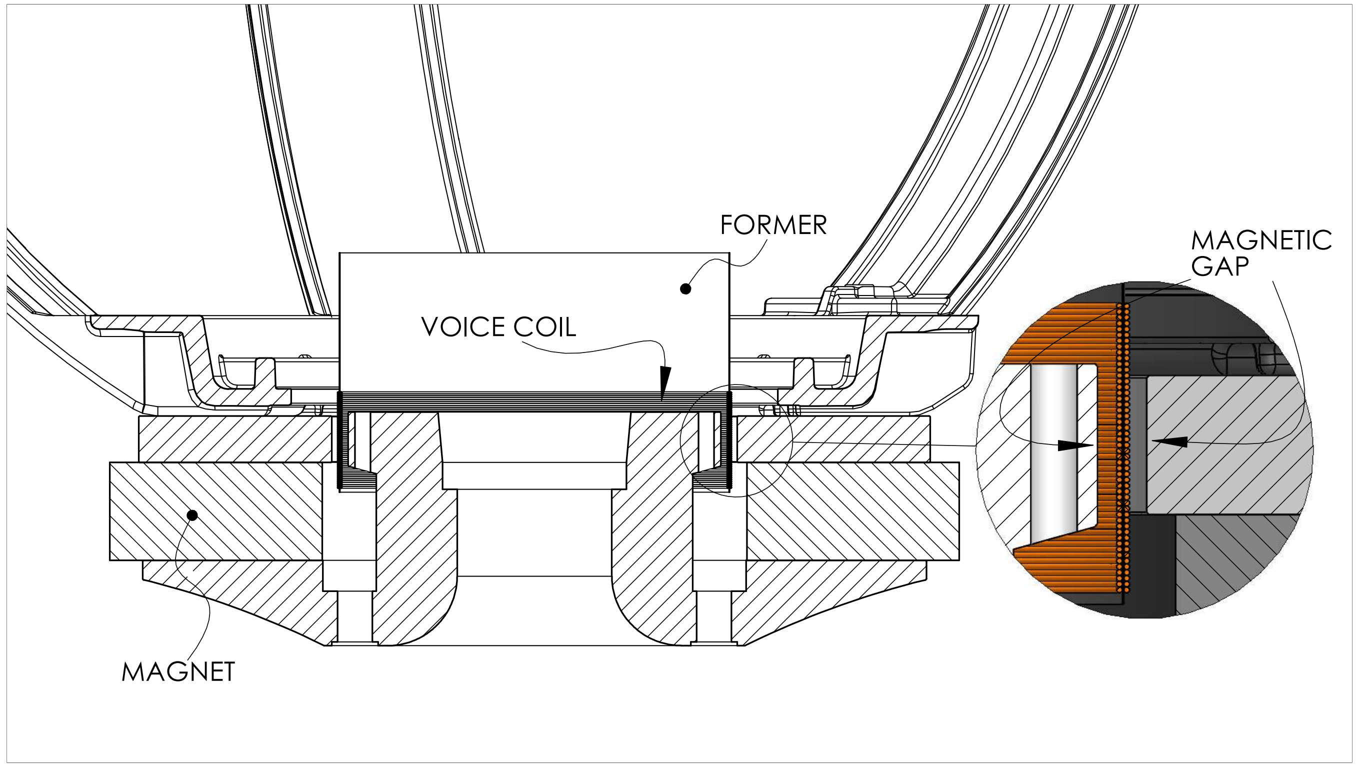


Nobody wants to pay (EQ)!

In Old Days was very hard to get flat response… no measurement gear or EQ available!
T-S provided equations that <u>solve to desired response</u> (by hand!) by adjusting driver or enclosure.
Focused on sensitivity: very low amp rails and no EQ available, need every volt to count.

Not a problem today (usually) with free EQ and high voltage output amps.

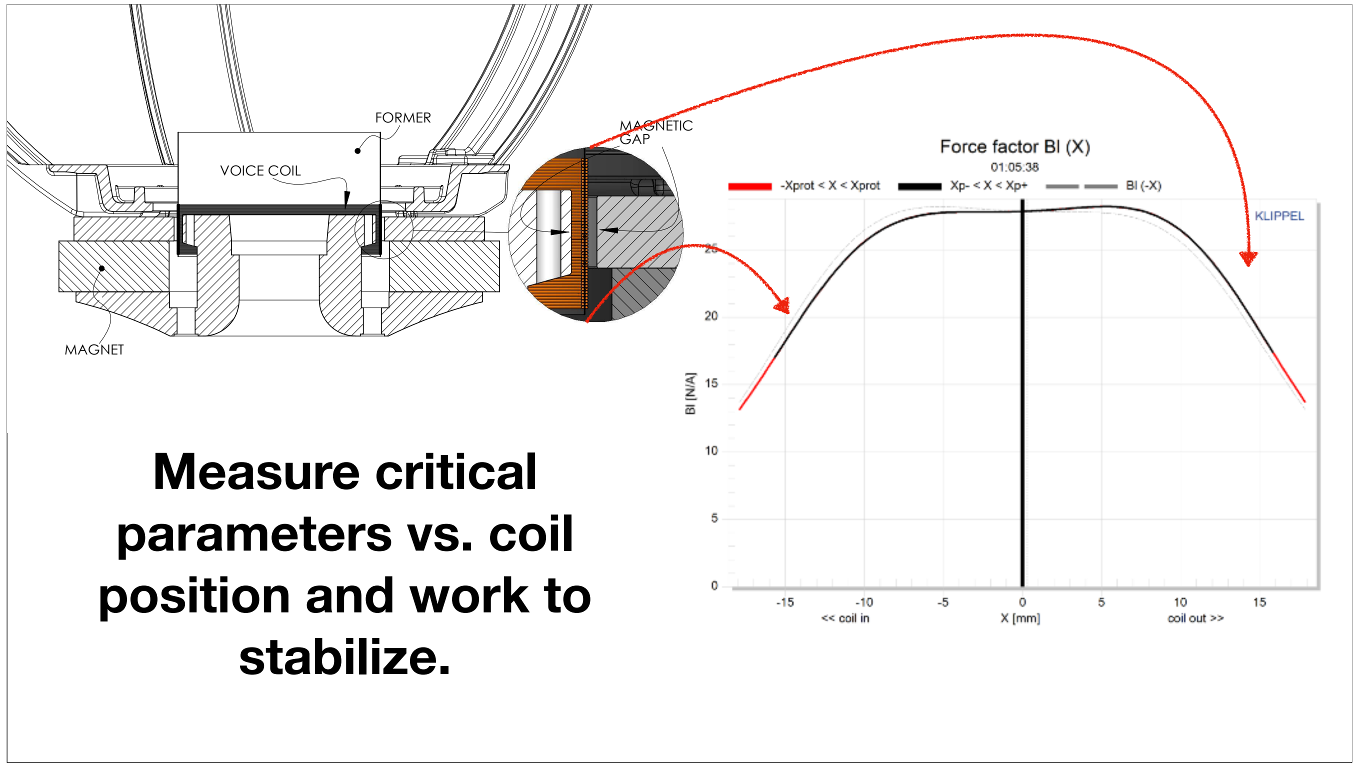
Both are pistons. Build a higher performance piston (more linear travel, better cooling, lighter without breaking, more motor strength) get a higher performance “engine”. Focus on behavior at full throttle, not with engine off. Design for extremes, not T-S parameters at rest!



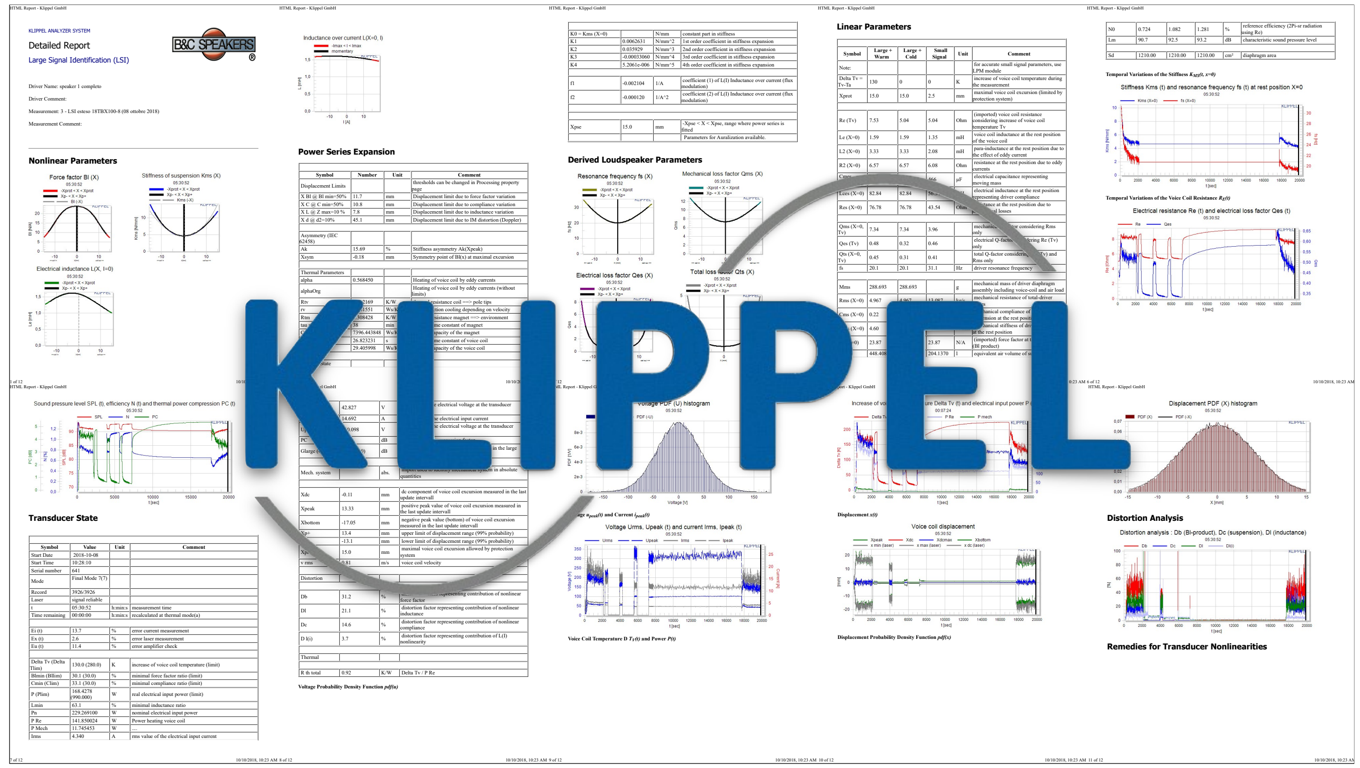
Cross section of modern ceramic woofer motor with coil (cone & suspension excluded)
Mechanical system keeps coil centered in gap.

    Provides some restorative force at high excursion, where Bl is low.

Electrical system drives coil, and provides <u>majority of coil control</u>. More Bl = better control.



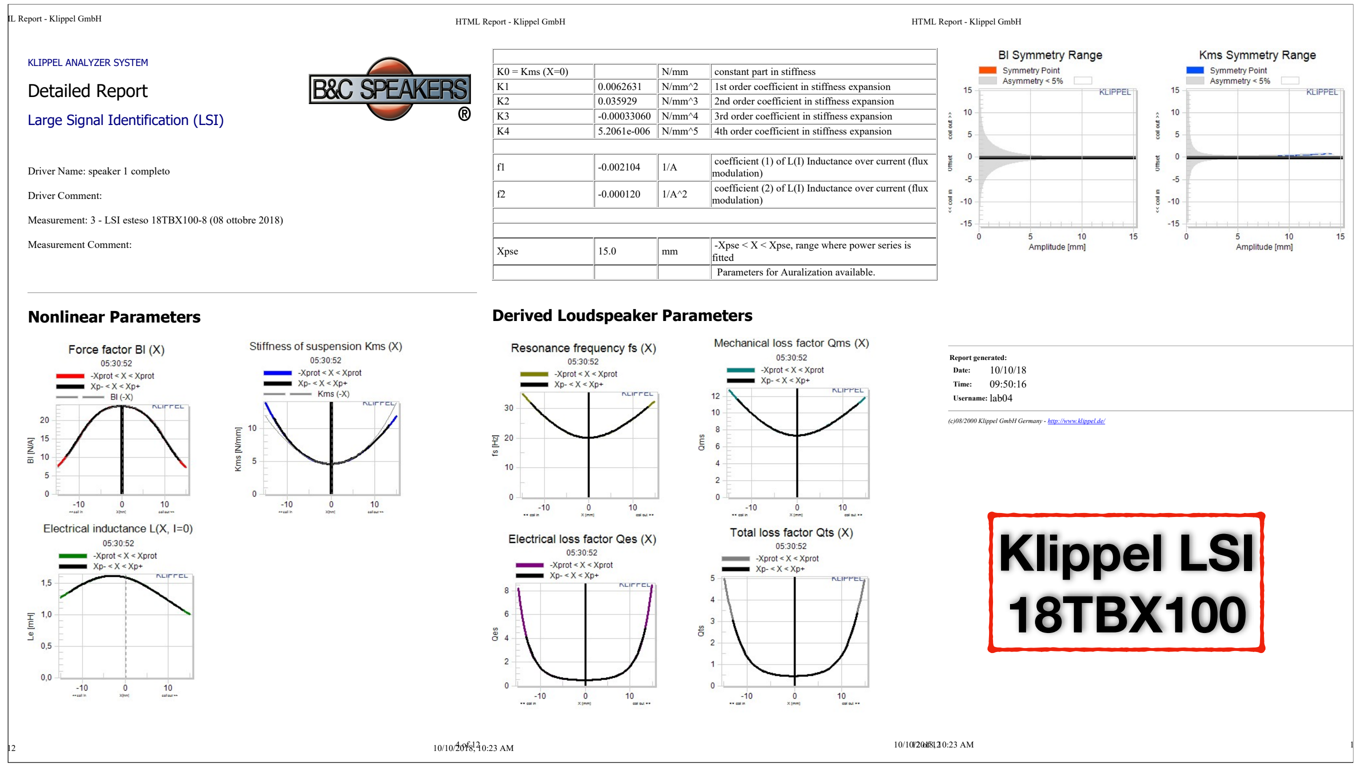
Bl(x) is force seen by coil as it moves from coil in (left), through rest, to coil out (right).
<u>All</u> parameters change w/coil position, how much is critical and not included in T-S params.
Xvar much more reliable than Xmax, includes Bl *and* Kms limits, use it for excursion limit evaluation.



What do we use to evaluate woofers if T-S parameters aren’t helpful? Klippel, for one.

12 pages of specs mostly concerned with large signal behavior.

Still doesn’t capture suspension aging or durability! Must test physical sample - to death.

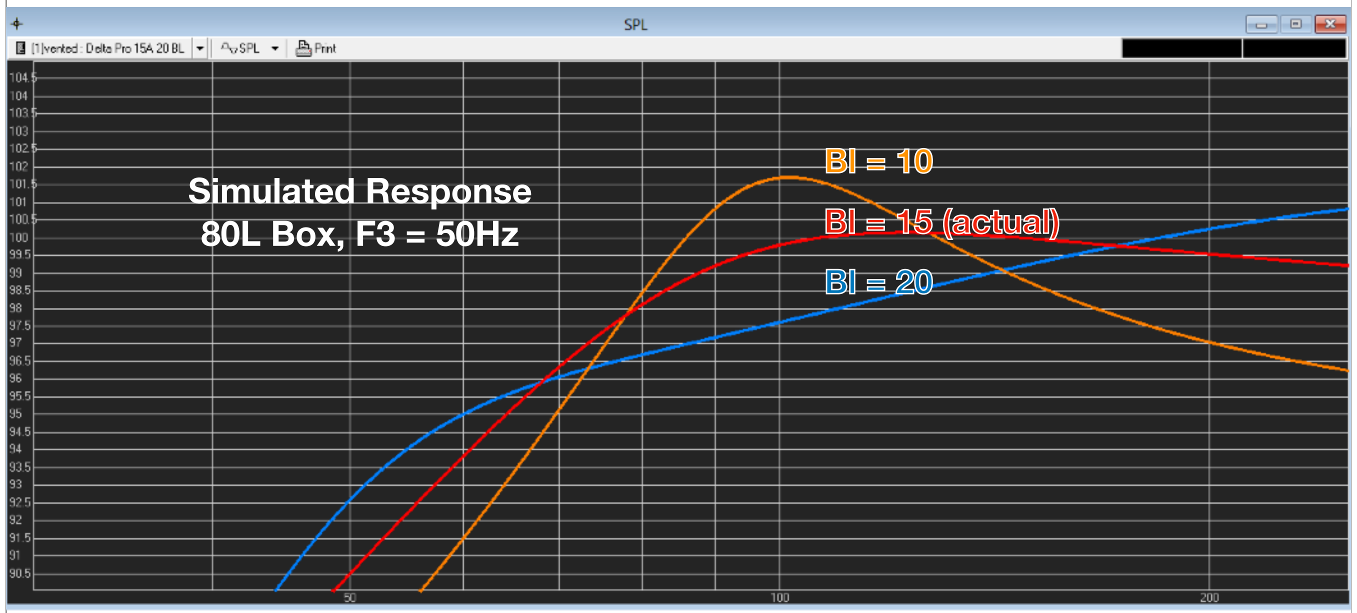


Three key pages of Klippel graphs showing how every parameter changes with coil position.

DC offset stability as power increases… Reduces available X and adds distortion.

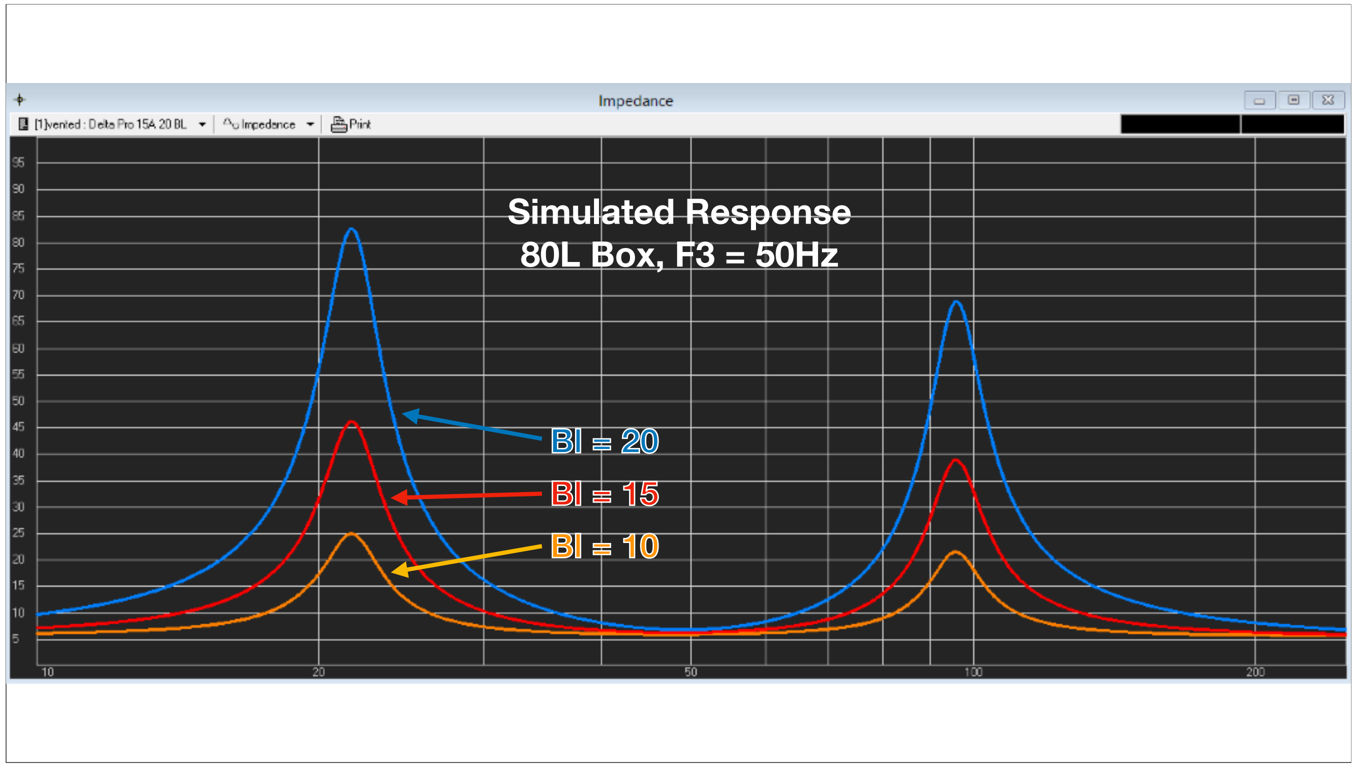
Non-linear behavior of whole system (woofer, box, ports, amp, limiters) defining characteristic.

High performance transducers are not flat. Adding more motor increases passband efficiency, but changes sensitivity especially around Fs. This can lead designers looking at sensitivity response - but not considering efficiency - to compromise their designs.

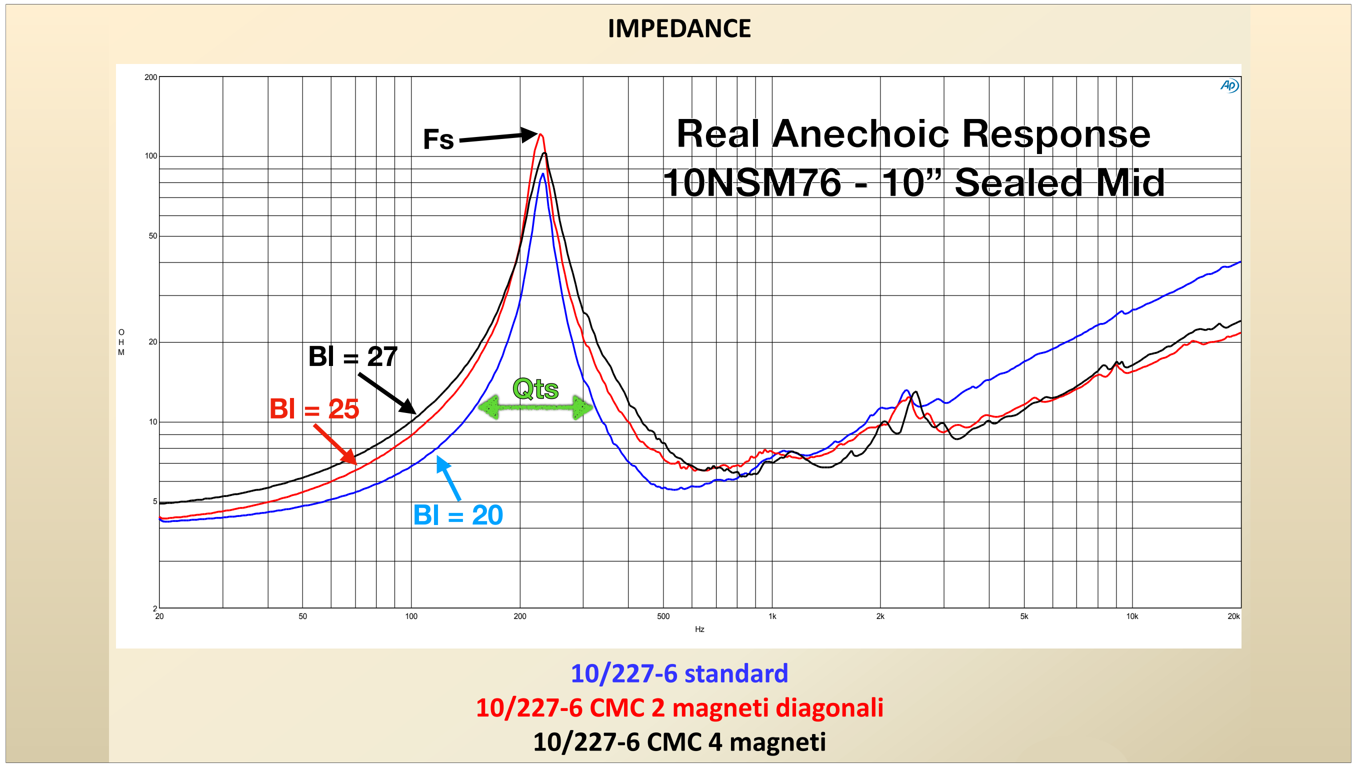


Simulated vented box, characteristic response hump and “double” impedance peaks.
These are all at 2.83v, not one watt @ one meter - heavily dependent on impedance changes.
Consider earlier Bl(x) graph, as coil moves response changes among these.

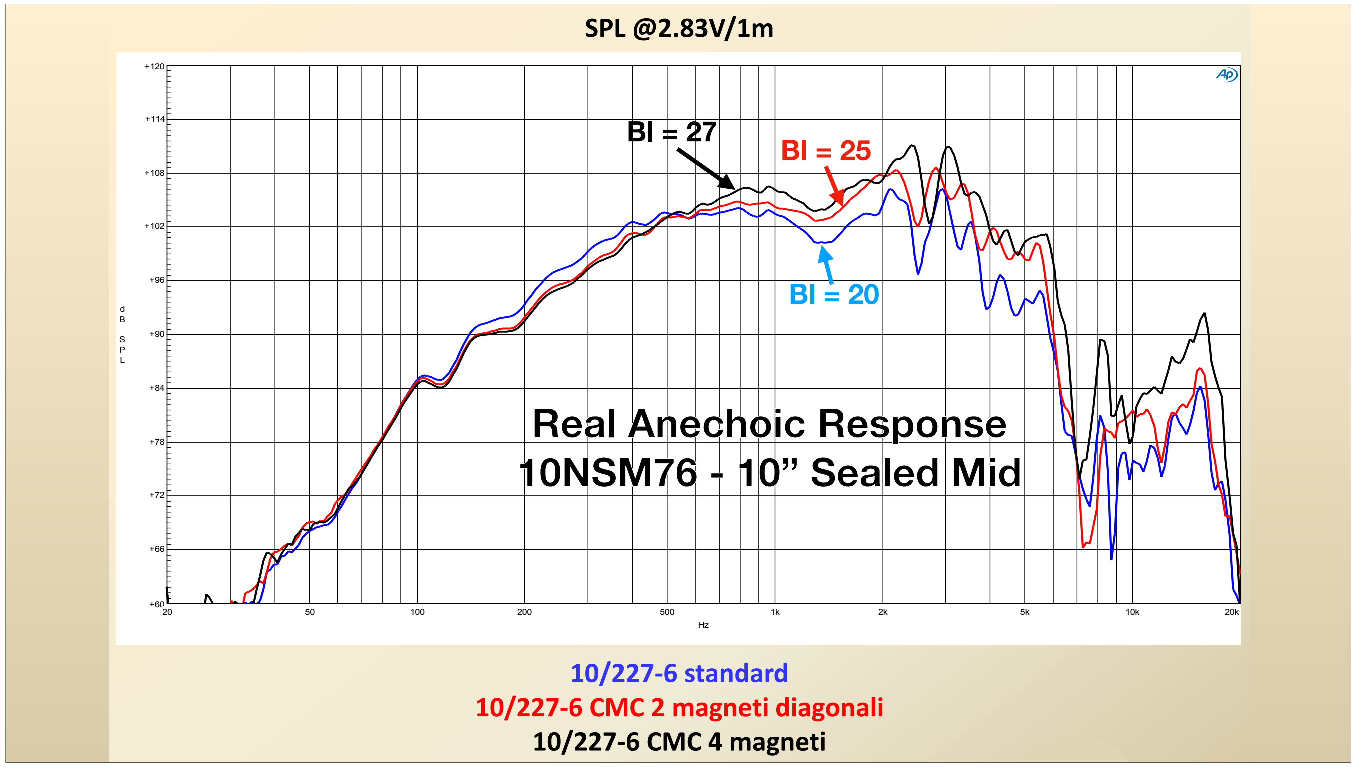
Need to consider how to make system most consistent. More Bl helps!



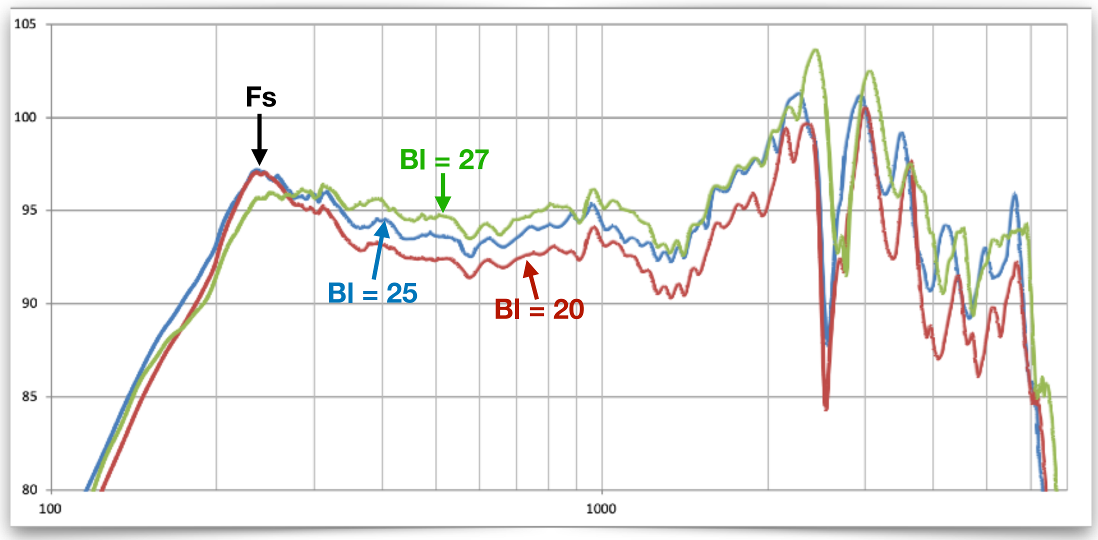
Additional Bl brings higher impedance, lose some sensitivity. Need to equalize flat, but overall performance, efficiency, sound quality are improved!
Reducing Bl is just doing the equalization “in the woofer” by reducing impedance near Fs.
Most box / woofer design choices are just moving impedance around.



Here’s a real woofer we made with increasing Bl.
Easier to see effects in sealed box: single impedance peak gets taller and wider.



Sensitivity (usually listed as 1W / 1M) response shows characteristic slump below 500Hz, near resonance. Sensitivity above 500Hz is better with increasing Bl already.



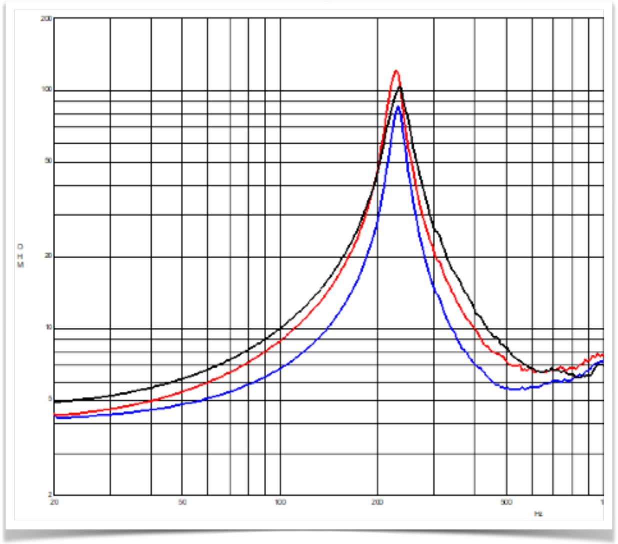
Actual 1W / 1M Response

Mathematically compensate for impedance rise from increased Bl. Now you have “real” 1W / 1M sensitivity - power sensitivity, not voltage like usual. Increased Bl gains ≈3dB everywhere!

Don’t think in watts when it’s really volts. Impedance change must be accounted for.

Still really hard to account for maximum output, but higher efficiency helps thermal a lot.

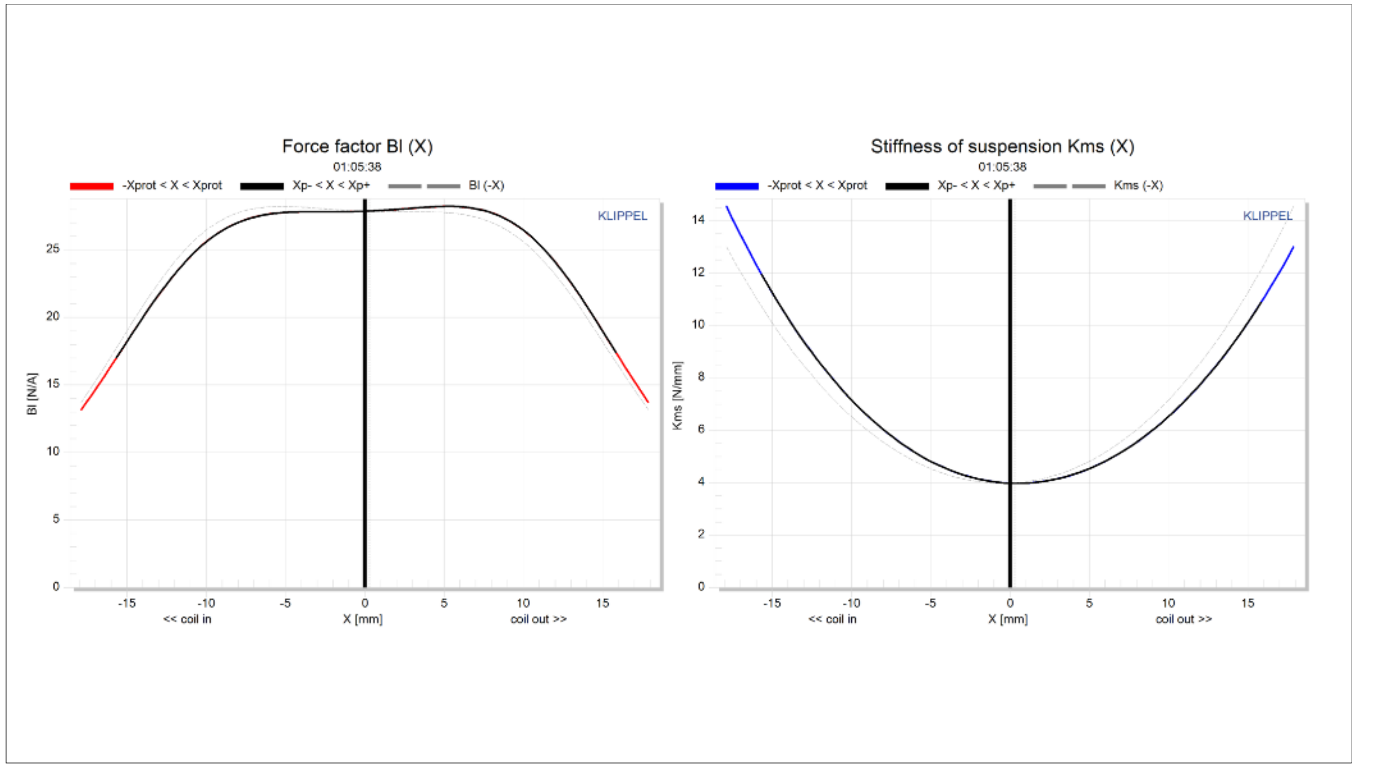
Higher Performance through EQ



- Buy the most Bl and Xvar you can afford.
- Optimize for performance at system limits - ports, suspension, etc.
- Use EQ to make response flat, it's the ideal tool!

Today we have free, practically unlimited equalization, and amplifiers with huge voltage capabilities.
Strong woofers, in small enclosures, are not flat. But they are efficient! So use EQ to solve the impedance mismatch and get more output, that sounds better, in smaller system.
Don't compromise woofer to apply equalization, use the correct tool (DSP) for the job.

Hope everyone is still awake.



Bonus slide to focus on Bl(x) and Kms(x) to discuss Xvar. This is 18SW115.