B&C Speakers…
Large Signal Parameters

Written by: Bennet Prescott

Every loudspeaker designer should be familiar with Thiele/Small parameters[1], usually abbreviated T/S. Originally defined in the 1960s, they are a simple model of how transducers behave – mostly useful for designing ported cabinets like subwoofers. In 1971 they were brought to the attention of the US audio world by A. Neville Thiele, a native Australian, and Richard H. Small, a San Diego native who moved "down under" to work with Thiele. This was an era before computers were common, when the best portable amplifier available (the Crown DC300) famously made 150 watts into 8Ω, and when a high-performance woofer handled 75 watts. T/S parameters allowed engineers to optimize loudspeakers mathematically for the first time, using nothing more than a pocket calculator. 50+ years later they are still the primary method for evaluating transducers, but have many serious limitations when applied to modern sound systems.

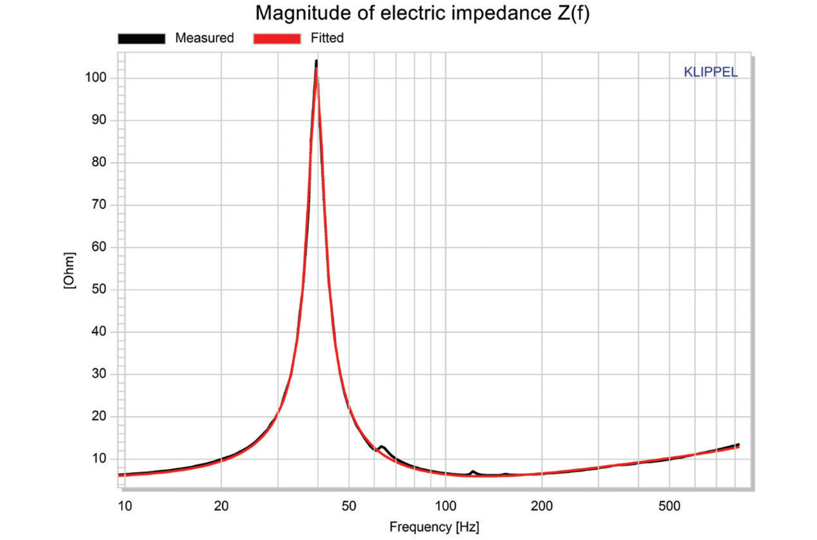

Figure 1

Thiele/Small parameters are calculated from an equivalent circuit model. Simulated resistors, capacitors, and inductors are adjusted until they match a woofer's measured impedance response (Figure 1) as closely as possible. This process is similar to how a passive crossover can have high-pass, low-pass, and equalization filters just like the ones provided in your digital loudspeaker processor. How well this equivalent circuit models the transducer itself depends on the accuracy of the woofer impedance measurement, as well as the complexity of the circuit model itself. Different models can give quite different results for the same woofer, and every manufacturer has their own preferred model to generate T/S parameters for their specification sheets.

One of the main limitations of T/S parameters is that they are measured with the voice coil near the rest position. In short, they are small-signal parameters which should not be used beyond one watt or a few hundred Hz (where cone resonances begin to invalidate the model). Even one watt may be generous around Fs (the woofer's resonant frequency), where impedance often exceeds 100Ω in a nominally 8Ω woofer. Since modern subwoofers are rated in kilowatts, and amplifiers in tens of kilowatts, the behavior of a woofer at one watt is not really so interesting anymore. Loudspeaker designers need to predict not just loudspeaker system sensitivity, but maximum output before excessive distortion or risk of damage. The woofer's behavior at high excursions must be measured and considered in its design, along with durability concerns like cone weight and suspension stiffness.

To try and describe the maximum capabilities of a transducer, large-signal parameters like X_{MAX} (excursion) and P_E (power handling) are used. Since there is no allowance for non-linearities in the small-signal parameters, the behavior of the system once the cone starts to move cannot be correctly accounted for by most software. In fact, all the parameters change considerably with cone motion, and they are not necessarily symmetrical (i.e. the woofer behaves differently coil in versus coil out). To more accurately characterize a woofer, it is important to measure changes in all fundamental parameters across the whole range of cone motion. The woofer can then be optimized to behave predictably at high power and excursion.

Looking through a loudspeaker specification sheet, an electronics engineer would likely ask where the missing pages are. Most woofer spec sheets are one page long. In electronics even a very simple operational amplifier[2] comes with dozens of pages of specifications, from packaging to application notes, detailed test conditions, and every major parameter versus voltage, load, and ambient temperature. Circuit diagrams are provided, and both standard operating and failure conditions are considered. A moving mechanical system like a woofer is much more complicated than a simple integrated circuit, especially considering the diversity of applications. The parameters prescribed by T/S cannot hope to account for the varieties in performance seen in practical applications.

At B&C Speakers, one of the tools used in transducer development is the Klippel R&D suite[3]. This suite is a combination of hardware and software that can be used to measure transducers at high excursion and power, and characterize their performance in a repeatable way. Using a laser to directly measure cone excursion, in combination with voltage and current measured at the amplifier terminals, our engineers can measure exactly how closely the transducer follows an input signal. The result of running a full Klippel Large Signal Identification (LSI) test is a twelve-page report with much more detailed information about suspension limits and symmetry, how fast the motor and coil heat up, and even how electrical damping is affected by a hot coil.

Instabilities and nonlinearities can be identified, and engineers can then look to address them in the design of the transducer.

For example, consider the Bl parameter. This parameter is a measurement of how strongly the electric current of the audio signal translates to force on the cone - like horsepower in a car engine. The strength of the magnetic field, B, is multiplied by the length of wire immersed in that field, l. Higher numbers indicate a stronger motor, which results in better sound quality, efficiency, and stronger electrical damping. Figure 2 shows the anatomy of a typical woofer motor. As the cone moves, the amount of coil immersed in the magnetic gap changes – until the cone has moved so far that most of the coil is no longer in the gap. Graphing the value of Bl as the cone moves from all the way in to all the way out gives a result like Figure 3 (taken from our 18SW115-4 subwoofer).

You may notice that the Bl curve in Figure 3 is relatively flat for ±10 mm of excursion. This linearity is a key advantage in our SW, TBW, DS, and IPAL series subwoofers. Using a combination of coil geometry and magnetic circuit design, our engineers are able to keep Bl relatively constant through the middle 2/3 of excursion (where the coil spends most of its life). Effectively, the peak Bl the motor could provide is spread out over a wider range of excursion. This distribution results in reduced distortion, and improved sound quality and durability. Another woofer could have higher Bl listed on its spec sheet, but be unstable and have higher distortion at high excursion as its motor force could be concentrated in the middle.

This example illustrates how one-dimensional specifications like T/S parameters tell only a very small part of the story, and can make two very different loudspeakers look similar. Transducers are complex mechanical systems with many compromises to make between cost, performance, and longevity. A pro-audio brand like B&C Speakers designs transducers for maximum output and durability, to be used in the lightest weight and smallest enclosure possible. We deploy advanced R&D techniques to analyze and predict large signal behavior and minimize nonlinearities. Make sure when you choose a woofer based on Thiele/Small parameters you understand whether they reflect a woofer designed using these same methods, or one designed to look good at rest, on paper.

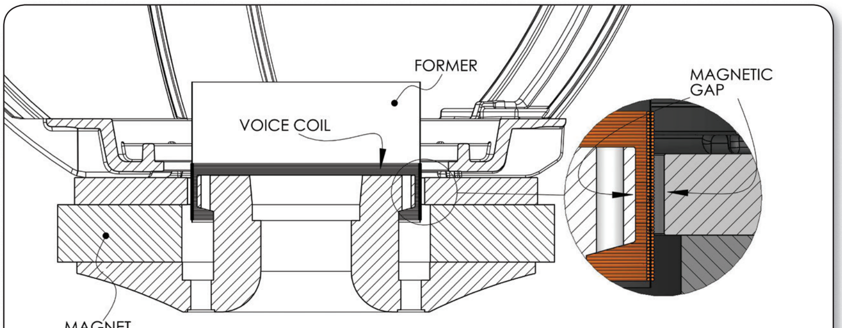

Figure 2

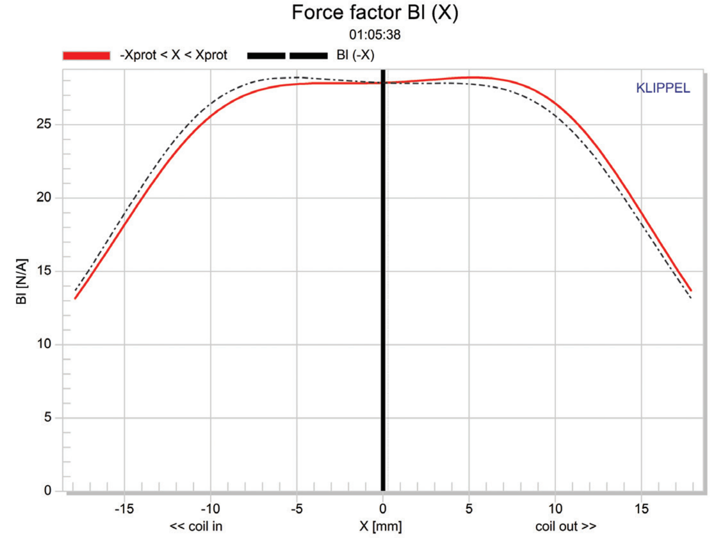

Figure 3

The B&C #18SW115-4
18" Professional Neodymium Subwoofer
used in graphing the value of Bl (Figure 3)
Parts Express #294-6006

For more information, please visit www.bcspeakers.com, or contact parts-express.com.

Figure 1: "Measured free-air impedance of 18SW115-4 subwoofer (black), and simulated impedance based on equivalent circuit model (red)."

Figure 2: "Cross-section of subwoofer motor showing metal parts which concentrate magnetic energy in the gap, where the coil is immersed."

Figure 3: "Bl(x) graph for 18SW115-4 subwoofer. Dotted line is the same curve inverted to help gauge symmetry."

About the Author:

Bennett Prescott is Sales & Operations Director for B&C Speakers in North America. One of the main benefits of his job is learning from the best OEM brands in the Pro Audio business. Whatever spare time is left he spends drinking whisky and riding bicycles with his small family in southern CT. His personal website at www.bennettprescott.com hosts other articles you might enjoy. You can reach him by email at bprescott@bcspeakers.com.

[1] https://en.wikipedia.org/wiki/Thiele/Small_parameters
[2] http://www.ti.com/product/TL074
[3] https://www.klippel.de/products/rd-system.html