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SPEAKER DESIGN & MANUFACTURING BEST PRACTICES

Proper implementation is based on understanding processes.

BY DAN DIGRE & STEVE TATARUNIS

Dan Digre, President of MISCO, a design and OEM manufacturer of loudspeakers since 1949, has dedicated more than 40 years to the loudspeaker industry working with MISCO, and is a past President of ALMA International, the loudspeaker industry's association. Steve Tatarunis, a Senior Engineer at Menlo Scientific who heads up the Menlo's Boston area Testing Lab, has worked in the loudspeaker industry for more than 30 years.

The audio industry is literally driven by loudspeakers. They're the final components in the signal chain, and the ones most likely to influence the overall sonic quality of the source material. An improperly specified and implemented loudspeaker can doom an otherwise competent system design. For the loudspeaker design/manufacturer, understanding the customer's need is the essential first step. Only then can the manufacturer engineer and build a product that satisfies all criteria, including quality, performance and cost parameters.

Loudspeakers are ubiquitous—from the PA system in a subway car to line arrays at a rock concert—so it's easy to take them for granted. But understanding what goes into the design and manufacturing of loudspeakers can help you make smarter decisions when specifying them for a project. You'll have better informed discussions with your loudspeaker manufacturer, too.

An industry colleague often refers to the process of loudspeaker design as "one part wisdom and one part witchcraft." Although there's still an element of magic at work in designing a loudspeaker, modern design tools, materials and processes have replaced much of the "witchcraft" that speaker designers were forced to practice a generation ago.

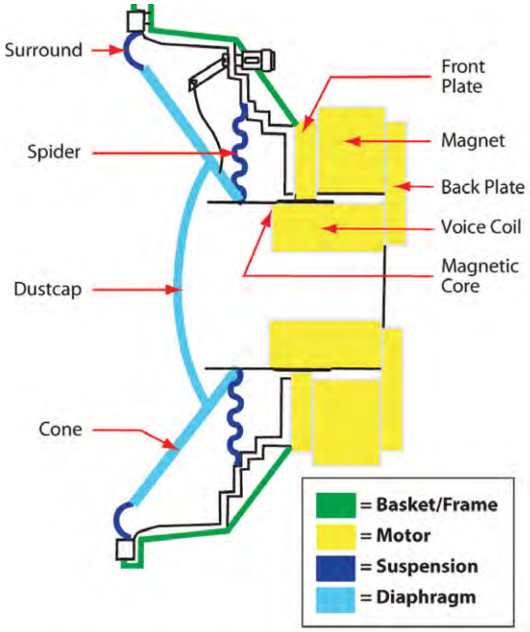
Most loudspeaker manufacturers take similar steps in the design process, but all of them have a unique approach that is used regardless of the speaker size. As an example, consider a 2½-inch outdoor loudspeaker with the target parameters in the accompanying chart:

2½" Loudspeaker	**Target Parameters**
Impedance	4Ω
Sensitivity	82dB SPL, 2.83V, 1 meter
Fo	125 to 150 Hz
Qts	0.7 to 0.8
Mechanical requirements	Must be extremely robust

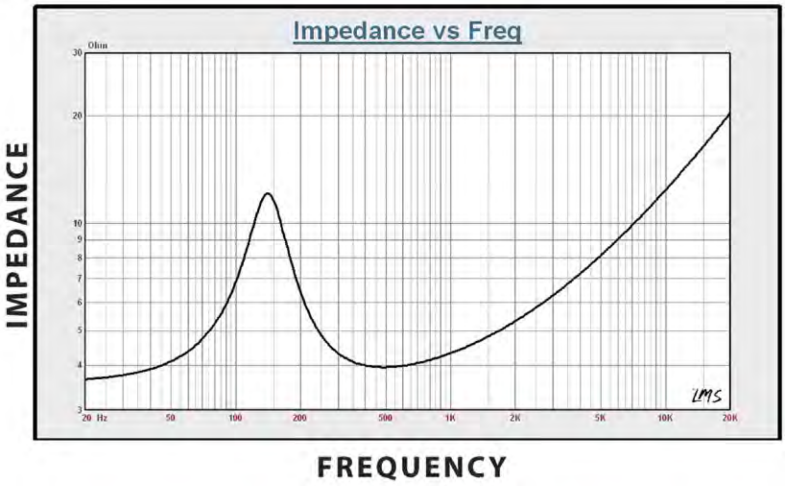
First, let's review these parameters so we understand their meaning.

In our example, the impedance target is really a nominal value rather than an actual target spec. Although most loudspeakers are categorized as being either 4Ω or 8Ω, the actual DC resistance of a 4Ω nominal loudspeaker's voice coil could range anywhere from 3Ω to 5Ω. Just to confuse you a bit more, if we were to measure a 4Ω nominal speaker's impedance *vs.* frequency, we would see that the impedance can range anywhere from the DC resistance of the voice coil all the way up to many times that value.

Fo is engineer-speak for the resonance frequency of the loudspeaker. Picture a spring-mass system with the spring being the spider and the mass being the diaphragm and voice coil. Dr. Gene Patronis of Georgia Tech gave a great demonstration of this concept at a Syn-Aud-Con seminar. He stood on a chair in front of the class, holding an enormous spring with a weight attached. Once he released the weight, the spring and weight settled into a smooth and regular up and down motion of about one cycle every second. The resonance frequency of this sys-

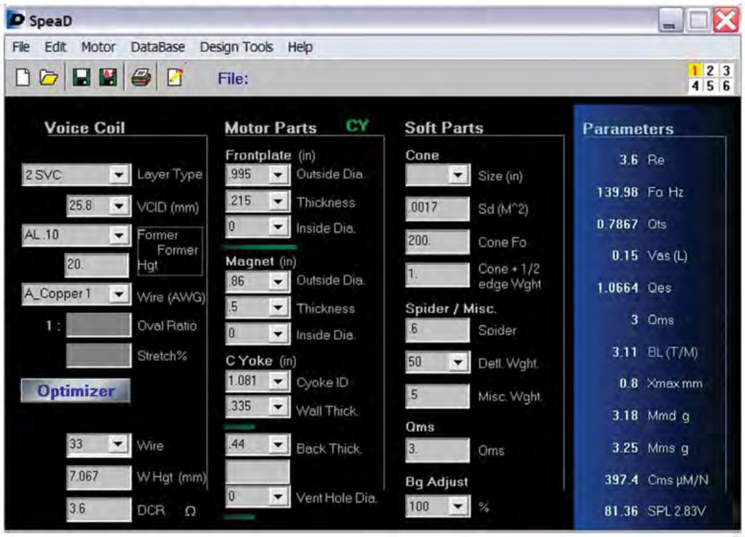


A basic loudspeaker breaks down into four sub-systems:
1. Motor (magnet and voice coil),
2. Suspension (spider and surround),
3. Diaphragm (cone and dust cap),
and 4. Frame (speaker basket.)



Sample loudspeaker modulus of impedance

Initial Design Target & SpeaD Simulation



This simulation translates performance targets to actual component parts.

tem was 1Hz!

In more technical terms, Fo is the frequency at which the maximum amount of energy is stored in the moving mass and suspension, and coincides with maximum cone velocity. *Fo* can be adjusted by changing the stiffness of the spider and the combined weight of the diaphragm and voice coil.

Qts is a complex term. Let's just say that it reflects the combination of mechanical and electrical damping that occurs in the loudspeaker. *Qts* is proportional to the loudspeaker's stored energy divided by its dissipated energy at *Fo*. Most loudspeakers have a *Qts* from 0.3 to 1.0.

Robust mechanical requirements indicate a rugged design that's capable of operating under extremes of excursion and input power and, in this case, a set of harsh environmental conditions encountered by temperature and humidity range.

Evaluating The Project

These target parameters go first to the sales engineer. The engineer reviews the customer's requirements (performance, environmental considerations, quantities and cost) to determine if there is a standard product that meets the customer's needs. If not, perhaps a slightly customized version can be built with standard parts or, failing that, a completely custom design will be required.

The sales engineer then collaborates with the design and manufacturing engineers to develop a project plan. The plan presents to the customer a clear picture of the costs (including Non-Recurring Engineering costs, or NRE), deliverables and timeline. The customer must agree to the project plan before the project moves forward.

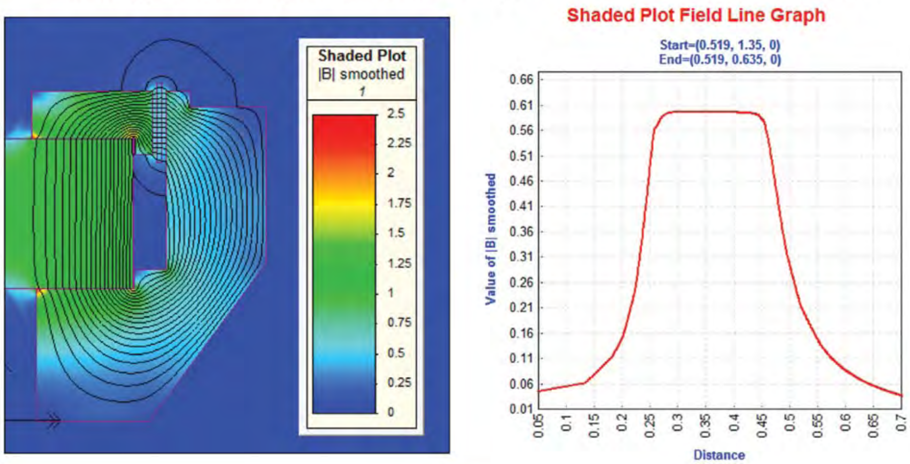
Creating The Design

The design engineer plays a critical role in the creation of the project plan, so let's discuss engineering's contribution to this process.

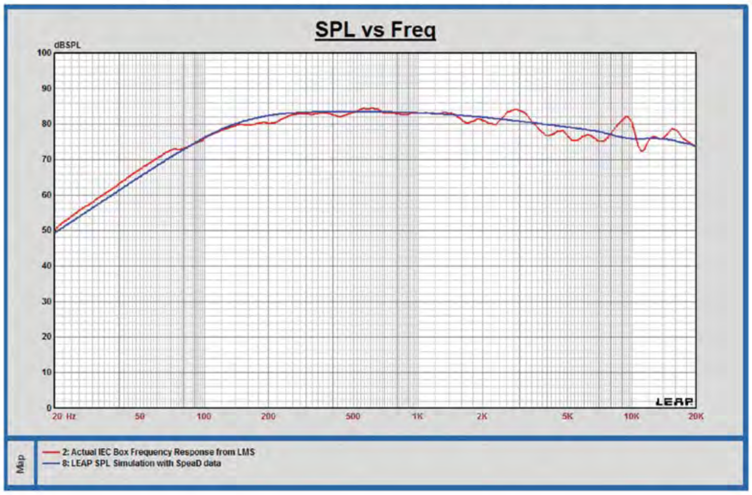
The engineer starts with the target parameters and any other specifications that the customer may have provided, such as power handling, sensitivity, frequency response and, perhaps, more advanced specs such as BL (motor force) and distortion limits.

Advanced modeling tools are then used to simulate various aspects of the design. Values for the voice coil, magnet and soft parts (diaphragm and suspension) are input into a program such as SpeaD or FINEMotor, which

FEA Magnetic Analysis to Confirm Gap Flux & Bl Motor Force Values



Actual Frequency Response Curve of Functional Sample vs LEAP Simulation Based on SpeaD Data



High-performance amplifiers combined with sophisticated software and analysis tools allow professional manufacturers to test high-power speakers while recording important data.

then outputs a complete set of parameters for the speaker design.

Next, the magnet and voice coil values are input to a Finite Element Analysis (FEA) program, which allows the design engineer to view a simulation of the motor (voice coil and magnet) and confirm its performance.

These modeling programs are powerful tools that reduce design time to days and create a model that is highly predictive of the actual finished loudspeaker. Years ago, before the advent of computer aided design, this process could take a week or more while the design engineer labored to find the right combination of parts to achieve the target specification. It was not uncommon for engineers to assemble a half-dozen or more prototype speakers before acceptable results were achieved.

From Plan To Prototype

Once the loudspeaker modeling is completed, several things happen:

- Drawings for new components are generated. These drawings become part of the project plan document and are sent to vendors for quotes.
- A sample bill of materials (BOM) is generated.
- Vendor quotes are received and used to complete the project plan.
- The project plan is presented to the customer.

Customer approval of the project plan is a major milestone that triggers another chain of events.

First, a functional prototype of the design is assembled, based on the sample BOM. Because some of the components may have to be produced on new tooling, it's a common practice to fabricate them in a machine shop.

Once the prototype is assembled, it is then tested to validate its performance. In the case of our example speaker, the accompanying graph shows the simulated frequency response *vs.* actual frequency response of the prototype. Results show that the simulation is extremely close to the actual frequency response, which demonstrates the accuracy of the modeling tools.

The manufacturer retains the original prototype. If a customer requires its own internal Design Verification Testing, additional prototypes can be assembled and sent to the customer.

Another good practice is that the prototype, build and test are always performed by the company's manufacturing group, with the results fed back to the design engineer. This enables the group to become familiar with the design and its manufacturing process.

Ultimately, this information will be

used to develop the detailed process documentation for the loudspeaker. Based on the results of the prototype build, another prototype build may be required to fine-tune certain aspects of the design.

The next step in the process is a pre-production build using all tooled parts. Typically, 10 to 50 pieces are produced. This exercise is critical because it validates manufacturing fixtures and processes in addition to verifying the performance of tooled parts. Additionally, valuable information that is used to establish the end-of-line test specifications and related pass/fail limits is gathered. Finally, once the specifications and limits have been determined, a "golden sample" is selected from this group of speakers and is retained by the manufacturing group.

Power testing a high-performance woofer in free air.

A custom-made high-speed magnetizing system.

All photos: MISCO Loudspeaker Design & Manufacturing

Power Testing

Validating the power rating of the loudspeaker is the last step before production. An industry standard power rating test is used, and there are several standards to choose from, such as AES, IEC and EIA.

Typically, a test signal (usually pink noise) is applied to the speaker under test for anywhere from two to 100 hours, stressing the speaker thermally and mechanically. At the end of the test, the speaker should still be operational with no significant change in its frequency response, impedance and distortion measurements.

Pumping 1000 watts of audio signal through a professional loudspeaker during a power test will generate a dangerous amount of noise. That's why power tests are conducted in a power testing chamber that protects the outside workspace from both loud noise and speakers that catch fire. Thick walls and a soundproof door keep deafening noise and potential fires inside, while the amplifiers and monitoring equipment run safely outside. The monitoring system typically tracks current, backplate temperature, resonant frequency shifts and changes in *Qts,* DCR and humidity over time.

The system should also detect loudspeaker failure modes, automatically shutting down the channel to prevent equipment damage. Each test can run anywhere from two hours to two weeks, and a report from this testing is presented to the customer for approval.

Ramping Up Production

Now that the design has been completed, validated and approved by the customer, it's ready for mass production. There's not enough space here to describe the entire process, so we'll touch on two points: magnetizing and production testing.

The magnets in loudspeakers come from their vendor in an uncharged state, so they must be magnetized during the production process. The magnetizer unit must have enough strength to charge the magnet's material using an intense magnetic field, and robust enough to do it with a short cycle time that keeps the production line moving. An undercharged magnet can cause reduced sensitivity and under-damped behavior in the finished loudspeaker.

Every finished loudspeaker ends the production process with a performance test. Manufacturers typically test the frequency response, impedance, distortion and other parameters. These tests can be completely automated, checking the results against pass/fail limits determined during the design phase. Each test can take less than five seconds, and the data is stored along with each speaker's serial number. Data from the entire production run can be analyzed for production trends, average values, pass/fail yields and so on.

Best Practices, Best Results

Although some fundamentals of loudspeaker design have not changed for decades, manufacturers have greatly benefitted from the latest computer-based design and production test systems. These tools give a manufacturer tremendous efficiencies and analysis power. They greatly shorten the product design cycle and enable fast, comprehensive end-of-line testing.

Manufacturers that embrace these practices give their customers fast-to-market designs that deliver the total package of performance, value, and quality. ■