ISCE

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Loudspeakers, impedance and power

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Specifications

'Impedance 8 ohms', it says on the data sheet, but below is a graph showing that it's 8 Ω only at four frequencies (at most!). 'Power 10 W', it says, too, but what power is that? The sound power output, maybe, but then what is the input power needed to produce that? And the impedance varies with frequency, so it's not a pure resistance. What is it, then, and does it matter?

Of course, it's only people who think about things that are bothered by this: those who don't think have a less stressful time — until one day their lack of insight gets up and bites them!

Impedance

What follows will perhaps sound like over-simplification or a fraud, but it works, and has done for some 70 years. The single-figure 'impedance specification', correctly called the 'rated impedance', is the value of pure resistance specified by the manufacturer of the loudspeaker for calculation purposes. That isn't quite what the standard, IEC/EN 60268-5 says, but it's an improvement (trust me!). The standard goes on to say that the *minimum* impedance within the rated frequency range shall not be less than 0.8 of the rated impedance, and if it is lower than that *outside* the rated frequency range, including d.c., the manufacturer should say so. Since it usually *is* lower at d.c., the d.c. resistance should be specified, but it often isn't.

To determine the rated impedance, the manufacturer should measure the minimum impedance of a number of samples, find the average and set the rated impedance at 1.25 (= 1/0.8) times that average value. The value can't be predicted very accurately (without a sophisticated simulation program) because the electrical impedance depends to some extent on the mechanical and acoustic characteristics of the drive unit, or of all the drive units and crossover networks in a multi-driver loudspeaker system.

For the rest of this E-note, we will concentrate on single drivers, because multi-unit systems involve many more topics.

So, if this single resistance value can be used to represent the frequency-dependent impedance of the loudspeaker, the following questions arise:

- How can it?
- What makes the impedance frequency-dependent, anyway?

How can it?

To answer this question, we have to remember that the frequency response of the loudspeaker is made as flat as the manufacturer will settle for, *with a constant voltage applied.* (Some hi-fi loudspeakers are made for constant-current drive, but we won't bother with them.) So, the *power* input to the loudspeaker cannot exceed $V^2/(0.8R)$, where V is the applied voltage and R is the rated impedance, and it only equals that value if, at the frequency where the impedance is a minimum, it is also purely resistive. (Actually, it usually *is* resistive at that frequency). At any other frequency, the impedance is higher and not purely resistive, so the actual power absorbed from the amplifier, 95 to 99% of which simply heats up the voice-coil, is *lower* than that maximum value. Since that maximum value only applies at one frequency, and the power exceeds V^2/R only over a small frequency range, it is reasonable to assume that the input power is always given by the expression V^2/R. At most frequencies, there is quite a significant 'safety factor' included in this assumption.

What makes the impedance frequency-dependent, anyway?

There are two causes of the frequency dependence:

- the inductance of the voice-coil;
- the mechanical resonance of the cone mass with the compliance of its suspension.

The inductance simply comes from the fact that the voice-coil is indeed a coil. Its 'core' is the magnet system, which doesn't have a very high permeability because it is nearly magnetically saturated by the permanent magnet. Values of inductance are in the millihenry region: 1 mH has a reactance of 2πfL = 63 Ω at 10 kHz, so it's not by any means a negligible effect.

The mechanical resonance of the cone assembly results in a large movement at the resonance frequency. This is reflected back into the electrical circuit by the generator action of the voice-coil moving in the magnetic field of the permanent magnet. The voltage so produced opposes the applied voltage, thus the effective impedance is increased. In the electrical circuit, the resonance appears as a *parallel* resonance, with the highest impedance at the resonance frequency.

At the resonance frequency, the impedance is high, and *purely resistive*. For a typical 8 Ω driver, it may be between 30 and 60 ohms. Even though this means that the input power is very much less than at other frequencies, the cone can move exceptionally freely, so that, rather than the frequency response showing a dip at the resonance frequency, it often shows a peak.

Below the resonance frequency, the impedance due to the cone movement, called the *motional impedance,* is inductive, while above the resonance frequency it is capacitive. At some higher frequency, often around 400 Hz, this capacitance resonates with the voice-coil inductance, which is what causes the dip to the lowest impedance within the rated frequency range. It is a dip because this resonance appears in the electrical circuit as a series resonance.

Efficiency and sensitivity

What we often see described as 'efficiency' is actually an *incorrect* expression of *sensitivity.*

Efficiency must be expressed as sound power output divided by electrical power input. But if we take the actual input power, it varies wildly with frequency and does not give a useful measure of efficiency, even if we have actual input power and sound power output data or can measure them. If we did that, the efficiency, even of a very good loudspeaker, would appear to vary equally wildly with frequency, but the audible effect would be that it remained reasonably constant. It is more appropriate to use the 'conventional' V^2/R value of power, since it is V that the amplifier has to provide, not a specific value of power, to get as flat a frequency response as the design allows. This point may be conceptually obscured if loudspeakers are evaluated only with noise or impulsive signals rather than sine waves. (Evaluation with sine waves has its own problems, though.)

What is wrong with the popular expression of sensitivity as 'X dB SPL [sound pressure level] at 1 m for 1 W input' or some even more incorrect expression like 'X dB per watt per metre' (yes, I've seen that!)? What is wrong is that the sound pressure is proportional to *voltage*, not power. Sensitivity should be expressed as 'X dB SPL at 1 m for 1 V input' (or maybe 2.83 V for 8 Ω units, for consistency with existing expressions).

People usually stumble across the error when they look at the decibel equations. SPL decibels obey the '20lg' equation, but watts obey the 10lg' one. So, if we double the input power level, the SPL only rises by 3 dB, not six. With the expression 'X dB SPL at 1 m for 1 V input' there is no apparent anomaly: double the voltage and you double the sound pressure, so the SPL rises by 6 dB, just as the voltage level did. Sound pressure is proportional to the applied voltage (apart from the effect of temperature on voice-coil resistance), and is thus proportional to the *square root* of the applied 'power', which, as we have seen, is not the actual input power anyway.

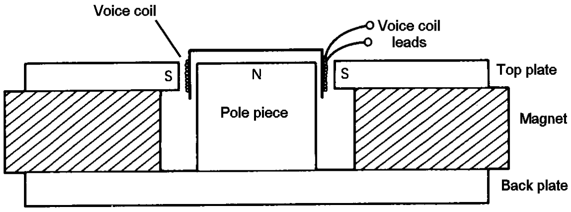
Power

Does this help us to work out what 'Power 10 W' means in a specification? Not a lot, because the statement is far too vague. It would be far better not to give any specification for 'power' at all, and use voltage instead, but even though the standard IEC/EN 60268-5 has been encouraging this for many years, it's very difficult to change established practice, however wrong it is.

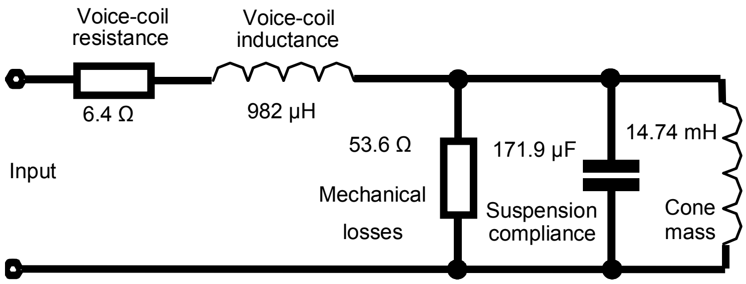
Remember that 95 to 99% of the input power, which varies a lot with frequency anyway, simply goes to heat up the voice-coil. This is just another way of saying that the efficiency is between 5% and 1 %. So (switching to the more sensible 'voltage-based' description), if we apply too many volts, the voice coil gets too hot and fails mechanically. But maybe, at a voltage lower than that causing burn-up the cone movement grows so large that the voice coil either hits part of the internal structure of the magnet assembly or parts company from the cone! We have two limitations on input voltage, then, a 'temperature limitation' and a 'damage-limitation' (also called 'excursion limitation'). Both of these, unfortunately, vary with frequency, which we can overcome to some extent by measuring with defined noise signals, but the damage-limited input voltage also varies with the way in which the driver is mounted; it is lowest for an unbaffled driver in free air and highest for one in either a sealed enclosure or possibly a labyrinth enclosure. You can begin to see why specifications are vague: to be explicit they need to be very detailed.

It used to be thought that the manufacturer could specify the 'maximum recommended amplifier power'. That would appear to be capable of dealing with both temperature and damage limits, but in fact it fails badly on the temperature front. The trouble comes if one uses a lower power amplifier which in fact isn't powerful enough to generate the required sound pressure level, and runs into clipping. This both increases the r.m.s. value of the signal relative to its peak level and increases the amount of high-frequency energy in the signal (think of all those sharp corners on the clipped waveform). The net result is that, especially for systems including a tweeter, a low power amplifier may cause *more* thermal damage than a higher power amplifier that is not driven into clipping. I suspect that pressure units can be damaged by the same effect, but I don't have any supporting data at present.

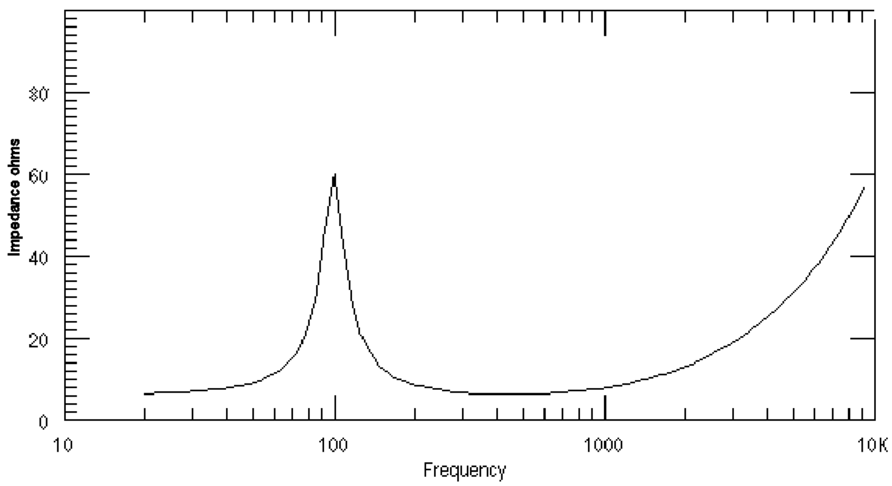
There is no easy solution to this, which is why this E-note is useful: to interpret the vague specifications you need extra insight. The standard IEC/EN 60268-5 gives four voltage ratings and four corresponding power ratings,. in an attempt to encourage the provision of meaningful specifications, but very few manufacturers quote a complete set of values. It's always worth asking the manufacturer what his 'power' specifications really mean, but don't expect always to get a helpful answer!



Cross-section through the magnet assembly and voice coil of a drive unit



Electrical equivalent circuit of a drive unit



Impedance/frequency curve of the equivalent circuit

The specification of this imaginary driver is:

Impedance 8 Ω

Resonance 100 Hz

Minimum impedance 6.4 Ω at 400 Hz

Impedance at 100 Hz 60 Ω